because endothelial cells possess several metabolic pathways that can lead to its formation and because it is a potent relaxant of vascular smooth muscle. If NH_3 does turn out to be an EDRF, it is intriguing that the endothelial cells have evolved to use very simple nitrogen derivatives (NO, NH_4) to signal a reduction in function to the underlying smooth muscle. This would probably be disappointing to modern pharmacologists eager to discover complex peptidergic transmissions between differentiated cells, but to me this result emphasizes the ancestral character of endothelium-dependent responses[6]. □

1. Palmer, R.M.J., Ferridge, A.G. & Moncada, S. *Nature* **327**, 524–526 (1987).
2. Furchgott, R.F. & Zawadzki, J.V. *Nature* **288**, 373–376 (1980).
3. Furchgott, R.F. *Circ. Res.* **53**, 557–573 (1983).
4. Peach, M.J. *et al. Hypertension* **7**, 194–1100 (1985).
5. Vanhoutte, P.M. *et al. Rev. Physiol.* **48**, 307–320 (1986).
6. Vanhoutte, P.M. *News Pharmac. Sci.* **2**, 18–22 (1987).
7. Griffith, T.M. *et al. Nature* **308**, 645–647 (1984).
8. Rubanyi, G.M., Lorenz, R.R. & Vanhoutte, P.M. *Am. J. Physiol.* **249**, H95–H101 (1985).
9. Gryglewski, R.J., Palmer, R.M.J. & Moncada, S. *Nature* **320**, 454–456 (1986).
10. Rubanyi, G.M. & Vanhoutte, P.M. *Am. J. Physiol.* **250**, H815–H821.
11. Furchgott, R.F. in *Mechanisms of Vasodilatation* (ed. Vanhoutte, P.M.) Ch. 1 (Raven, New York, in the press).

Paul M. Vanhoutte is in the Department of Physiology and Biophysics, Mayo Clinic, Rochester, Minnesota 55905, USA.

Planetary science

Measuring the Io plasma torus

Fran Bagenal

RATHER than twiddling their thumbs while waiting for delayed missions, planetary scientists have been busy making the most of the extensive datasets already available and looking for ways to apply remote sensing to planetary problems. Although local plasma measurements obtained on planetary fly-bys have generated a wealth of detailed information about plasma properties, they can only provide a snapshot of the magnetosphere. To understand the plasma processes it is often necessary to monitor temporal and spatial variability with remote sensing techniques. D. Jones, for example, on page 492 of this issue[1], draws our attention to the outer boundary of the plasma torus generated by Jupiter's innermost large satellite, Io. Radio emissions observed there for more than a month before and after each Voyager fly-by of Jupiter provide measurements of the radial gradient in plasma density.

The nature of the outer boundary of the torus is important in understanding how the plasma that is generated by Io (roughly at a rate of 1 tonne per second of sulphur and oxygen ions) subsequently spreads throughout the jovian magnetosphere and, ultimately, how the magnetosphere responds to changes in volcanic activity on Io. The initial analyses of the Voyager plasma data suggested that the density of thermal (<100 eV) plasma reaches a maximum value of more than 2,000 electrons cm^{-3} near Io's orbit at 6 Jupiter radii (R_J) and drops sharply between 7 and 8 R_J. This outer boundary of the torus is the same region where the number of energetic (10^4 – 10^6 eV) radiation-belt particles sharply increases with radial distance. The initial interpretation of these observations was that the radiation-belt particles have diffused inwards from a source in the outer magnetosphere and are scattered by the cooler, more dense, iogenic plasma (or accompanying plasma waves). The scattered particles are diverted along the magnetic field into the upper atmosphere of Jupiter where they could stimulate the intense auroral emission observed in Jupiter's polar regions. The resulting radial gradient in particle pressure was thought to hinder the centrifugally driven outward diffusion of torus plasma, impounding the iogenic plasma and producing the sharp outer boundary of the torus.

In the past couple of years considerable effort has been put into verifying this picture, discussed at a symposium on the magnetospheres of the outer planets held at the University of Iowa last September. Although some people have concentrated on theoretical studies of the mechanism of plasma diffusion, others have been improving the observational constraints[2]. Summers and Siscoe[3] conclude that the pressure gradient of the energetic particles measured by the Voyager instrumentation is not sufficient to impound effectively the torus plasma. They calculate that about twice as many keV radiation-belt particles are needed if the thermal-particle density gradient is as steep as first reported by the Voyager experimenters. Summers, Thorne and Mei[4] find they cannot generate a steep slope of outwardly diffusing thermal plasma even if the modification of ionospheric conductivity by precipitating particles is included.

Unfortunately the gap between the energy ranges covered by Voyager's plasma and particle instrumentation is in this key intermediate energy range and we will have to wait for the Galileo or Ulysses results for clarification. The Voyager plasma-study team, however, reported at Iowa that further analysis of the Voyager data suggests that the density of keV ions in the torus could have been underestimated and the gradient in the iogenic plasma may not be as steep as initially reported.

In a recent letter to *Nature* Jones[5] used radio emissions to determine radial profiles of plasma density at the magnetic equator, which he found to be much shallower than the initial Voyager results. He has successfully applied his mechanism for linear conversion of electrostatic (upper hybrid) waves to electromagnetic (radio) emission to the magnetospheres of Jupiter, Saturn and the Earth. His mechanism requires that in the source region, the gradient of the plasma density is perpendicular to the magnetic field and produces a radio beam with characteristics given by the plasma density and magnetic field in the source region. Assuming the source of jovian broadband-kilometric emission to be at the magnetic equator, Jones used the geometry of a magnetic-field model and the Voyager trajectory to derive the radial distance for a particular emission frequency and corresponding plasma density. In his paper in this issue[1], Jones now applies the same emission mechanism to the narrowband-kilometric emission which he believes is produced at higher latitudes (> 8°) on the flanks of the torus. At these latitudes there are no direct plasma measurements, but Jones's preliminary results are compatible with density models based on Voyager data.

At present the laborious nature of the technique means it is not particularly accurate for determining plasma density. But it could be a means of testing the diffusion hypothesis without waiting for the Galileo or Ulysses missions. The technique also promises to be a powerful tool for investigating plasma processes by monitoring time-variability of the outer torus boundary.

Time-variable phenomena in the jovian system will be discussed this summer in Flagstaff, Arizona. The International Jupiter Watch, inspired by the successes of the International Halley Watch, has been set up to co-ordinate observations of the planet and its satellites and magnetosphere. It was evident at the Iowa meeting that there exists a wealth of particle, field and ultraviolet data obtained by Voyager at Jupiter that have rather been neglected because of the Saturn and Uranus encounters, to which experimenters are keen to return. Moreover, with planetary missions becoming scarce, magnetospheric physicists are increasingly appreciating the value of observations of plasma emissions from radio to X-rays for explaining plasma processes in planetary magnetospheres. □

1. Jones, D. *Nature* **327**, 492–495 (1987).
2. Richardson, J.D. & McNutt, R.L. Jr *Geophys. Res. Lett.* **14**, 64–67 (1987).
3. Summers, D. & Siscoe, G.L. *J. geophys. Res.* **90**, 2665–2671 (1985).
4. Summers, D., Thorne, R.M. & Mei, Y. *Planet. Space Sci.* (in the press).
5. Jones, D. *Nature* **324**, 40–42 (1986).

Fran Bagenal is at the Blackett Laboratory, Imperial College, Prince Consort Road, London SW7 2BZ, UK.