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The rotation of Jupiter is very rapid ($36^{o}$ per hour). If its magnetospheric plasma co-rotates with the planet, the effect of centrifugal force on the plasma distribution will be considerable. At 6 equatorial radii from the centre, corresponding roughly to the orbit of the satellite Io, the centrifugal force on a co-rotating body is 18 times that due to gravity; the two forces are equal at 2.3 radii. Thus, we may expect that the co-rotating plasma, trapped in the magnetic field, will be thrown out to those parts of the lines of force which are the most remote from the axis of rotation.

There is, however, a maximum plasma density which can co-rotate at a given distance from the axis. The magnetic field must be able to exert enough force on the plasma to provide the required centripetal acceleration. If the plasma density is too great, it will break away, carrying the magnetic field with it. We may estimate the maximum number density of the plasma in the equatorial plane by equating the magnetic and rotational kinetic energy densities:

$$B^2/2\mu_o = \tfrac{1}{2} N_{max} m\Omega^2 L^2 r_o^{\,2} \tag{1}$$

Here B is the magnetic induction at radius $r = Lr_o$, where $r_o$ is the equatorial planetary radius and L will later be used to identify the magnetic field line on which this plasma lies. $N_{max}$ is the maximum electron or ion number density which can co-rotate, m the mass of an ion, $\Omega$ the angular velocity and $\mu_o$ the permeability of free space. Assuming the magnetic field to be that of a dipole aligned along the rotational axis, of induction $B_o$ at the equatorial planetary surface, we find:

$$N_{max} \approx \frac{B_o 2}{\mu_o m\Omega^2 r_o{}^2 L^8} \qquad (2)$$

This equation has been derived by a different method by Hines[1].

We may now use a method similar in principle to that of Angerami and Thomas[2] to calculate the distribution of plasma along the line of force L. The potential energy of unit mass at the point r, θ in the gravitational-centrifugal field has the form:

$$V = -g_o \frac{r_o{}^2}{r} - \tfrac{1}{2}\,\Omega^2 r^2 \sin^2\theta + \text{constant}. \qquad (3)$$

where $g_o$ is the gravitational acceleration on the equator at the surface of the planet. From this, the equation of hydrostatic equilibrium of plasma along the field line crossing the equatorial plane at $Lr_o$ is readily solved to give:

$$N = N_{max} \exp\left[\frac{mg_o r_o}{2kT}\left\{\left(\frac{r_o}{r} - \frac{1}{L}\right) - \frac{\Omega^2 r_o}{2g_o L}\left(L^3 - \frac{r^3}{r_o{}^3}\right)\right\}\right] \qquad (4)$$

Here k is Boltzmann's constant and T is the temperature of the plasma, assumed to be uniform.

It is known from observations of the plane of polarization of Jupiter's decimetre radiation[3] that the magnetic axis is inclined at an angle of $10^{\circ}$ to its rotational axis, the northern hemisphere pole lying on the system III longitude of $190^{\circ}$. An approximate calculation shows that with this tilted dipole the points on the field lines which are farthest from the rotational axis lie nearly in a plane tilted at $7^{\circ}$ to the equatorial plane of the planet and intersecting the latter in longitudes $100^{\circ}$ and $280^{\circ}$.

Substitution of reasonable numerical values into Equation 4, assuming a fully ionized proton-electron gas, shows that the effect of the centrifugal force is to confine the plasma to a discus-like region about the plane at $7^{\circ}$ to the equatorial plane (see Fig. 1). As the planet rotates, this plasma discus goes round with it, and Io, whose orbit lies in the equatorial plane, must pass obliquely through it twice every revolution. Thus, the plasma frequency in the vicinity of Io will rise to a maximum and fall again during each such passage.

Now an examination of typical spectra of the "early" or B source[4] shows that their most prominent feature is a narrow-band emission which rises to a maximum frequency of about 40 MHz and then falls again. This suggests that we should make this the plasma frequency corresponding to $N_{max}$ at $L = 5.9$, the radius of Io's orbit being $5.9\ r_o$. From Equation 2 we then find $B_o = 30$ gauss. The time taken for the observed frequency to increase from 20 to 40 MHz is typically of the order of an hour. A plasma temperature of $1800^{\circ}K$ in Equation 4 gives a distribution such that it takes an hour for the plasma frequency at Io's orbit to rise from 20 to 40 MHz. It is assumed that mechanisms exist which will allow the generation by Io of radio waves at or near the plasma frequency.

Numerical calculations based on Equation 4 using these values then lead to the magnetospheric model shown in Figure 1. It must be stressed that this shows the maximum plasma densities which can co-rotate. Processes such as recombination would act to reduce the values, especially where they are very high inside $4r_o$. Any increase above the amounts shown would presumably result in the ejection of plasma near the equatorial plane. This instability offers a possible source of non-Io-related radio noise. On the other hand, densities less than those shown should be stable. An objection to models which identify the radio frequencies emitted with the plasma frequency has been that the spectra of the different sources are remarkably reproducible from revolution to revolution and from year to year. Many authors have therefore preferred to regard the maximum frequency of 40 MHz as the gyro-frequency in the emitting region, arguing that only the magnetic field strength is likely to be sufficiently constant to give the observed stability over long periods. It should be noted that, in the present model, the maximum plasma frequency is directly controlled by the magnetic field, thus accounting for the reproducibility of the spectra.

All four of the Io-related "sources" on Jupiter appear to correlate, at least qualitatively, with the model. The configurations are set out in the table following:

| SOURCE | CENTRAL MERIDIAN LONGITUDE | Io PHASE FROM SUPERIOR GEO-CENTRIC CONJUNCTION | RELATION OF Io TO PLASMA DISCUS |
|---|---|---|---|
| Early (B) | $70^{\circ}$-$190^{\circ}$ | $70^{\circ}$-$100^{\circ}$ | Being overtaken by denser plasma, entering discus from above. |
| Main (A) | $190^{\circ}$-$280^{\circ}$ | $200^{\circ}$-$260^{\circ}$ | Emerging from denser plasma towards upper surface. |
| Third (C) | $280^{\circ}$-$360^{\circ}$ | $220^{\circ}$-$260^{\circ}$ | Being overtaken by denser plasma, entering discus from above. |
| Fourth (D) | $0^{\circ}$-$70^{\circ}$ | $90^{\circ}$-$110^{\circ}$ | Being overtaken by denser plasma entering discus from below. |

Details of the calculations and refinements will be published elsewhere. Possible radiation mechanisms and ray paths are at present being studied.

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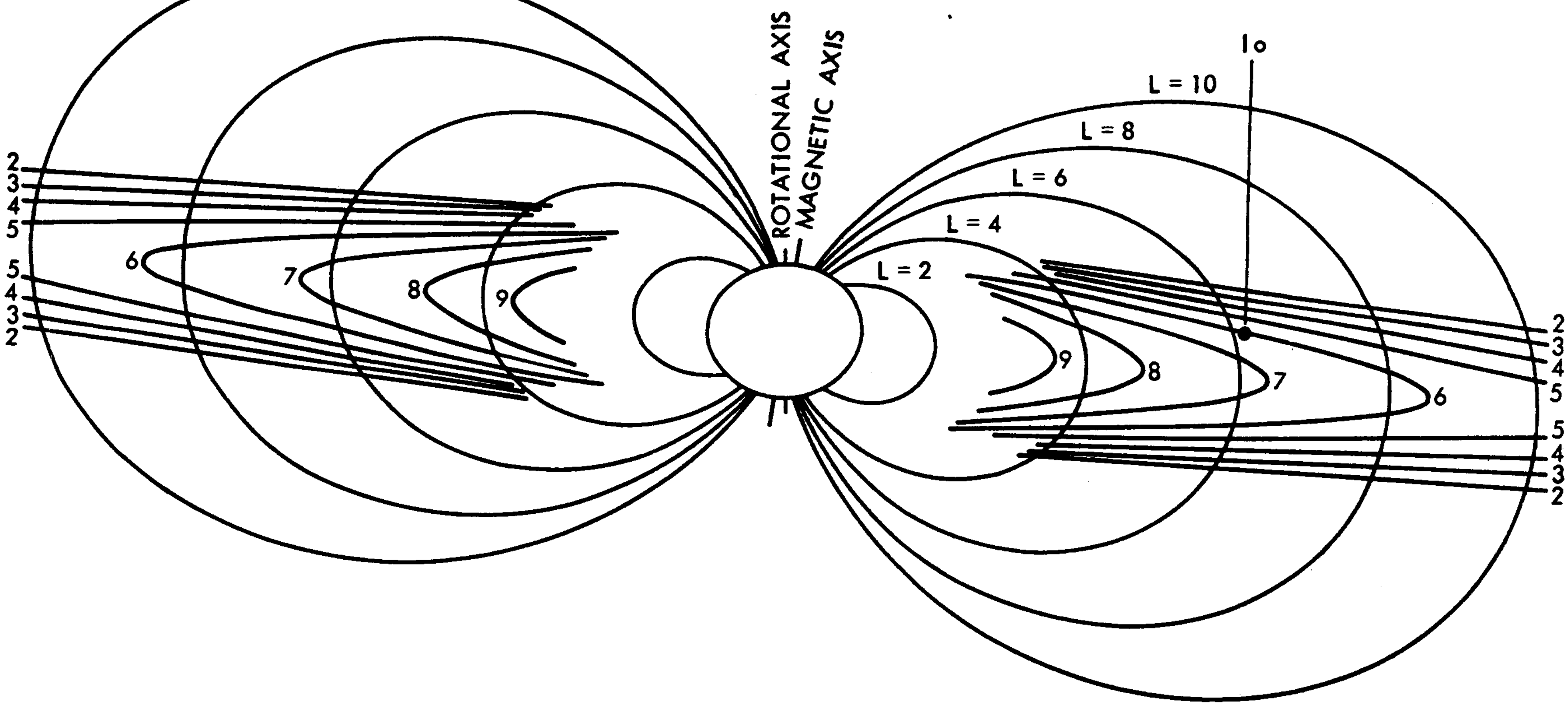
## REFERENCES

1. Hines, C. O., Space Science Rev. 3, 342 (1964).
2. Angerami, J. J. and Thomas, J. O., J. Geophys. Res. 69, 4537 (1964).
3. Roberts, J. A. and Komesaroff, M. M., Icarus 4, 127 (1965).
4. Dulk, G. A., NCAR Cooperative Thesis No. 1, University of Colorado and H.A.O., Boulder, Colorado (1965).

## CAPTION FOR FIGURE

Figure 1. Model of Jupiter's magnetosphere. $B_o = 30$ gauss; $T = 1800^oK$. The numbers on the contours are $\log_{10} N$, where N is in $cm^{-3}$.


ROTATIONAL AXIS
MAGNETIC AXIS
Io
L = 10
L = 8
L = 6
L = 4
L = 2
2
3
4
5
5
4
3
2
6
7
8
9
9
8
7
6
2
3
4
5
5
4
3
2