Properties of the magnetic field in the Jovian magnetotail

Margaret G. Kivelson and Krishan K. Khurana
Institute of Geophysics and Planetary Physics, University of California, Los Angeles, California, USA

Received 3 August 2001; revised 6 November 2001; accepted 26 November 2001; published 21 August 2002.

1 Magnetometer data acquired as the Galileo Orbiter apoapsis rotated from dawn to dusk across the magnetotail of the Jovian magnetosphere between late 1995 and the end of May 2000 are used to characterize the magnetic field and the distribution of magnetic pressure in the inner part of the Jovian magnetotail. The distances probed extend to \( \sim 150 \, R_J \) or roughly 3 times the distance to the nose of the magnetopause, analogous to distances within 30 \( R_E \) in the magnetotail of Earth. The magnetic pressure in the center of the plasma sheet is typically almost an order of magnitude smaller than the lobe pressure, which therefore is roughly equal to the peak thermal plasma pressure in the plasma sheet. The lobe magnetic pressure decrease with radial distance can be described roughly as a power law with an exponent of \(-2.74\), and the lobe field magnitude decreases with distance to the \(-1.37\). In comparing radial variations of the lobe magnetic fields of Jupiter and Earth we argue that rescaled lengths based on nominal magnetopause standoff distances and rescaled field magnitudes based on planetary dipole field strengths are required. Comparison of rescaled fits suggest that the power law dependence on radial distance should not be extrapolated beyond 150 \( R_J \) and that beyond this distance the trend may become asymptotically constant. Systematic asymmetries of the field structure and magnetic pressure across the midnight meridian in the region beyond 25 \( R_J \) downtail are notable, with the flux tubes being less stretched (with larger equatorial \( B_z \)) near dusk than near dawn. The lobe pressure attains its minimum value in the dusk sector where the plasma sheet magnetic pressure maximizes. We argue that only a small fraction of the magnetic flux remaining in the lobes in the magnetotail beyond 100 \( R_J \) closes across the plasma sheet, but the structure of open and closed flux tubes may be nonuniform across the tail. We discuss briefly mechanisms that may lead to the observed asymmetry.

INDEX TERMS: 2756 Magnetospheric Physics: Planetary magnetospheres (5443, 5737, 6030); 5737 Planetology: Fluid Planets: Magnetospheres (2756); 2744 Magnetospheric Physics: Magnetotail; 2740 Magnetospheric Physics: Magnetospheric configuration and dynamics; KEYWORDS: planetary magnetosphere, Jupiter’s magnetosphere, magnetospheric configuration

1. Introduction

[2] Sheet-like currents, sometimes referred to as “theta currents,” flow near the nightside equatorial plane and close across the antisolar magnetopause to produce the magnetotails of planetary magnetospheres. The strength of the current flowing in the equatorial current sheet can be inferred from the magnitude of the magnetic field in the tail lobes, regions of low plasma density between which the current-carrying plasma is confined. By characterizing the variation of the lobe magnetic field with position in the magnetotail, one also characterizes the currents that form the magnetotail.

[3] At Earth, decades of data have been used to reveal how the lobe magnetic field varies with distance down the tail [Mihalov et al., 1968; Nakai et al., 1991] and, in some cases, to determine as well how the properties of the magnetotail vary with geomagnetic activity [Behannon, 1968; Slavin et al., 1983, 1985] and solar wind properties [Fairfield and Jones, 1996]. Fits to the variation of the lobe magnetic field with downtail distance have proved useful for characterizing the plasma pressure required for magnetohydrodynamic equilibrium [Birn et al., 1977; Spence et al., 1989].

[4] Data in the Jovian magnetotail, although limited in local time coverage, have been used to fit the variation of the lobe magnetic field to power laws in radial distance from Jupiter [Behannon et al., 1981]. Additional data are now available from all local times between dusk and dawn across the Jovian magnetotail and the amplified data set is analyzed here to gain insight into the dependence of the magnetotail field on radial distance and local time. Despite the extensive coverage added by Galileo’s magnetic field measurements, data from Jupiter remain sparse, so it is not possible to account for effects of magnetospheric activity or solar wind conditions. However, the local time dependence that is found in the Jovian system provides an important constraint on models of plasma transport.

2. Background

[5] Since the Galileo Orbiter entered the Jovian magnetosphere in December 1995, the orbit has rotated from dawn
to dusk through the inner portion of the magnetotail, providing measurements of the properties of the plasma sheet from its inner edge near 30 \( R_J \) to a downtail distance of nearly 150 \( R_J \) near the midnight meridian. Because of the tilt of the Jovian dipole moment relative to the spin axis, the magnetotail current sheet passes up and down over the spacecraft almost every rotation period.

On most orbits the extreme displacements occur well away from those regions in which plasma pressure is significant, regions analogous to the lobes of the terrestrial magnetosphere. In developing analogies to properties of the terrestrial magnetotail, it is worth remarking that the limitation of Galileo data to antisolar distances within 150 \( R_J \) or less than 3 times the characteristic distance to the nose of the magnetopause corresponds to characterizing Earth’s magnetotail only within \( \sim 30 \ R_E \). We designate regions in which the magnetic pressure is close to the total pressure as the lobes of the Jovian magnetotail, but the nomenclature does not require that flux tubes open to the solar wind thread the region.

For quasi-static conditions, pressure balance in the direction transverse to the current sheet is valid so the magnetic pressure in the lobes is a proxy for the sum of magnetic and thermal pressure in the center of the current sheet at the same radial distance from Jupiter (\( R \)) and local time (LT). Thus, by assessing the variation of the magnetic pressure throughout the magnetotail, we provide indirect evidence for the variation of thermal pressure in the plasma sheet. The magnetic pressure divided by the plasma density in the center of the plasma sheet has been used to estimate the temperature variation within the plasma sheet (J. Ansher and D. A. Gurnett, Plasma density in the Jovian magnetotail, submitted to Geophysical Research Letters, 2002).

### 3. Magnetic Pressure Distribution

This report is based on measurements made by the Galileo Magnetometer Investigation [Kivelson et al., 1992] from its initial entry into the magnetosphere of Jupiter to 31 May 2000. Data from the other spacecraft (Pioneer 10, Pioneer 11, Voyager 1 and Voyager 2, and Ulysses) that have encountered the Jovian magnetosphere have also been used in this analysis. The trajectories of these spacecraft and of the Cassini pass are plotted in Figure 1. Regions where the dominant radial and azimuthal components remained close to constant between current sheet crossings were identified by inspection following the procedure described by Khurana [2001] and illustrated in his Figure 3. The average vector magnetic field (\( B_{\text{lobe}} \)) and its magnitude were obtained for each interval in the lobe.

Figure 2 shows the distribution of \( P_{\text{lobe}} = \frac{B_{\text{lobe}}^2}{2 \mu_0} \) \( \mu_0 \), the magnetic pressure measured in the lobes, versus local time (LT) and cylindrical radial distance. The pixels are centered on the midpoints of the lobe encounters along

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**Figure 1.** Spacecraft trajectories within the Jovian magnetosphere. This study incorporates data from Pioneer 10 and 11, Voyager 1 and 2, and Ulysses and all Galileo data through 31 May 2000 (portions of the trajectory shown with solid lines). Average locations of the magnetopause and the bow shock are those determined from the Voyager 2 observations.

**Figure 2.** Distribution of field pressure \( (B^2/2 \mu_0) \) in the lobes versus radial distance and local time. Representative contours of the magnetopause are shown in black. In order to guide the eye, circles indicate the 40 and 80 \( R_J \) contours and lines indicate antisolar distances of 20, 40, 60, 80, and 100 \( R_J \). At fixed radial distances, the lobe pressure increases from dusk to dawn. The corresponding field magnitude can be found from the relation \( B \text{ (nT)} = 50.13 \ [P \text{ (nPa)}]^{1/2} \). Also sketched are the average locations of the magnetopause and the bow shock determined from the Voyager 2 observations.
the orbits. Most obvious is the decrease of magnetic pressure with radial distance. There is a hint that the field magnitude at a fixed radial distance is smaller near dusk than near dawn.

[10] The dependence on radial distance is made more quantitative in Figure 3, which provides plots of the average lobe magnetic pressure versus radial distance in local time sectors of 3-hour widths whose center times are shown on the label. Points are centered in 10 RJ bins. The magnetic pressure, \( P_M^{\text{lobe}} \) (nPa), beyond 30 RJ (where the internal field contribution is of order \( 1/2 \) of the total field) is found to depend on \( \rho \) the cylindrical radial distance from Jupiter’s spin axis, as \( P_M^{\text{lobe}}(\text{nPa}) = (3.45 \pm 0.16) \times 10^7 \rho^{-2.74} \pm 0.03 \) and the lobe field magnitude (\( B_{\text{lobe}} \)) falls off as \( B_{\text{lobe}}(\text{nT}) = (2.94 \pm 0.07) \times 10^7 \rho^{-1.37} \pm 0.01 \). The error bars were obtained using the error propagation procedure outlined by Bevington [1969]. The power law was fitted to the individual data points, not the bin averages. Closer in, the pressure varies more strongly with distance (as \( \rho^{-4.1} \) in the region where the internal field contributes significantly. The variation of the lobe field is in the range reported for Pioneer 10 (\( r^{-1.7 \pm 0.08} \)), Voyager 1 (\( r^{-1.50 \pm 0.10} \)), and Voyager 2 (\( r^{-1.36 \pm 0.04} \)) by Behannon et al. [1981] [see also Acuna et al., 1983] as illustrated in Figure 4.

[11] In Figure 5 the magnetic pressure data sampled in 10 RJ bins centered at 15, 25, 35, 45, 55, 65, and 75 RJ are plotted versus local time. Beyond 20 RJ there is a tendency for the highest pressure to be found in the bin centered at 0300 LT. The minimum near midnight in the bin centered at 15 RJ may be an anomaly associated with the inner edge of the current sheet in the region of transition to the quasi-dipole field of the inner magnetosphere, a location where local field minima are observed in the magnetotail at Earth [see, e.g., Iijima et al., 1990]. Between 25 and 55 RJ where the lobes are fully defined, the pressure is lower at dusk than at dawn, but the pressure variation is weak in the outermost bins centered at 65 and 75 RJ. Slavin et al. [1985] report that \( B_{L,0} \) averaged over the range \( 140 < |X| < 225 \) RJ is roughly constant across the magnetotail, and it may be significant that at Jupiter the lobe pressure shows a trend toward increasing uniformity across the tail at the largest distances that we show in Figure 5. The comparison with Earth’s magnetotail is of interest although it is particularly important in interpreting the differences to recognize that Galileo explored only the inner portion of the magnetotail (to \( \sim 3 D_{\text{SSIP}} \)) with \( D_s \), the distance to the dayside subsolar point) whereas Slavin’s coverage reached distances as great as 225 RJ or 20 \( D_{\text{SSIP}} \).

[12] In the center of the plasma sheet \( P_{\text{thermal}}^{\text{lobe}} \), the thermal pressure of plasma, dominates, but the component of the magnetic field normal to the current sheet, on average aligned with the spin axis of Jupiter (defined as the \( z \) direction), does not vanish and its contribution to the total pressure should be evaluated. The condition \( \nabla \cdot \mathbf{B} = 0 \) and the fact that the scale length of the magnetic field variation in \( z \) is small compared with the scale lengths of variations in radius and azimuth implies that \( \partial B_z/\partial z \approx 0 \) in the vicinity of the plasma sheet [Vasyliunas, 1983]. Thus we can use \( B_z \) in the lobe as a proxy for the finite field that threads the current sheet center and we obtain \( B_z^2/2 \mu_0 = P_{\text{thermal}}^{\text{lobe}} \), the magnetic pressure in the center of the plasma sheet. We plot this quantity in 3-hour bins of local time versus radial distance in Figure 6 and, in this case, fit the bin-averaged data beyond 25 RJ to obtain \( P_{M}^{\text{lobe}}(\text{nPa}) = (7.43 \pm 2.19) \times 10^4 \rho^{-2.44} \pm 0.17 \). This corresponds to \( B_z(\text{nT}) = (4.32 \pm 0.64) \times 10^4 \rho^{-2.44} \pm 0.09 \). The bin-averaged data were used in the region where natural noise produces fluctuations of order the average pressure, a situation that produces singular values for a logarithmic distribution and thereby skews the fit.
The pressure in the center of the plasma sheet is only ~2% of the lobe pressure, as can be seen by comparing Figure 6 with Figure 3. Figure 7 shows the magnetic pressure in the center of the plasma sheet, $P_{ps}^M$, versus local time in different bins of radial distance. A strong pressure asymmetry is found at all radial ranges, with the largest values appearing near the dusk meridian.

The quasi-static assumption, which assumes that flows do not modify north-south pressure balance, implies that $P_{thermal}^{ps} = P_{lobe}^M - P_{ps}^M$. The best fit to this difference (fitted to all of the individual data points in the region beyond 30 $R_J$) is $P_{thermal}^{ps}$ (nPa) = $(3.16 \pm 0.16) \times 10^3 \rho^{-2.73\pm0.03}$. Figures 8 and 9 show properties of the plasma sheet thermal pressure in forms analogous to Figures 2 and 5 for the lobe magnetic pressure. They show the distribution in both radial distance and local time and the local time dependence, respectively.

4. Discussion

The rate of decrease of Jupiter’s lobe field magnitude with radial distance (see Figure 3) can be contrasted with the falloff of the magnetic field in the lobes of Earth’s magnetotail for which a number of models have been published. Fairfield and Jones [1996] reviewed previous studies of the radial structure and reported on their own analysis of an exceptionally large number of tail lobe measurements at antisolar distances between 15 and 70 $R_E$ obtained from 11 different spacecraft. Their expression, $B \sim 7.47 + 1659.2 r^{-1.46}$, asymptotes to a finite value, and successfully represents the lobe field both close to Earth and in the distant magnetotail. This form differs from the purely power law fits used by Mihalov et al. [1968], Slavin et al. [1985], and Nakai et al. [1991]. The power law ($B \sim 125 r^{-0.53}$) of Slavin et al. is based on ISEE 3 data obtained between 22 $R_E$ (where the Earth’s dipole field contributes ~1/3 of the total field) and 130 $R_E$. Mihalov et al. represented Explorer 33 data out to 80 $R_E$ as $B \sim 207.3 r^{-0.767}$. Behannon modeled the same data set with a function that includes a constant with a weak dependence on geomagnetic activity (parametrized by $Kp$) and distance from the current sheet. At a nominal position...
in the lobe and for $Kp = 1$, Behannon’s form reduces to $B (nT) = 69.13 r^{-0.3} - 8.27$. Nakai et al. fitted ISEE 1 and 2 data between $X = -10$ and $-23 R_E$ to $B (nT) = 1030 r^{-1.2}$. These fits are plotted in Figure 10 and, except for the Nakai et al. fit, are extended to $120 R_E$, although their regions of validity are more limited. The curves appear somewhat inconsistent, but Fairfield and Jones [1996] have accounted for many of the differences. They argue, for example, that the Mihalov et al. and Behannon fits apply for low geomagnetic activity levels whereas Slavin et al. used data from 1983, which was a very active year. The expression provided by Nakai et al.

**Figure 7.** As for Figure 5, but for, $P_{ps}^m$ the magnetic pressure at the center of the plasma sheet. Vertical dashed lines again delimit the magnetotail region. Here again the scales vary in the successive panels.

**Figure 8.** As for Figure 5 but for the difference between the lobe magnetic pressure and the magnetic pressure in the center of the plasma sheet. For quasi-static force balance this difference equals the thermal pressure. Comparison of this figure with Figure 6 shows that in the center of the plasma sheet, the magnetic pressure is typically less than 0.1 of the thermal pressure.
Figure 9. Distribution of thermal pressure in the plasma sheet determined as the difference between lobe and plasma sheet magnetic pressures versus radial distance and local time. Representative contours of the magnetopause are shown in black. In order to guide the eye, circles and lines are provided as in Figure 2. At fixed radial distances the plasma sheet pressure decreases from dusk to dawn.

applies only close to Earth ($r < 23 R_E$) where its rapid falloff reflects the residual importance of Earth’s internal field. The Slavin et al. fit emphasizes data from very large distances and yields a slow fall-off with distance. Finally, Fairfield and Jones explain that the difference between fits to $X$ and $R$ accounts for some of the discrepancies inside of $\sim 25 R_E$.

In Figure 10 we also plot our fit to the lobe field of the Jovian magnetotail versus radial distance in planetary radii ($R_J$). Inside of $25 R_J$, the Jovian field values are larger than the terrestrial values inside of $25 R_E$, but the line approximately parallels the models of Fairfield and Jones and of Nakai et al. that represent the near Earth regions; at large distances the Jovian field decreases far more rapidly than do the terrestrial models that apply at large distances. However, we suggest that a meaningful comparison between Earth and Jupiter requires that both distances and field magnitudes be rescaled. The dipole field of Jupiter is 13.5 times larger than that of Earth, suggesting that the constant factor be reduced by $1/13.5$. Distance scales should be more meaningfully based on a relative magnetospheric scale length rather than the planetary radius. Using $10 R_E$ and $50 R_J$ as the nominal distances to the nose of the magnetosphere as the relevant scale length, we express the rescaled Jovian fit as $B (nT) = (2900/13.5) \times [5/r (R_J)]^{1.37} = 215 [5/r (R_J)]^{1.37} = 1950 r (R_J)^{-1.37}$. This function is plotted along with the Fairfield and Jones fit to the field of the terrestrial magnetosphere in Figure 11. This curve has been singled out as the one that best represents the lobe field over the full range of distances from 10 to $15 R_E$ to over $100 R_E$ downtail. The trend of the rescaled Jovian fit would diverge considerably from the Fairfield and Jones function at downtail distances $> 30 R_E$. However, the Jovian fit was derived from data taken within $\sim 150 R_J$. Following rescaling, the fit must be regarded as valid only within $30 R_E$ and consequently is plotted only over this range. In this limited region of the magnetotail it lies close to the model of Fairfield and Jones and also to the Nakai et al. model which is applicable close to Earth. Thus we conclude that the near planet magnetotails to distances of roughly three times the distance to the nose of the magnetopause are similar at Earth and Jupiter. More significant is that the most distant orbits of Galileo seem to have grazed the region of transition beyond which it seems likely that the field magnitude would slowly start to asymptote to a near constant value, behavior that is clearly seen in the Fairfield and Jones form. Support for the proposal that the field in the magnetotail falls off more slowly than the power law adduced within $\sim 150 R_J$ is provided by the evidence that Jupiter’s magnetotail extends out to the orbit of Saturn [Lepping et al., 1983], a distance of order $10,000 R_J$ from Jupiter. If the lobe field continued to fall at the rate dictated by the power law fit $B_{obs} (nT) = 2.94 \times 10^3 \rho^{-1.73}$, its magnitude at Saturn’s orbit would be a mere $\sim 0.003$ nT, whereas the magnitudes observed were a few tenths of a nanotesla. Thus it seems probable that an additional constant term such as that incorporated in the Fairfield and Jones model for the terrestrial magnetotail will be required in order to describe the tail over large antisolar distances.

Within the near-Earth magnetotail (inside of $\sim 130 R_E$), a decrease in magnetic [Slavin et al., 1983] and thermal [Spence et al., 1989] pressure with downtail distance has been discussed extensively. Both at Earth and at Jupiter, part of the decrease relates to the fall-off of the internal...
Figure 11. As for Figure 10, but for the Fairfield and Jones fit to the field of Earth's lobes and the newly reported fit to the field of the Jovian lobes, rescaled as described in the text. The Nakai et al. fit, valid close to Earth, is also shown. A vertical line indicates the boundary of the region in which the scaled Jovian fit is constrained by data.

field. In addition, magnetic pressure decreases with downtail distance both because the tail cross section increases and because some flux closes through the current sheet or couples with the solar wind through the magnetopause.

[18] Models of the Jovian magnetopause show that the tail flares with downtail distance in the regions probed by Galileo. Over the limited region of interest \([-30 > x(R_J) > -150]\), we model the half-width of the magnetotail from a recently developed magnetopause model [Joy et al., 2002] as \(r_{\text{MP}}(x) = 140 + 0.33x\). At \(x = -30 R_J\), the half-width is \(-150 R_J\), at \(-100 R_J\), it is \(-173 R_J\), and at \(-150 R_J\), it is \(-190 R_J\), hence the area increases by 1.6 between 30 and 150 \(R_J\). Our fit to the lobe magnetic field indicates that over this range of distances, the field magnitude drops by a factor of 0.01. Thus only a small part of the pressure decrease can be attributed to flaring. (In the flux estimates, we use one of the Joy et al. models, but the results would be little changed if magnetopause flaring followed other reasonable forms.)

[19] Let us focus on the region from 100 to 150 \(R_J\) in which a magnetotail-like structure is at least partially developed. Provided that one can neglect loss of magnetic flux through the magnetopause boundary, the decrease of magnetic flux in one lobe between 100 and 150 \(R_J\) must equal the flux that crosses the current sheet across an equatorial area confined between the same limits and bounded by the magnetopause, i.e.,

\[
\begin{align*}
\left\{ \int_{-\pi/2}^{\pi/2} d\phi \int_{0}^{173} dr (100/\rho)B_{\text{lobe}} \left[ (100^2 + r^2 \sin^2 \phi)^{1/2} \right] \\
- \int_{-\pi/2}^{\pi/2} d\phi \int_{0}^{190} dr (150/\rho)B_{\text{lobe}} \left[ (150^2 + r^2 \sin^2 \phi)^{1/2} \right] \right\} \\
= 2 \int_{-100}^{-150} dx \int_{0}^{\psi(x)} dy \langle B_z(\rho) \rangle,
\end{align*}
\]

where the coordinates are expressed in terms of Jovian magnetospheric coordinates: \(x\) along the Jupiter-Sun direction, \(y\) (positive toward dusk) and perpendicular to both \(x\) and Jupiter’s magnetic moment, and \(z\) selected to complete an orthogonal coordinate system. Here \(\psi\) is the angle about the Sun-Jupiter line measured from the \(z\) axis, \(r = (x^2 + y^2)^{1/2}\) and \(\rho = (x^2 + y^2)^{1/2}\). The factors \((100/\rho)\) and \((150/\rho)\) project the \(\rho\) component onto the \(x\) direction. For \(B_{\text{lobe}}\), we use the fit in Figure 3, neglecting its variation across the lobe. Figure 6 provides measurements of \(B_z(\rho)\). Beyond 100 \(R_J\), the values fluctuate by almost an order of magnitude and the fitted line significantly underestimates the night-sector measurements, so we represent the right side of equation (1) in terms of an average value of the field \(\langle B_z \rangle\) to be determined. Numerical values given in Table 1 show that the fluxes on the two sides of equation (1) balance if \(\langle B_z \rangle \approx 1.5 \text{ nT}\). Figure 6 indicates that in the midnight to dusk sector, this is an acceptable nominal value for \(B_z(\rho)\) at 150 \(R_J\).

[20] In the analysis we assumed that the lobe pressure is only very slightly modified by loss of flux through the magnetopause in this range of downtail distances. The validity of that assumption is supported by the following argument. The magnetic field of the solar wind near Jupiter’s orbit varies from a few tenths to a few nanoteslas with an average value of the order of 1 nT. If reconnection efficiency were 10%, the average normal component through the boundary would not be greater than \(\sim 0.1 \text{ nT}\) even on the dayside and would become smaller on the flanks. The flux through the boundary between 30 and 150 \(R_J\) would satisfy

\[
\text{flux (nT } R_J^2) < 0.1 \pi \int_{30}^{150} dx (140 + 0.33x) \approx 6400. \tag{2}
\]

The flux crossing surfaces at \(X = -30, -100, \text{ and } -150 R_J\) in one lobe is of order \(10^5 \text{ nT } R_J^2\), more than an order of magnitude larger than the upper limit given by equation (2). In particular, the decrease between \(-100\) and \(-150 R_J\) (Table 1) is a factor of 5 larger than the upper limit flux estimated to be crossing the magnetopause in this segment of the tail. Thus the flux in this section of the magnetotail either closes through the current sheet or is on open field that cross the magnetopause and link to the solar wind beyond \(-150 R_J\).

[21] We can estimate the fraction of the lobe flux near 100 \(R_J\) corresponding to field lines that couple to the solar wind (open field lines). The open field lines in the magnetotail link to the region within the open-closed field line boundary in Jupiter’s ionosphere. Let us estimate how much magnetic flux is linked by this boundary. The angular size of the region is not firmly established but several lines of argument suggest that the polar cap has an angular half width of order

<table>
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<th>Table 1. Magnetic Flux and Related Parameters</th>
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<tr>
<td>Half-Width</td>
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<td>Tail</td>
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<td>In one lobe at surface (x(R_J) = -30)</td>
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<tr>
<td>In one lobe at surface (x(R_J) = -150)</td>
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<td>Net flux left side of equation (1)</td>
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<td>Flux right side of equation (1)</td>
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<td>Open flux out of polar cap</td>
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~10° of colatitude [Southwood and Kivelson, 2001]. For example, the polar arcs reported by Pallier and Prangé [2001] span a region of half-width ~10° as does the open-closed field line boundary in magnetohydrodynamic simulations of Jupiter (R. J. Walker, personal communication, 2001). The locus of the last closed field line in the O6 model differs little from these estimates; in Figure 6 of Connerney [1991] the footprint spans a region of half width ~15°. The polar arc defines a region where the field magnitude is ~10° nT, thus enabling us to estimate the open flux in each polar cap as ~1–2 × 10° nT RJ. Thus the flux in the lobe at 100° and ~50° RJ shown in Table 1 is of the same order as the flux in the polar cap, and most of the lobe flux at these distances must connect to the solar wind. At most a small fraction of the flux observed at ~150° RJ is available to close across the tail current sheet. This estimate is based on average values of the lobe field and ignores any dependence on local time, which may require that closed and open flux tubes be nonuniformly distributed across the tail.

[22] The change of magnetotail properties with local time calls for a physical interpretation. The total magnetic pressure (and, as well, the magnetic field magnitude) plotted versus LT in Figure 4 in the lobes at fixed radial distance between ~50° and about ~60° RJ is smaller by 20–40% near dusk than near midnight. In terms of magnetic field structure, the anticorrelated changes of the radial component (which dominates the lobe magnetic field) and z component of the field between dawn and dusk imply that field lines in the dusk sector are much less stretched than they are in the dawn sector. This difference has been identified in MHD simulations (R. J. Walker, personal communication, 2001) such as those of Ogino and Walker [1998] and Walker et al. [2001] although the degree of stretching is underestimated in the existing simulations.

[23] As the lobe magnetic pressure is smaller in the dusk sector than in the dawn sector, it follows that the structure of the magnetotail departs from cross-tail symmetry. In the center of the plasma sheet beyond ~50° RJ the magnetic (thermal) pressure has a maximum (minimum) in the dusk sector, then decreases (increases) abruptly and varies little with local time between 2100 LT and dawn. A thermal pressure decrease in the near equatorial portion of a flux tube means that the plasma is less concentrated near the equator of the flux tube but does not necessarily imply that the flux tube content has changed even though that possibility must be allowed. In the rotating magnetosphere, the plasma may move away from the equator in regions where centrifugal effects are not imposed by coupling with the ionosphere. A thick plasma sheet near dusk was reported by the Ulysses team [Krupp et al., 1999]. They related its appearance to temporal variations. Thickening near dusk could, however, be a characteristic of the time-independent plasma sheet [Kivelson et al., 2001] and would be consistent with evidence that corotation is modest or absent in the dusk to 2100 LT sectors [Krupp et al., 2001], although the slowing of flow has been interpreted elsewhere as related to a neutral line in the magnetotail [Khurana, 2001].

5. Summary

[24] The properties of the magnetotail inferred from its average magnetic structure provide constraints that should prove useful for developing theoretical interpretations of the plasma processes of importance and for testing magnetohydrodynamic models of the Jovian magnetosphere. In particular, models that require reconnection in the magnetotail as an important aspect of the global dynamics [Khurana, 2001, also Does Jupiter’s magnetosphere lie within its plasmasphere?, submitted to Geophysical Research Letters, 2001; Vasyliunas, 1983; Walker et al., 2001] must account for the structure and the asymmetries reported here.

[25] Acknowledgments. The authors are pleased to thank Duane Bindschadler and the rest of the Galileo team at JPL for their continued support of a complex and challenging mission. At UCLA, we owe thanks to Steve Joy and Joe Mafl for development of the data sets that were used in this work and Todd King for providing many of the tools needed to analyze the data. This work was partially supported by the Jet Propulsion Laboratory under contract JPL 958694 and by a NASA grant NAG 5-9546.

[26] Janet G. Luhmann thanks Michelle Dougherty and Joachim Woch for their assistance in evaluating this paper.

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M. G. Kivelson and K. K. Khurana, Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095-1567, USA. (mkivelson@igpp.ucla.edu)