8 The geomagnetic tail

After we have discussed the interaction of the solar wind and the terrestrial magnetic field on the dayside, we now turn our attention to the nightside. As we shall see, the nightside magnetic field is pulled into a long tail, extending to over 100 R_e downstream.

8.1 Formation of the tail

During periods when the IMF is anti-parallel to the dayside magnetic field (0), reconnection occurs, connecting terrestrial magnetic field lines with the IMF (1). Since the IMF is frozen into the solar wind flow, its magnetic field lines and by extension also the terrestrial magnetic field lines are pulled toward the nightside (2-4). These elongated magnetic field lines form the geomagnetic tail, extending many tenth or Earth radii into space.

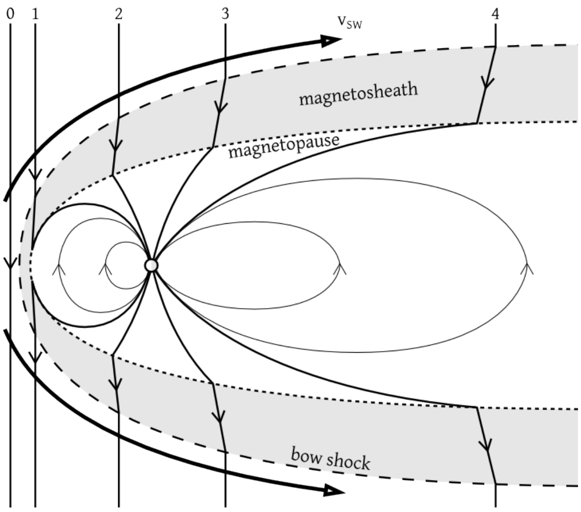

Figure 1: View of the magnetosphere from the side. Dayside reconnection connects terrestrial magnetic field lines with IMF lines and the solar wind flow drags the field lines antisunward, forming an elongated tail.

8.2 Cross tail current

The interaction between the dayside terrestrial magnetic field and the IMF forms the geomagnetic tail, extending the terrestrial magnetic field many R_e downstream.
Across the center of the tail there exists a magnetic shear which requires a current to sustain. This current is called the cross tail current and it flows in a region called the plasma sheet. The tenuous regions above and below the plasma sheet are called the northern and southern lobes.

Inside the plasma sheet the thermal pressure is higher than in the lobes, causing a pressure gradient away from the center. However, across the plasma sheet the magnetic field goes through zero, creating a magnetic pressure gradient pointing toward the center. In the equilibrium situation these two gradients are balanced.

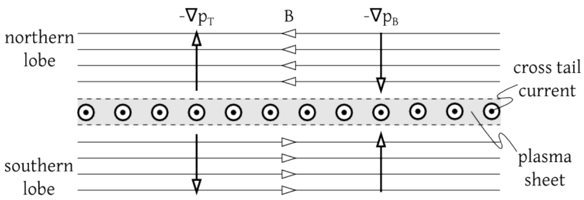

Figure 2: View of the cross tail current sheet from the side. In this scenario the magnetic pressure is balanced by the thermal pressure.

8.3 Open/closed magnetic field lines

Dayside reconnection connects terrestrial magnetic field lines with the IMF. Magnetic field lines which connect to the planet on both ends are called closed field lines; those connected to the IMF are referred to as open field lines. Therefore, dayside reconnection opens previously closed magnetic field lines. The last closed field line forms the open/closed field line boundary (OCB). When followed toward the planet all open field lines lie poleward of the OCB whereas all closed magnetic field lines map to the region equatorward of the OCB. The area inside the OCB, threaded by open magnetic field lines, is called the polar cap.

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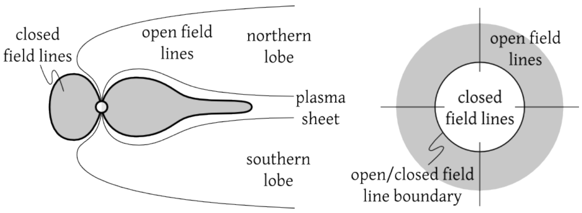

Figure 3: Sketch showing open and closed field lines. Open field lines are those connected to the IMF, closed field lines connect to the planet on both ends. Projected into the polar regions, the boundary between open and closed field lines is a circle centered on the geomagnetic pole.

Most of the magnetic field lines from the polar cap (PC) map into the lobes such that, to first order, we can assume that the magnetic flux inside the OCB in one hemisphere Φ_{PC} is the same as the magnetic flux threading one of the lobes Φ_T. Furthermore, we assume the OCB is located at a colatitude of φ_{PC} and that the magnetic field is vertical and constant inside the polar cap:

$$\Phi_{PC} = \int_{PC} \vec{B}\cdot d\vec{a} \approx \pi(R_e \sin\varphi_{PC})^2 2B_{eq}. \quad (8.1)$$

In one lobe of the (cicular) tail the magnetic flux is roughly

$$\Phi_T = \frac{1}{2}\pi R_T^2 B_T, \quad (8.2)$$

where B_T is the tail magnetic field strength and R_T is the tail radius. Equating Φ_{PC} and Φ_T allows us to estimate the tail radius in units of Earth radii:

$$R_T = \sqrt{\frac{4B_{eq}}{B_T}}\sin\varphi_{PC}. \quad (8.3)$$

For typical values of $\varphi_{PC} \approx 15^\circ$ and $B_T \approx 25$ nT we obtain a typical tail radius of $R_T \approx 25$.

8.4 Tail flairing

At the magnetopause of the lobes, the magnetic pressure of the lobes $p_{l,B}$ is balanced by the dynamic and thermal pressure of the solar wind, $p_{d,SW}$ and $p_{t,SW}$ respectively. Introducing a flaring angle α we obtain

$$p_{d,SW} + p_{t,SW} = p_{l,B} \quad (8.4)$$

$$\rho_{SW}(v_{SW}\sin\alpha)^2 + p_{t,SW} = \frac{B_T^2}{2\mu_0} \quad (8.5)$$

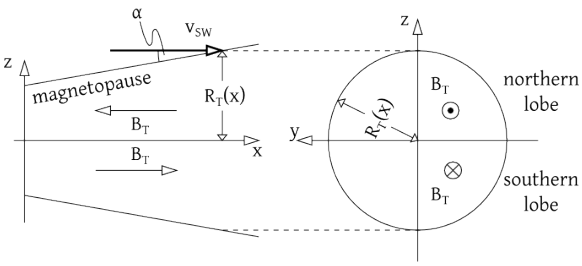

Figure 4: View of the magnetotail from the side (left) and looking down tail (right).

The flaring angle α is given by

$$\tan\alpha = \frac{R_T}{x} = \frac{dR_T}{dx} \quad (8.6)$$

but because $\alpha \ll 1$ we can approximate $\sin\alpha \approx \tan\alpha \approx \alpha$ and combine to obtain:

$$\rho_{SW}\left(v_{SW}\frac{dR_T}{dx}\right)^2 + p_{t,SW} = \frac{1}{2\mu_0}\left(\frac{2\Phi_T}{\pi R_T^2(x)}\right)^2 \quad (8.7)$$

or

$$\gamma M^2\left(\frac{dR_T}{dx}\right)^2 + 1 = \left(\frac{R_A}{R_T(x)}\right)^4 \quad (8.8)$$

where we have introduced the asymptotic radius $R_A = 2\Phi_T^2/\mu_0\pi^2 p_{t,SW}$. It is called the asymptotic radius because far down the tail we see that $dR_T/dx \to 0$ and hence

$$\lim_{x\to\infty} R_T(x) = R_A. \quad (8.9)$$

Separating the variables and introducing $r = R_T/R_A$ we can find the distance down the tail where the flaring angle is zero x_A, based on a reference radius R_0 at some reference distance x_0 as

$$x_A = x_0 + R_A M \int_{r=R_0/R_A}^{1} \frac{1}{\gamma}\left(\frac{1}{r^4} - 1\right)^{-1/2} dr. \quad (8.10)$$

For typical values values of the solar wind and the tail magnetic field, the flaring angle is zero about 110 Earth radii down tail.