Geophysics

The nightside magnetosphere

from S. W. H. Cowley

THE first sets of data collected by the International Sun Earth Explorer-3 (ISEE-3) spacecraft during its passage through the nightside magnetosphere, and recently published, are yielding results of major importance for magnetospheric physics[1-9]. They provide the first direct evidence for the long-held belief that the Earth's magnetosphere has a very asymmetric shape and new insight into the behaviour of the magnetospheric tail during substorms.

All we know about the Earth's magnetosphere, the cavity in the solar wind plasma formed by the Earth's magnetic field, points to the fact that it should have a very asymmetric shape, but direct evidence has, until now, been lacking. The field on the sunward side is compressed by the ~ 400 km s^{-1} solar wind flow, and extends to distances of only ~ 10 Earth radii (1 R_E ~ 6,400 km). On the nightside, however, coupling between magnetospheric flux tubes and the solar wind stretches the magnetosphere into a long cylindrical magnetic tail consisting basically of two bundles of oppositely-directed magnetic flux connected to the Earth's polar regions (Fig. 1*a*). As long ago as 1965 Dungey showed, by considering the motions of the polar ionosphere, that the tail should extend ~ 1,000 R_E downstream of the Earth[10].

Until recently, detailed spacecraft observations of the tail were available only out to distances of a few tens of Earth radii and relatively little was known about the properties of the nightside magnetosphere beyond the lunar orbit (~ 60 R_E). In mid-1982, however, the ISEE-3 spacecraft was moved from its orbit about the dayside Lagrangean point 234 R_E sunward of the Earth, where it had been monitoring solar wind particles and field since its launch in 1978, and, by means of novel lunar gravity-assisted orbit manoeuvres, sent on a series of passes through uncharted nightside territory extending ~ 235 R_E from the Earth.

The first major result to emerge from the new data is that although the distant tail retains a well-ordered magnetic structure similar to that found near the Earth[2,4], the character of its plasma populations is distinctly different. In the region near the Earth, the magnetic lobes of the tail contain only a tenuous low-energy plasma, and between the lobes, during magnetically quiet conditions, there is a thick (~ 5 R_E) region of hot (~ 5 keV) plasma, named the 'plasma sheet', which drifts slowly towards the Earth with average speeds of 100 km s^{-1} (Fig. 1*a*). At ~ 200 R_E, ISEE-3 made two discoveries: first, the tail lobes are often pervaded by plasma streaming tailward at speeds of ~ 200 km s^{-1}, but still having fairly low densities compared with, for example, the density of the solar wind (~ 5 ions per cm^3); and second, at the centre of the tail, between the lobes, are plasma jetting tailward at speeds of 500 –1,000 km s^{-1} and tailward-flowing energetic particles[1,3,6]. The first of these findings is rather unsurprising and can easily be explained by continual drift into the tail lobes of solar wind plasma gaining access along 'open' magnetic field lines at the tail boundary. The second finding is much more important, and provides the first insight into the location of the much-sought quiet-time tail magnetic neutral line. This line lies at the centre of the 'X' in the magnetic field shown in Fig. 1*a*, and forms the boundary between 'closed' field lines which flow earthward at the tail centre plane and 'disconnected' field lines which flow tailward (according to Dungey's 'open' model of the magnetosphere). The ISEE-3 flow measurements at the tail centre plane indicate that the quiet-time neutral line lies at a downtail distance of ~ 100 R_E (ref.8).

The second major result concerns the behaviour of the tail during substorms. These 'storms' occur a few times each day, last about 1 hour, and are associated with brilliant disturbed auroral displays that can be seen from Earth at high latitudes and with magnetic disturbances caused by the flow of intense currents in the ionosphere and magnetosphere. The ISEE-3 data provide new information strongly supporting the view that substorms are closely linked with large-scale rearrangements of the configuration of plasmas and fields in the nightside tail (refs 5 and 9 and see Fig. 1*b*, *c*). At the onset of a substorm, a new neutral line forms in the near-Earth tail (Fig. 1*b*) at a point where magnetic reconnection is sufficiently rapid that, within minutes, a large fraction of the pre-substorm plasma sheet becomes disconnected from the Earth, forming a large (tens of Earth radii) 'plasmoid' of closed field loops which flows downtail at speeds of ~ 500 km s^{-1} (Fig. 1*c*). The ISEE-3 spacecraft first detects substorms ~ 20–25 min after their onset when it becomes magnetically connected to the hot plasma accelerated downstream of the new neutral line (for example, at the cross in Fig. 1*c*) and observes electrons and high-energy ions moving quickly from the 'tail' of the tailward-flowing thermal plasma, along the newly 'disconnected' field lines. After a further 5–10 min, ISEE-3 is engulfed for 20 min by the hot plasma and disturbed magnetic field region of the plasmoid, before emerging into the hot substorm-accelerated tailward-streaming plasma itself. After ~ 40 min the new neutral line is believed to start moving tailward towards a position at ~ 100 R_E, and this signals the beginning of an ~ 40 min recovery period. Towards the end of this period, ISEE-3 usually leaves the tailward-streaming plasma and moves into the tail lobes, though it can remain in the plasma sheet for hours.

With the advent of Halley in 1986, it is interesting to note that similar 'disconnection' phenomena appear sometimes to occur in the plasma tails of comets. In the case of comets, however, the tail is not formed by magnetism intrinsic to the comet, as is the case for the Earth, but by solar wind field lines which are 'caught up' near the comet head in cometary plasma and which are then stretched out downstream to form an 'induced' magnetotail. ISEE-3 should provide the first observations *in situ* of these magnetotail phenomena as well. When it had completed its deep-tail passes, the spacecraft was targeted within ~ 120 km of the lunar surface on its last lunar interaction in December 1983, and received sufficient impulse to escape the Earth altogether and pass through the tail of comet Giacobini-Zinner on 11 September 1985. □

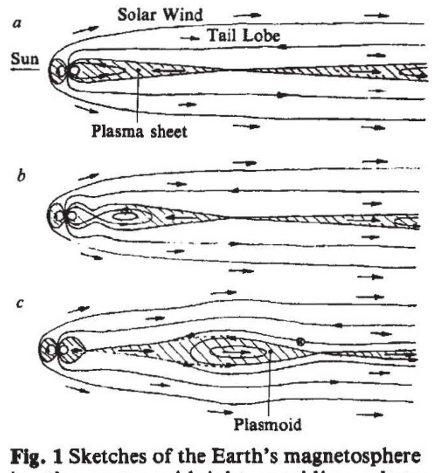

Fig. 1 Sketches of the Earth's magnetosphere in the noon–midnight meridian plane showing, approximately to scale, the large-scale reconfiguration which occurs during substorms (after ref. 5). Solid lines are magnetic field lines, short arrows indicate the direction of plasma flow and hatching the regions of hot accelerated plasma. *a*, Pre-substorm configuration with the tail neutral line at ~ 100 R_E from Earth. At the beginning of the substorm a new neutral line forms in the near-Earth plasma sheet resulting in its rapid disconnection from the Earth. The resulting 'plasmoid' of closed flux loops flows downtail (*c*) followed by hot tailward-streaming plasma accelerated downstream of the new neutral line.

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