3. Compile a global scalar and vector crustal magnetic anomaly map. Accuracy goals are 3 γ rss in magnitude and 6 γ rss in each component for the scalar and the vector magnetometers, respectively. The spatial resolution goal of the anomaly map is 300 km; and
4. Interpret the crustal anomaly map, in conjunction with correlative data, in terms of geologic/geophysical models of the earth's crust for assessing natural resources and determining future exploration strategy.

The objectives will be achieved by investigations that will be carried out at the Goddard Space Flight Center and at the USGS by distinguished members of the scientific community. Fields being investigated include geology, geophysics, field modeling, marine and core/mantle studies, and magnetosphere/ionosphere interactions. APL will be involved in the last investigation (Table 1).

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ENCOUNTERS WITH JUPITER: THE LOW ENERGY CHARGED PARTICLE RESULTS OF VOYAGER

Like the Earth, Jupiter has a magnetic and charged particle environment—a magnetosphere—that presents an obstacle to solar wind plasma flowing outward from the sun. Using a gas dynamics analogy, one envisions a viscous interaction in which solar wind flow molds the magnetosphere into a comet-like shape. The magnetosphere itself is subject to internal forces that may alter this picture somewhat, although the basic idea of an "obstacle to a flow" is a useful analogy. Filled with intense fluxes of high energy particles, the Jovian magnetosphere extends over 10 million km away from the planet and thus represents an object of truly astrophysical scale.

Launched in the summer of 1977, the twin Voyager spacecraft flew past Jupiter in March and July, 1979. The Voyager trajectories enabled the spacecraft to encounter the Galilean satellites (the four largest moons of Jupiter) and to make *in situ* measurements of the Jovian magnetosphere. As seen in Fig. 1, both spacecraft approached the planet in before-noon local time meridians. Voyager 1 left Jupiter in the meridian near 5 a.m. and Voyager 2 left further downstream in the meridian at about 3 a.m. In effect, the outbound Voyagers sampled different regions of the Jovian magnetosphere. Both spacecraft remained close to the ecliptic plane at low Jovigraphic latitudes.

Each voyager probe carried 11 scientific experiments designed to investigate Jupiter, its major satellites, its particle and field environment, and the interaction of that environment with the solar wind. Included was the Low Energy Charged Particle (LECP) experiment. Designed and built by the Applied Physics Laboratory in collaboration with several other institutions, the LECP instrumentation can measure ions of energies of 28 keV or greater and electrons of energies of 15 keV or greater.[1] The LECP can also provide compositional information about the particle environment it samples. The LECP detector array is mounted on a scan platform that rotates the instrument in eight discrete 45° steps so as to provide 360° coverage. The instrument has an effective dynamic range of

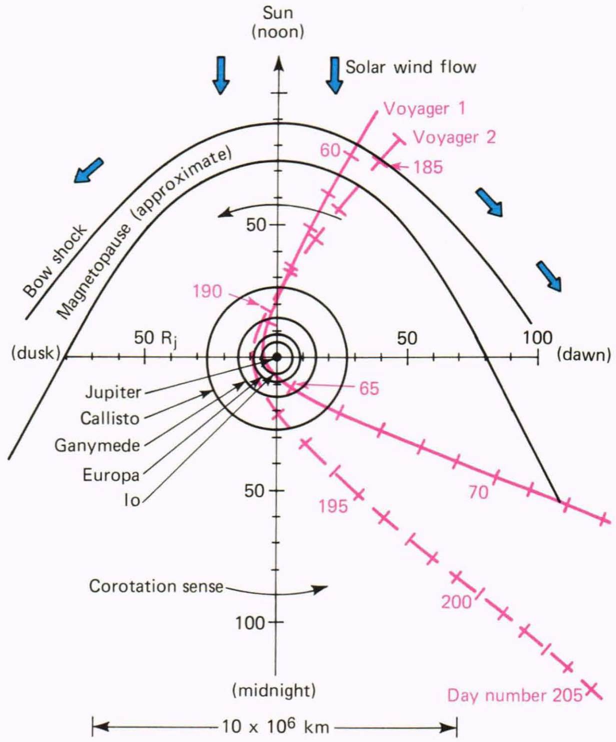

Fig. 1—Polar plot of Voyager 1 and 2 trajectories for the Jupiter encounters. The "magnetopause" curve represents the approximate boundary of the Jovian magnetosphere while the "bow shock" curve represents the detached shock generated by supersonic solar wind flow past the magnetosphere (blue arrows). The orbits of the four Galilean satellites are indicated.

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11 orders of magnitude and a fast time resolution of 400 ms. The LECP has three basic modes of operation: cruise (low time resolution, low intensity), far encounter (high time resolution, low intensity), and near encounter (high time resolution, high intensity). Each mode is appropriate for a particular environment the spacecraft encounters.

Several weeks before the Voyagers entered the Jovian magnetosphere, the LECP instrument observed intense particle bursts coming from the planet.[2] The Jovian nature of these events was recognized by their strong anisotropies away from Jupiter and by their nonsolar composition. These interplanetary "upstream" events lasted from a few minutes to a few hours and were seen about 60 million km from Jupiter.

Inbound near the noon meridian, both Voyagers crossed the magnetosphere boundary (or magnetopause) at distances of over 50 R_J (1 R_J is one Jupiter radius, or 71,400 km). Because of fluctuations in the balance between the solar wind and the magnetosphere pressure, this boundary moved back and forth several times across the spacecraft (see Fig. 2). Each encounter with the magnetopause was marked by abrupt changes of an order of magnitude or more in the low-energy particle fluxes. Furthermore, the ion flows changed direction at the magnetopause. Within the magnetosphere, the ion

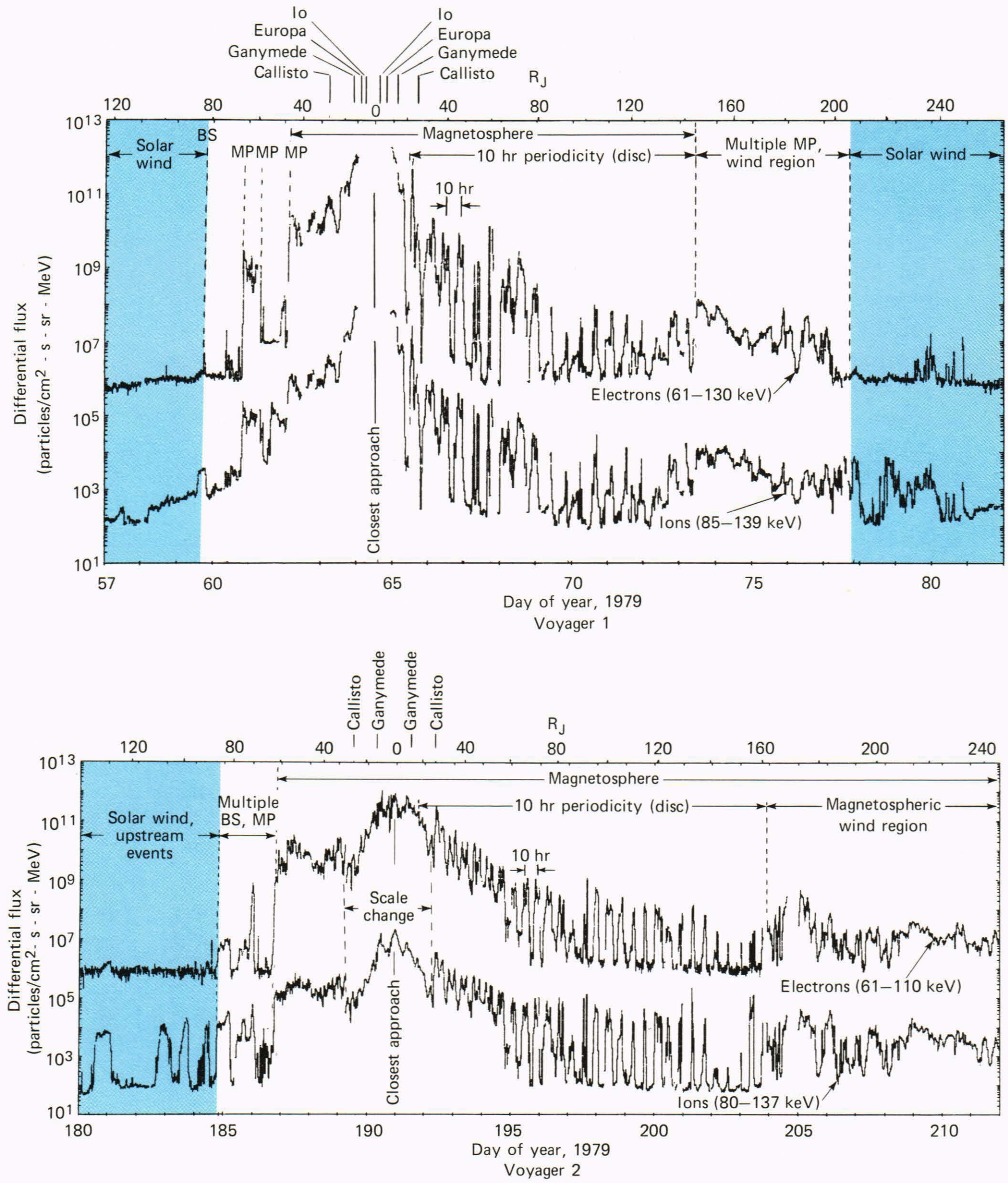

Fig. 2—Overviews of representative particle data for the Voyager 1 (Fig. 2a) and 2 (Fig. 2b) encounters. The plots are log-linear, with flux intensities on the ordinates and time on the abscissas. The data at closest approach (day 64) from Voyager 1 are not shown because they are not fully corrected. Multiple bow shock (BS) and magnetopause (MP) crossings were observed inbound. Crossings of satellite orbits are marked. Strong 10-hour periodicities in the fluxes were seen outbound. Beyond 140 to 160 R_J, the periodicities break down as the spacecraft enters the wind region.

flows were strongly corotational (i.e., in the direction of Jupiter's rotation).

In the outer magnetosphere, the Voyager LECP's discovered extremely hot, corotating plasma. Maxwellian fits to the observed spectra revealed temperatures of 20 to 30 keV (about 2.5×10^8 K) and flow speeds of up to about 1000 km/s. Though much hotter than the solar corona (at about 1.5×10^6 K), this Jovian plasma is exceedingly tenuous and has densities of 10^{-3} to 10^{-1} ions/cm^3. The hot plasma consists primarily of a nonsolar mix of hydrogen, helium, oxygen, and sulfur.

The four Galilean satellites (Callisto, Ganymede, Europa, and Io) orbit within the inner Jovian magnetosphere (i.e., inside about 30 R_J) and were primary objects for study by the Voyager mission. The innermost satellite, Io, was especially interesting because it was known to exert an influence over Jupiter's decameter radio emissions. The Voyager 1 spacecraft flew within 22,000 km of Io to make close-range observations. Photographs revealed a volcanic surface and several active volcanoes. In conjunction with the Io encounter, the LECP observed at some energies an abrupt decrease in higher energy particle fluxes while fluxes at lower energies showed no clear effect of Io; however the Io data are still under intensive study. General decreases in LECP fluxes were associated with crossings of the orbit of Io. Similar though less pronounced features were observed in connection with Europa and Ganymede, indicating that the Jovian satellites act as absorbers of particles measured by the LECP.

However, the satellite Io is undoubtedly a major source of low energy particles for the Jovian magnetosphere. Other experiments observed a toroidal plasma "cloud" coincident with Io's orbit.[3] Composition measurements by the LECP detectors showed that the proportions of oxygen and sulfur increased as the spacecraft approached this torus. This composition reflects volcanic origin, since a primary volcano emission is SO_2 gas. Indeed, the entire Jovian magnetosphere is filled with the sulfur and oxygen from the Ioan volcanoes.

One of the LECP's most dramatic observations was that of the 10-hour periodicities in the particle fluxes. The fluxes may vary by several orders of magnitude with the 10-hour rotation period of the planet. As indicated in Fig. 2, these modulations are especially evident on the outbound ("tailside") parts of the Voyager trajectories.[4]

The outbound periodicities break down at distances of 140 to 160 R_J. Beyond that distance, intense and variable fluxes are still observed but they no longer occur periodically. Also, the particles flow in directions approximately away from Jupiter. The flows are so extremely anisotropic that at times they closely resemble the monoenergetic beams of laboratory accelerators.[5,6] Composition measurements in this region reveal abundant oxygen and sulfur, a mix quite similar to that found in the inner magnetosphere. Thus, the spacecraft was probably still within the Jovian magnetosphere. This outflow region has been christened a "magnetospheric wind." The wind region may extend many tens of Jupiter radii down the Jovian magnetotail.

These recent observations of the Jovian magnetosphere have prompted a revision of ideas held before the Voyager encounters. One new version of the Jovian magnetosphere is illustrated in Fig. 3.[7,8] As with older models, particles are confined to a thin "magnetodisc" centered on Jupiter. The disc wobbles in response to the precession of the magnetic axis $\bar{M}$ about the rotation axis $\bar{R}$. This periodic wobbling motion causes the magnetodisc to wave up and down with approximately a 10-hour period (see Fig. 3a), thus giving rise to the periodicities observed by the Voyagers. On the frontside of the magnetosphere, solar wind pressure acts to blunt the disc configuration so that strong periodicities are not seen in this region. Furthermore, the flow of particles is in the corotational sense throughout the disc region. A principal feature of this model is the hot plasma within the disc. Preliminary calculations suggest that the pressure of the gas is sufficient to ward off the solar wind pressure as well as to balance the magnetic forces outside the disc. A second important feature of the new model is the disruption of the disc at large radial distances and the generation of the magnetospheric wind. Similar disruptions may cause the upstream bursts. At any rate, substantial portions of the magnetodisc seem to be ejected outward from the magnetosphere.

A fuller analysis of the LECP encounter data is in progress. In particular, one would like to understand the nature of the satellite/particle interactions of the inner magnetosphere. The boundary between the corotating disc region and the outflowing wind region should be investigated in detail. A more complete analysis of the LECP spectra is underway to refine the temperatures and number densities.

The two Voyager spacecraft are now moving toward encounters with Saturn late in 1980 and early in 1981. In spite of intense particle radiation, the LECP instruments operated flawlessly throughout the Jovian magnetosphere and are expected to provide reliable data from the Saturnian magnetosphere.

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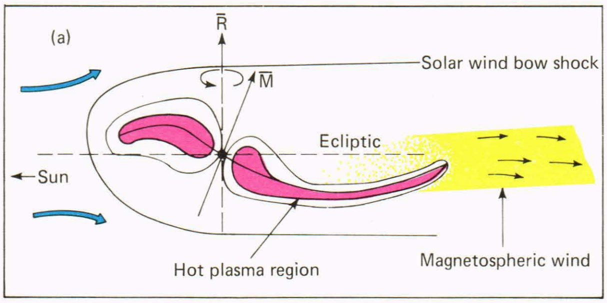
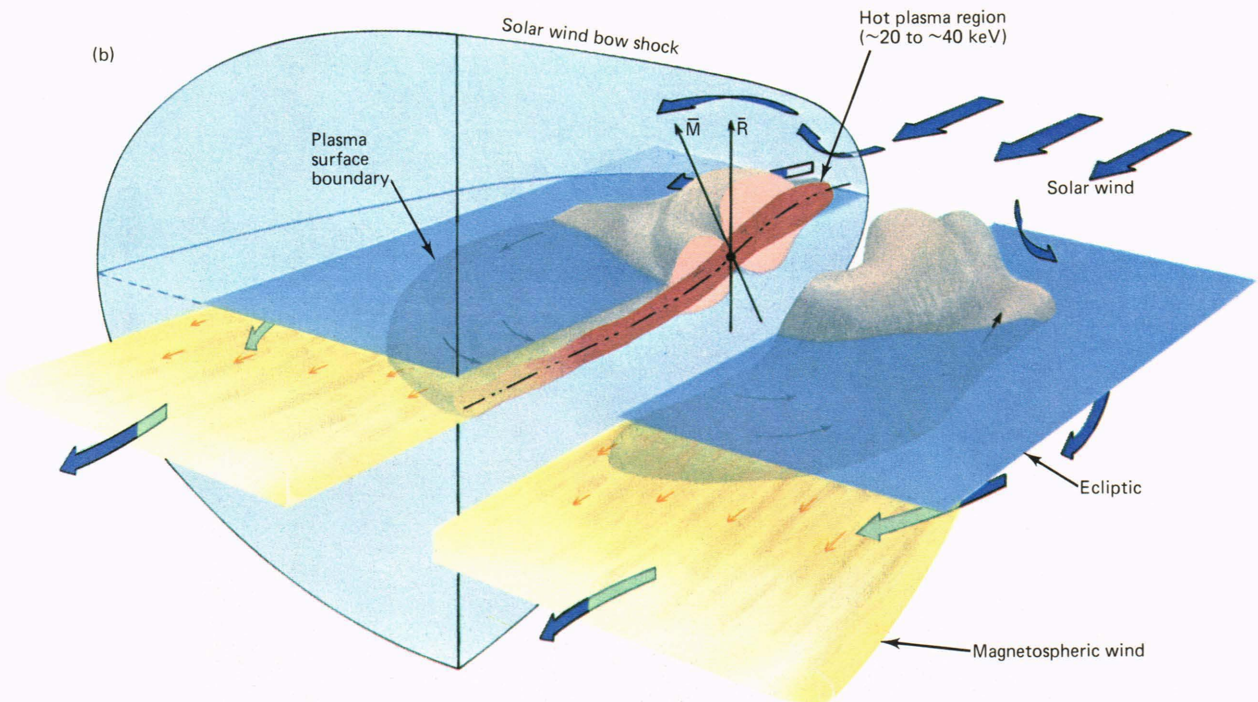


Fig. 3—The hot plasma model of the Jovian magnetosphere that has resulted from analysis of the LECP data. Figure 3a shows a noon-midnight meridional cross section. Figure 3b gives a three-dimensional view. The red region denotes the hot plasma of the corotating magnetodisc. Solar wind pressure (blue arrows) causes the disc to be blunt on the dayside and extended on the nightside. In the far magnetotail (yellow), the disc is disrupted and particles are expelled away from the planet in a magnetospheric wind.



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