

LOW ENERGY CHARGED PARTICLES AT SATURN

Voyager 1 observations of low energy charged particles (electrons and ions) in the magnetosphere of Saturn are described. The ions consist primarily of protons. Molecular hydrogen and a low concentration of helium are also present.

Space scientists had long suspected that Saturn, like Earth and Jupiter, had a magnetic field capable of presenting an obstacle to the supersonic flow of the solar wind. This obstacle — a magnetosphere — could not be detected remotely from the Earth via Saturnian radio emissions because of the great distance between Earth and Saturn. However, in September 1979, the Pioneer 11 spacecraft penetrated the magnetosphere of Saturn and confirmed the expectations that the planet possessed such an environment. In November 1980, the Voyager 1 spacecraft flew past Saturn and made a full set of magnetic field and charged particle observations of its magnetosphere.

The Voyager 1 and 2 spacecraft each carry a number of scientific experiments that are designed to investigate the planets Jupiter and Saturn and their magnetic environments. The Low Energy Charged Particle (LECP) experiment, designed and built at the Applied Physics Laboratory in collaboration with other institutions,¹ measures charged particles with energies greater than about 20 kiloelectron volts and

can provide information about the chemical composition of the particles.^{2,3} In addition, the instrument scans through a full 360° and is thus the only detector on board Voyager (a three-axis stabilized spacecraft) capable of determining actual flow anisotropies of charged particles.

The trajectory of Voyager 1 during its encounter with Saturn is shown in Fig. 1. In this three-dimensional view, the bullet-shaped surface labelled "magnetopause" represents the magnetohydrodynamic boundary between Saturn's magnetic field and the solar wind. The magnetosphere exhibits a high degree of symmetry due to the alignment of the planet's magnetic axis with its spin axis.⁴ Note that Voyager 1 entered the Saturnian magnetosphere at low latitudes but exited at high latitudes. The orbits of major Saturnian satellites are shown in Fig. 1. As indicated below, these satellites play a major role in determining the charged particle characteristics of Saturn's magnetosphere.

An overview of representative particle data from the Saturn encounter is shown in Fig. 2. As can be in-

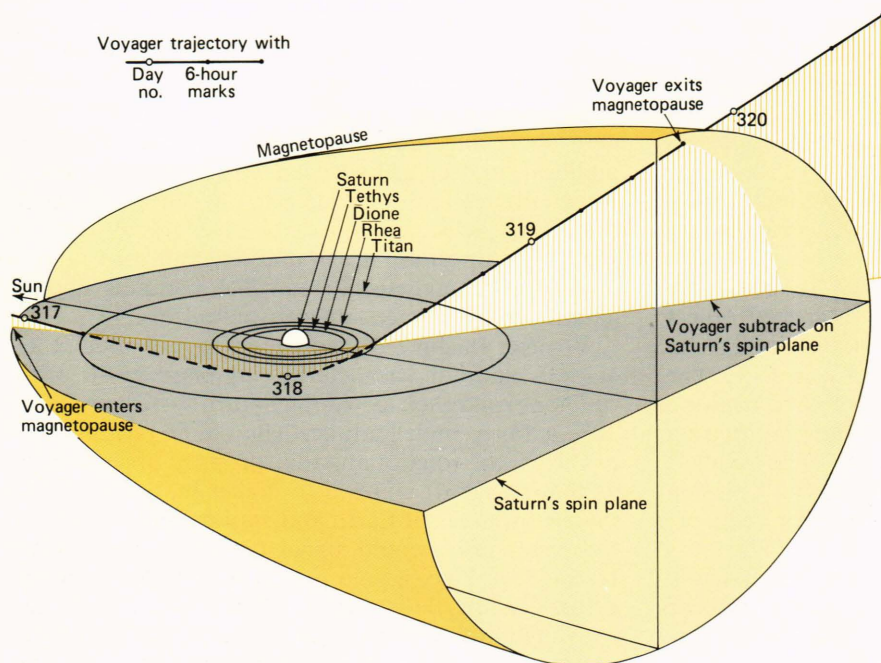


Fig. 1—Voyager 1 trajectory for the Saturn encounter. The "magnetopause" surface indicates the location of the plasma boundary of the Saturn magnetosphere. The orbits of major satellites are also shown.

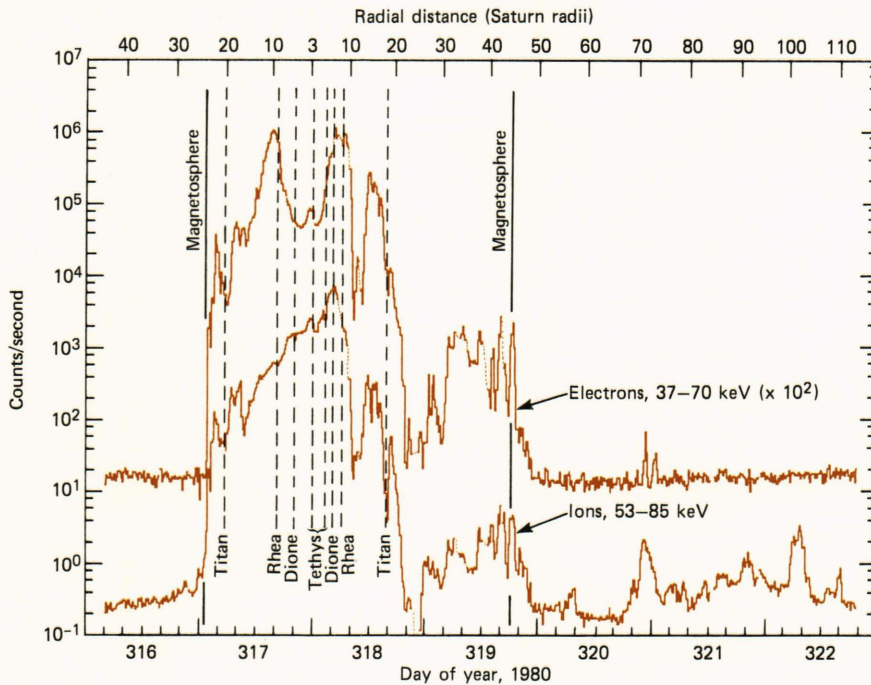


Fig. 2—Representative data profiles for the Saturn encounter. Shown here are 15-minute averages of count rate data for low energy electrons and ions (essentially protons). The dashed lines indicate when the spacecraft crossed field lines passing through the orbits of major satellites.

ferred from the low, steady rate profiles observed before the magnetopause was crossed, the solar wind was in an undisturbed state. Pioneer 11 encountered Saturn during a period of disturbed solar wind that pushed the magnetopause inward to 17 R_S (1 R_S is one Saturn radius, or 60,000 km), and particle measurements within the magnetosphere were compromised because of the pressure of solar energetic particles.^{4,5} The quiescent solar wind conditions prevailing during the Voyager encounter allowed the dayside magnetosphere to expand outwards to 24 R_S , which is well beyond the orbit of the satellite Titan. Apparently, then, changes in solar wind conditions cause Titan to orbit sometimes inside the magnetosphere and sometimes outside. The outward expansion of the dayside magnetosphere during times of quiet solar wind gives rise to a “mantle” region made up of low energy particles ($E_p \leq 500$ kiloelectron volts).⁶ The mantle extends from 17 to 24 R_S , depending on solar wind conditions, and may vanish completely, as happened during the Pioneer encounter.

As it is the only satellite known to possess a substantial atmosphere, Titan was a special object for examination. Unfortunately, its thick cloud cover prevented the observation of Titan’s surface. The LECP instrumentation, however, was able to measure perturbations in the corotational flow of plasma caused by the relative motion of Titan. The “wake” region, also detected by magnetometer and plasma instrumentation, is apparently a region of reduced, turbulent flow.

Within about 17 R_S , particles are permanently trapped in the Saturn magnetosphere. Pronounced changes in the rate profiles, spectra, and angular distributions occur in the magnetosphere. Usually, such

changes are associated with the spacecraft’s crossing the magnetic field lines connected to orbits of the satellites Rhea, Dione, and Tethys. One example of a satellite effect is the abrupt decrease in the electron rate profile inside the field line of Rhea (see Fig. 2). Note that this feature is not evident in the ion profile. The electron angular distribution also changed at Rhea. Similar features associated with the other satellites indicate that these bodies play an important role in controlling magnetospheric particles.

The composition of the Saturnian magnetosphere is particularly interesting. At energies sampled by the LECP detectors, nearly all the ions are protons. The proton to helium ratio can be as large as 5000:1 and is larger than that seen in any other magnetosphere. This ratio is much larger than that seen in the solar wind and suggests that plasma within Saturn’s magnetosphere does not originate in the solar wind. In addition, molecular hydrogen was detected. Finally, essentially no ions were detected at energies greater than 2 megaelectron volts.⁶ These characteristics of particle composition are in marked contrast to those of Jupiter’s magnetosphere, which contains significant fluxes of energetic oxygen and sulfur ions.⁷

Voyager 1 achieved a close approach of about 3 R_S at -38° latitude, crossed the ring plane at the orbit of Dione, and then exited the Saturn system at about 30° , a fairly high latitude. The count rate profiles peaked at the equator and then dropped precipitously as the spacecraft climbed to higher latitudes. In the magnetospheres of Earth and Jupiter, such a drop in the count rates would signal the entry into a high latitude tail lobe, a void in which particle fluxes are extremely low. However, at Saturn the count rates recovered and peaked again at higher latitudes, suggesting that the tail lobes of Saturn are not at all like

those of Earth or Jupiter. These observations suggest that the magnetotail of Saturn may be "closed;" i.e., Saturnian field lines do not interconnect with those of the interplanetary magnetic field.

The spacecraft crossed the Saturn magnetopause on the latter half of day 319. The transit from inbound to outbound magnetopause crossings took less than three days. By comparison, the transit of Voyager 1 across the Jovian magnetosphere required about two weeks. This emphasizes the scales of the two magnetospheres: Jupiter has a scale size of 10×10^6 km, while Saturn has a scale size of 1×10^6 km.

The Voyager 1 spacecraft is now moving toward high heliographic (sun-referenced) latitudes into the reaches of deep space. Voyager 2 is due to arrive at Saturn in August 1981 to augment the observations made by Pioneer 11 and Voyager 1. Voyager 2 will come closer to Saturn than its sister spacecraft, and the LECP experiment should provide key observations of low energy charged particles in the inner magnetosphere adjacent to the rings. Saturn's gravity will

then catapult Voyager 2 toward a rendezvous with the planet Uranus in 1986.

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