Titan’s Magnetic Field Signature During the First Cassini Encounter

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The magnetic field signature obtained by Cassini during its first close encounter with Titan on 26 October 2004 is presented and explained in terms of an advanced model. Titan was inside the saturnian magnetosphere. A magnetic field minimum before closest approach marked Cassini’s entry into the magnetic lobe or layer. Cassini then exited the northern and entered the southern magnetic tail lobe. The magnetic field before and after the encounter was approximately constant for ~20 Titan radii, but the field orientation changed exactly at the location of Titan’s orbit. No evidence of an internal magnetic field at Titan was detected.

We report results from the Cassini magnetometer experiment obtained during the first close encounter [closest approach (CA) altitude: 1174 km] of Cassini with Saturn’s moon Titan on 26 October 2004. This was the first opportunity to investigate Titan’s environment with in situ measurements since the Voyager 1 flyby in 1980. With its extended neutral atmosphere, Titan orbits Saturn at a distance of 20.3 Saturn radii (R_s) and an orbital period of 15.95 days. For most of its orbit Titan is inside Saturn’s magnetosphere (J), which is populated by neutral atoms and plasmas from several potential sources (saturn atmosphere) and rings, icy satellites, Titan’s own ionosphere, and at least partially convects with the planet. Because Titan’s orbital period is much larger than Saturn’s rotational period (10.7 hours),
Fig. 4. One-minute exposure image in 50 to 90 km H during the 13 December 2004 Titan encounter. The latitude-longitude grid represents Titan's position (north up) at the beginning of the image acquisition, whereas the heavy dotted lines represent the time that Titan is at the edge of the acquisition area at 11:23 UT. The image acquisition was restricted to 130 km altitude in the atmosphere at the beginning of image acquisition, whereas the light dashed contour locates the same points at the end of acquisition. (Top) H2DA emission as it appeared during approach to Titan. (Bottom) H2DA emission as it appeared after closest approach, when the true altitude boundary appears to close to Titan's limb.
Titan is embedded in a flow of magnetized plasma with a relative velocity on the order of 100 km/s. The magnetic field data measured in Voyager 1 by Titian placed an upper limit on Titan's internal magnetic field of 4.1 nT at the equatorial surface, which is approximately equal to the magnetic field of Earth at Titan's orbit. Thus, the interaction of Titan with Saturn's magnetosphere is of an atmosphere-type like, for example, the interaction of Venus with the solar wind, but has some unique features. At times of high solar wind dynamic pressure, the magnetopause is pushed inward toward Saturn. Titan can lose the magnetic foreshock to the solar wind, and the plasma flow interacts with magnetosphere plasma over the solar wind. In addition, the ionospheric properties on the side of Titan that faces the equatorial plasma flow vary with solar latitude (Fig. S). The Voyager data also showed that the magnetospheric plasma properties are different from those of plasma in the solar system, transverse, beam-like, and oblique. (Fig. S).

Cassini's magnetometer experiment is described in (6). Throughout the encounter, 32 vectors per second were measured by the flank magnetometer. At its first close encounter (T1), Cassini passed through the noncircular part of the equatorial plasma flow. At 125 km/s at 20:05 on 26 October 2004, only the leading front of Titan's ionosphere crossed. At about 12:15 on 25 October and at a nadir distance of about 20.3 km, Cassini observed the magnetosphere by an ionosphere. The bow shock and entered the magnetosphere, where strong magnetic waves were observed (Fig. S). The bow shock was closer to Saturn than it was to Saturn and innermost magnetosphere. The interaction of Cassini with the magnetospheric plasma is shown in (6).

**Fig. 1. Geometry of Cassini's T1 encounter.** The Titan interaction coordinate system (TICS) is centered at Cassini with the x-axis pointing in the direction of Titan's orbital motion, the y-axis pointing toward Saturn, and the z-axis being perpendicular to the spin axis. Under ideal conditions, the interaction plasma flow is along the x-direction and the ambient plasma magnetic field points in the +z-direction. Cassini's trajectory and the projections of the three planes are shown. The frame vector with its origin in Titan's center indicates the direction to the Sun. The frame is related to the spacecraft by the magnetic field direction.

**Fig. 2. MASC data leading up to the Cassini T1 encounter (CA).** The coordinate system is the Kronocentric Solar Magnetosphere (KSM) coordinate system (x in the solar direction, y in the plane formed by x and the Saturnian spin axis, and z is perpendicular to the system). At 12:15 on 25 October 2004, Cassini crossed the bow shock (BS) at a stagnation distance of about 28 Rₖ. The magnetic field in the magnetosphere showed strong wave signatures. After several magnetopause crossings, Cassini finally entered the magnetospheric plasma at 10:40 on 26 October 2004 at a distance of 216 Rₖ from Saturn's center (MP). The shaded area marks periods of steady field emission and outbound of the encounter.
Figure 3 (A) Magnetic field measured by the Castor Iodine instrument within a linear interval centered at CA 15:00 UT (black line) plotted with the magnetic field along Castor's trajectory obtained by a model (13). The magnetic field signature of Titan's interaction was discernible between 15:10 and 15:30. The main features of the signature—maximum of 8.2 nT below CA and an abrupt change of sign of \( \Delta B \) after \( \Delta B \) was well represented by the model. The magnetic field after the encounter is shown with respect to the field before the encounter (B). Numerical tracking of the magnetic field was cut through the same data (Fig. 3A).
by magnetostrictive electrons is an order of magnitude lower than the photodissociation rate. Both effects cause the peak location to shift from CA toward Titan’s dayside, i.e., toward times before CA. The rotation of the magnetic field magnitude is a consequence of shield- ing currents flowing in a layer that we call the magnetic isopause, which separates the upper magnetostronosphere from the lower non-or- weakly magnetostronosphere. The presence of this layer has been predicted by 3D models (20, 21) for the side of Titan facing the stagnating plasma. The model (21) successfully describes the 3D structure of this layer and explains the observed magnetic field min- imum. After the minimum, the magnetic field increased and was oriented toward Titan, indicating that Cassini was still in the northern lobe. About 5 min after CA, B changed sign abruptly. This point marks the transition from the northern into the southern magnetic lobe (Fig. 3B), which occurs as a rotation of the magnetic field at nearly constant field magni- tude (22). Cassini left the southern magnetic lobe at 15:39 and returned into the unshielded southern magnetic field. The good agreement between the modeled (21) and measured mag- netic field signature of Titan implies that the signature can be explained without imposing any internal magnetic field. This conclusion is consistent with the upper limit derived from Voyager 1 (3). However, the geometry of the T_e trajectory was not favor- able for detecting an internal field. In addition, the occurrence of the magnetic field minimum before CA indicates the existence of a magnetic isopause at Titan, implying that the lower isopause is non-or weakly magnetized. The model also shows that the plasma velocity vector derived from the rotation angles in order to obtain the best fit aligns nearly perfectly with the rotation direction in the equatorial plane, with a small northward component. From the similarities between model and MAG data, we suggest that the incident field plasma conditions were not substantially different from Voyager 1 conditions.

References and Notes

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References

6. The layer between the northern and the southern lobe can have two configurations in the first, the magnetic field is at a minimum. In this case, a V-shaped "neutral sheet". In the second configuration, the magnetic field rotates continuously from the dawn direction in the northern lobe to the dusk direction in the southern lobe, while the field magnitude is constant. In this case, the configuration is called "neutral sheet". This is not appropriate and was called it "spatial magnetic layer" instead.
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