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Deep Space 1 at comet 19P/Borrelly: Magnetic field and plasma observations

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ABSTRACT

On September 22, 2001 the Deep Space 1 spacecraft performed a flyby at comet 19P/Borrelly at a solar distance of 1.36 AU leading the Earth by 74° in longitude. The spacecraft–comet distance at closest approach was 2171 km. The bow shock had a magnetic compression ratio of 2.5 at a distance of 147 100 km from the nucleus. Deep Space 1 first entered the sheath region essentially from the north polar region. Fluctuations from the cometary ion pickup were present throughout the sheath region and even well upstream of the shock, as expected. The magnetic field pileup region had a peak field strength of 83 nT and was shown to be consistent with a pressure equal to the solar wind ram pressure. The peak field location was offset from the time of closest approach. It is uncertain whether this is a spatial or temporal variation. Draping of magnetic fields around the nucleus was sought, but evidence for this was not apparent in the data. A possible explanation is that the interplanetary solar wind was composed of turbulent short-scale fields, and thus the fields were not symmetric about the point of closest approach. During the flyby phase there were in general few intervals of ACE data where there were large scale Parker spiral fields. With the addition of plasma data, the shock properties are investigated. The characteristics of magnetic draping, pileup and fluctuations are explored. These comet 19P/Borrelly results are contrasted with other cometary flyby results.

1. Introduction

Cometary research reveals essential facts about the evolution of our universe. The interaction of comets with the solar wind and the interplanetary plasma (e.g. Coates and Jones, 2009) as well as cometary composition can be studied by investigation of the magnetic field in the vicinity of a comet. A particular opportunity for such an investigation was provided by the flyby of Deep Space 1 (DS1) at comet 19P/Borrelly. Plasma observations made during this flyby (Young et al., 2007) reveal an interesting asymmetry in the bow shock location which is probably due to non-spherical neutral distribution profiles on the comet–solar wind interaction region (e.g. Delamere, 2006; Jia et al., 2008). This makes the DS1 flyby at 19P/Borrelly a very interesting topic for further studies. The DS1 mission (Rayman et al., 2000) was the first mission of NASA's New Millennium Program. This program was created to test and validate advanced technologies for the future space exploration in the third millennium. DS1 was launched successfully at Cape Canaveral on October 24, 1998. The most remarkable feature of DS1 was the first use of an ion propulsion system in a deep space mission. DS1 was equipped with ion engine diagnostic sensors (Brinza et al., 2000) including two ultra small three-axes high-resolution fluxgate magnetometers (FGM) shown in Fig. 1.

This instrument, a prototype of the ROSETTA magnetometer (Glassmeier et al., 2007a), was developed at the Institute for Geophysics and Extraterrestrial Physics in Braunschweig. The instrument is able to resolve the magnetic field with a resolution of 0.04 nT within the measurement range of $\pm 25\,000$ nT, and it can operate in a temperature range of $-150\,^{\circ}$C to $+150\,^{\circ}$C. In spite of the high vector sampling rate of 20 Hz, it only consumes 200 mW of power. The primary scientific mission objective was a flyby at the asteroid 9969 Braille on July 29, 1999. Here DS1 revealed the first direct evidence for an asteroidal magnetic field (Richter et al., 2001).

In the extended mission, the second scientific objective was the encounter with comet 19P/Borrelly on September 22, 2001 (Rayman and Varghese, 2001). This took place at a distance of 1.36 AU from the Sun and 1.47 AU away from the Earth. DS1 passed 19P/Borrelly with a velocity of 16.58 km/s at a closest approach (C/A) distance of 2171 km at 22:29:33 UTC in the solar wind upstream region. 19P/Borrelly flew through the ecliptic plane from south to north, while DS1 cruised in the ecliptic plane. The angle between the 19P/Borrelly-orbital plane and the DS1 trajectory is 90.8°. The angle between the DS1 trajectory and the comet-Sun line is 90.05° (Figs. 2 and 3).

In this paper we provide an analysis of the magnetic field measurements at 19P/Borrelly. The magnetic field data are

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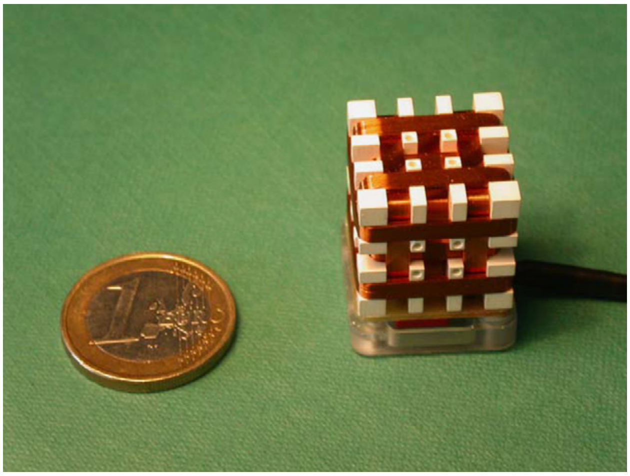

Fig. 1. The fluxgate magnetometer sensor.

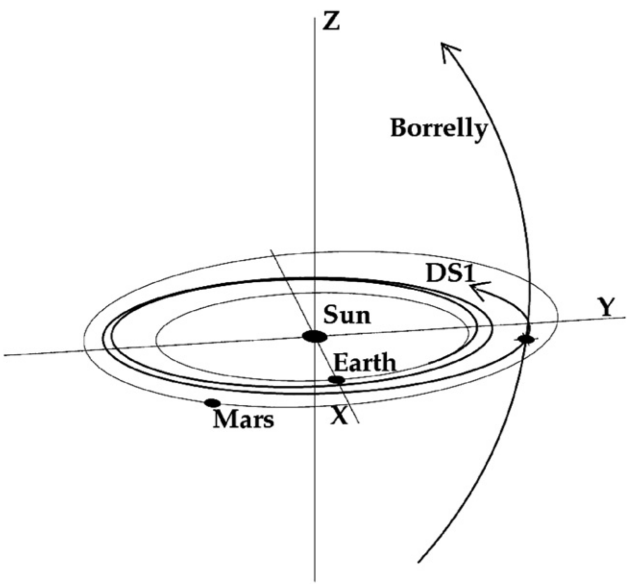

Fig. 2. The celestial situation at the flyby time on September 22, 2001. Orbits are displayed in ECLIPJ2000 coordinates. Here x points from the Sun to vernal equinox, y is in the ecliptic plane pointing against the orbital motion of the Earth and z completes the system to be right handed.

contaminated by spacecraft magnetic fields, requiring corrections to remove the interferences. Therefore, we describe the method used to extract the real magnetic background field; namely applying a long-term temperature model of the ion engine fields and a spike detector to get rid of thruster-induced signatures. Furthermore, the unknown DC-level of the background field will be adjusted using the Parker model. With the calibrated data the signature of comet 19P/Borrelly is investigated and compared with the data of different cometary encounters.

2. Data reduction and calibration

The two FGMs (inboard: IB, outboard: OB) of DS1 are located outside the spacecraft on a 50-cm-long boom, close to the ion engine beam for diagnostic purpose. The separation distance between both sensors is 46 cm. At this short distance from the spacecraft, the FGM observations are strongly influenced by the ion engine permanent magnets, the field of which is temperature

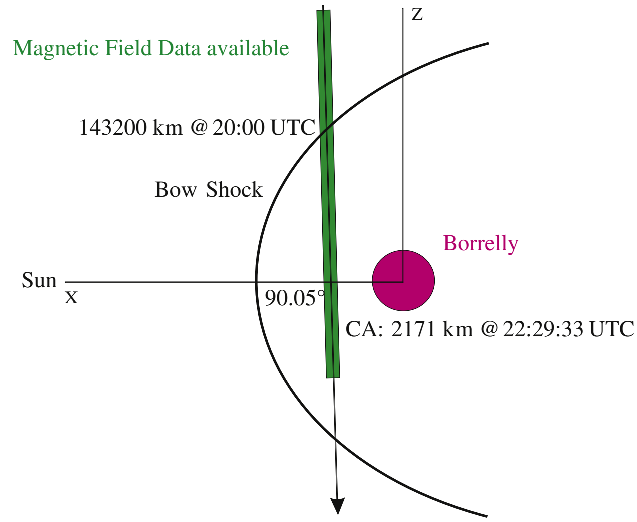

Fig. 3. The flyby geometry. The figure shows the xz-projection of the schematic DS1-trajectory in cometo-centered-solar-equatorial (CSEQ)-coordinates, where x is pointing toward the Sun, z is the component of the rotation axis of the Sun which is perpendicular to x, and y completes the right-handed system. The shown bow shock is just a sketch.

dependent, the intermittently emitted ion beam, and the magnetically activated hydrazine thrusters used for attitude control of the spacecraft. Due to these interferences, extensive data processing (Richter et al., 2001) is required to extract the scientific signatures from the raw data. First, the instrument raw data is adjusted using the results of the ground calibration (temperature-dependent sensitivity and misalignment of the sensor) and rotated into s/c-coordinates. In the next step, the temperature-dependent influence of the ion engine magnets (permeability is temperature dependent) is eliminated using a linear, long-term model of their magnetic moments. Such a model was developed using quiet phases of the magnetic field over a period of half a year for different temperatures of the ion engine. These temperature dependencies are specified for every sensor location/orientation. The largest gradient (-2.6 nT/K) is seen at the IB Z-axis sensor. The ion engine magnetic fields at $T=0\,^{\circ}$C varied from 190 to 6390 nT for the six different sensors. This temperature behavior of the magnets did not change during the mission, therefore a trustable model could be generated. During the flyby interval from 17:00 to 00:00 UTC the engine cooled from 40 to 0 °C. The temperatures at the FGMs, however, were nearly constant ($T=2\,^{\circ}\mathrm{C}\pm 2\,^{\circ}\mathrm{C}$). Spikes originating from the hydrazine thrusters are eliminated by a spike detector. The parameters of this filter are chosen empirically to match the detector with the thruster firings, which occurred rather infrequently at the 19P/Borrelly flyby, and generated spikes of about 15 nT amplitude and 0.3 s duration in the magnetic field data. Due to this large amplitude, the spikes can easily be identified and removed using a short time/long time filter: every data point (short time sample) which deviates more than 8 nT from the moving average (taken over 12 points, long time sample) is removed from the data set.

After resampling the data to 1 s means and taking into account the s/c-attitude information (provided by SPICE kernels, see Acton, 1996), the magnetic field data are available in comet centered solar equatorial coordinates (CSEQ), where x is pointing toward the Sun, z is the component of the rotation axis of the Sun which is perpendicular to x, and y completes the right-handed system (y is parallel to the Sun's equatorial plane). This coordinate system is chosen as the x-axis as the comet-Sun line is the major symmetry axis and the Sun equatorial plane is the major symmetry plane for the solar wind.