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Magnetic field measurements during the ROSETTA flyby at asteroid (21)Lutetia

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ABSTRACT

On July 10, 2010, the ROSETTA spacecraft performed a flyby at asteroid (21)Lutetia at a solar distance of 2.72 AU. The spacecraft–asteroid distance at closest approach was 3120 km. The magnetometers onboard ROSETTA were operating but did not detect any conclusive signature of the asteroid. Any magnetic field signature which could possibly be attributed to the asteroid was below 1 nT. Consequently an upper limit for the global magnetic properties of asteroid (21)Lutetia could be derived: maximum dipole moment $\leq 1.0\times10^{12}$ A m^2, global maximum magnetization $\leq 2.1\times10^{-3}$ A/m, specific moment $\leq 5.9\times10^{-7}$ A m^2/kg. Draping of magnetic fields around the nucleus was sought, but evidence for this could not be clearly identified in the data. Plasma simulations taking into account the estimated upper limit of the magnetization and possible outgassing revealed interesting structures very close to the asteroid. The results obtained at Lutetia are contrasted with the results of other asteroid flyby results.

1. Introduction

Asteroid research reveals essential facts about the evolution of our Solar System. The interaction of asteroids with the solar wind and the interplanetary plasma as well as information concerning asteroidal composition can be studied by investigating of the magnetic field in the vicinity of an asteroid. Different interaction scenarios are possible. If the asteroid consists of electrically conductive materials, a unipolar generator will be established and a current system (Ip and Herbert, 1982) that changes the topology of the external magnetic field can be induced. On the other hand, a purely magnetic interaction is possible if the asteroid contains remanent magnetized material. Such magnetization can be present if the parent body of the asteroid was initially magnetized by a dynamo (Weiss et al., 2008) and its field was frozen in during the cooling phase. Thus, asteroids with strong magnetic fields are believed to be fragments of larger parent bodies. Alternatively, the asteroid might have been subjected to one of a range of possible alteration processes (for example shocks, weathering or thermal influences), that, in the course of its lifetime, changed its magnetic properties (Weiss et al., 2010).

An opportunity to study the magnetization of an asteroid was provided by the flyby of asteroid (21)Lutetia (Barucci et al., 2007) by the ROSETTTA spacecraft. Lutetia is one of the largest known asteroids with a diameter of $\sim$100 km.

1.1. The ROSETTA project

The ROSETTA project (Schwehm and Schulz, 1999; Glassmeier et al., 2007a) is a cornerstone mission of the European Space Agency (ESA) which was launched on March 2, 2004, from Kourou in French Guiana. Its main scientific objective is the investigation of comet 67P/Churyumov–Gerasimenko, which will be reached in 2014. In the course of its (10-year) journey through our Solar System, magnetic measurements were made during several swingbys of planet Earth (Glassmeier et al., 2007b; Eastwood et al., 2011) and of Mars (Edberg et al., 2008, 2009; Boesswetter et al., 2009) as well as during the flyby of asteroid (2867)Šteins (Auster et al., 2010).

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1.2. The present study

In this paper we report on magnetic field measurements made during the flyby of asteroid (21)Lutetia. The closest approach (C/A) of ROSETTA was at a distance of 3120 km from the asteroid's surface at 15:44:54 UTC on July 10, 2010. The relative flyby velocity was 15 km/s. ROSETTA approached the target from the upstream side above the ecliptic plane. At the time of the encounter (21)Lutetia was located at a distance of 2.72 AU from the Sun and 3.05 AU from the Earth (Fig. 1). The approach profile of the flyby is displayed in Fig. 2.

In this paper we provide (Section 2) an account of the instruments used to obtain the magnetic measurements. An analysis of these measurements is contained in Section 3, where it is shown that, in addition to sensor effects which require correction, the magnetic field data are contaminated by spacecraft magnetic fields. These latter effects can be removed through calibration of the data, application of a long-term temperature model for the offset correction, and elimination of disturbances caused by ROSETTA's reaction wheels (RW). Further, the interference by several Lander instruments was identified.

Comparison of the data measured by the three onboard sensors ROMAP, RPC-MAG/OB and RPC-MAG/IB reveals (Section 4) upper limits for the magnetic properties of asteroid (21)Lutetia.

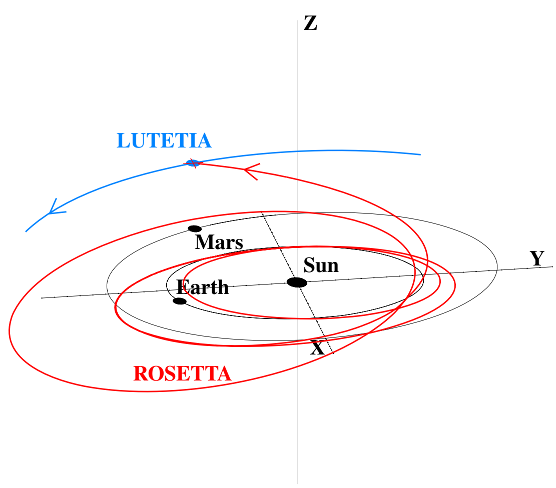

Fig. 1. The celestial situation at the flyby time of ROSETTA on July 10, 2010. Orbits are displayed in ECLIPJ2000 coordinates. Here *x* points from the Sun to the vernal equinox, *y* is in the ecliptic plane pointing against the orbital motion of the Earth and *z* completes the right-handed coordinate system.

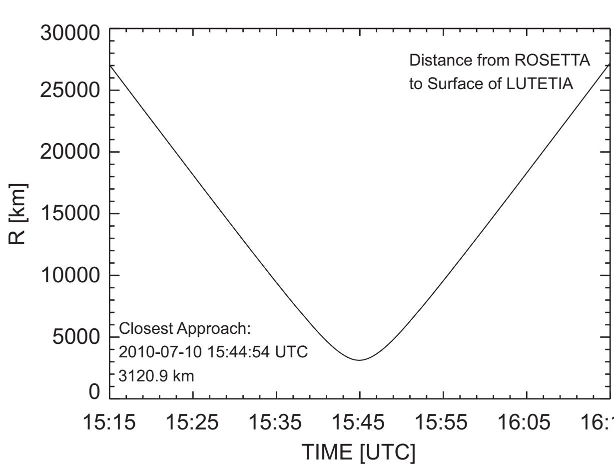

Fig. 2. Profile of the ROSETTA—Lutetia flyby distance during the encounter.

Also, using the calibrated data, the signature of asteroid (21)Lutetia was investigated in both the time and frequency domains.

Magnetic field draping effects measured at asteroid (951)Gaspra (Kivelson et al., 1993) are contrasted with ROSETTA measurements in Section 5 and various theoretically possible interaction scenarios are discussed in deriving upper limits for the magnetic properties of asteroid (21)Lutetia.

In Section 6, plasma simulations of structures close to Lutetia (taking into account possible outgassing and magnetization) are described. These would not have been seen at the C/A distance of 3120 km. In Section 7 the flyby results are compared with data obtained during other asteroid encounters. Section 8 presents a general summary and conclusions.

2. The magnetometers

The ROSETTA spacecraft is equipped with two independent magnetometer systems: namely the ROSETTA Lander magnetometer ROMAP (Auster et al., 2007) and the orbiter magnetometer RPC-MAG (Glassmeier et al., 2007b), the latter of which is part of the ROSETTA plasma consortium RPC (Carr et al., 2007). Both instruments (which were developed at the Institute for Geophysics and Extraterrestrial Physics in Braunschweig) are 3-axis fluxgate magnetometers (FGM) with a resolution of 0.03 nT. RPC-MAG can operate within the measurement range of $\pm 16\,000$ nT, and over a wide temperature range of $-150\,^{\circ}$C to $+150\,^{\circ}$C. In the normal operating mode the instrument is run at a 1 Hz sampling rate. In burst mode the vectors are sampled at 20 Hz. A prototype of the RPC-MAG instrument has already been flown successfully onboard NASA's DEEP SPACE 1 mission where it detected the magnetic signature of asteroid (9969)Braille (Richter et al., 2001) and characterized the magnetic properties of comet 19P/Borrelly (Richter et al., 2011).

The two RPC orbiter FGMs (inboard: IB, outboard: OB) are located outside the spacecraft on a deployed, 1.55 m-long boom. The separation distance between the sensors is 15 cm. The Lander magnetometer ROMAP is located on a stowed boom inside the Lander PHILAE (this boom will be deployed at the target comet 67P/Churyumov–Gerasimenko).

During the asteroid (21)Lutetia flyby, the magnetometers were switched on from July 7, to July 13, 2010.

3. Data processing

3.1. Standard calibration

As a first step in data processing, the raw data obtained are adjusted using the results of previous ground calibrations, namely by the application of the temperature-dependent sensitivity and misalignment matrices. The temperature dependence of the sensor offsets was eliminated through the utilization of a third-order-polynomial temperature model. This latter model was developed using magnetic field measurements made during quiet phases over a 6 years period of cruise. The temperature dependencies in the range of $-150\,^{\circ}$C to $+50\,^{\circ}$C were specified individually for each single sensor component. The obtained calibrated data are rotated into s/c-coordinates to establish a common coordinate system.

3.2. Disturbance analysis

Fig. 3 exhibits calibrated data of the RPC-MAG/OB, the RPC-MAG/IB and the ROMAP magnetometer for July 10, 2010 in spacecraft-coordinates. Closest approach occurred at 15:44:54