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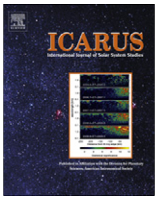

Field-aligned beams and reconnection in the jovian magnetotail

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ABSTRACT

The release of plasma in the jovian magnetotail is observed in the form of plasmoids, travelling compression regions, field-aligned particle beams and flux-rope like events. We demonstrate that electrons propagate along the magnetic field lines in the plasma sheet boundary layer (PSBL), while close to the current sheet center the electron distribution is isotropic. The evidences of the counterstreaming electron beams in the PSBLs are also presented. Most of the field-aligned energetic ion beams are associated with the field-aligned electron beams and about half of them have the bipolar fluctuation of the meridional magnetic field component. Moreover they often show a normal velocity dispersion for the different species which fits well in the scenario of particle propagation from a single source. All features above are observed during jovian reconfiguration events which are typically bonded with plasma flow reversals. From all these characteristics, which are based on energetic particle and magnetic field measurements, we believe that the reconfiguration processes in the jovian magnetotail are associated with reconnection.

1. Introduction

One of the dynamic reconfiguration processes of the magnetosphere is called substorm and is a key process responsible for the energy transport and release in the terrestrial magnetosphere. It is believed that reconnection is responsible for the break of stability in the magnetospheric configuration and also for the transfer from magnetic to kinetic energy (e.g. Angelopoulos et al., 2008). During this process the magnetic field forms a so-called X-line surrounded by the diffusion region, where acceleration of particles takes place. In the diffusion region the electric field accelerates high-energy ions and electrons away from the magnetic reconnection region and electrons at low-energy flow toward the reconnection site simultaneously (Nagai et al., 2001; Manapat et al., 2006). The energetic particles are released as bursty bulk flows and are widely studied by e.g. Angelopoulos et al. (1994). The bursty bulk flows often contain structures with closed magnetic field lines – plasmoids. Such a large tailward-moving loop-like magnetic structure is generated as the result of X-type reconnection on the closed field lines in the near magnetotail (Hones, 1979). In two dimensions the typical observational signatures of a plasmoid have been defined by a bipolar magnetic deflection in the meridional direction. The examination of the three-dimensional topology and morphology of plasmoids in the Earth's magnetotail showed rather complicated configurations compared to the original 2-dimensional Hones scenario: helical flux ropes and travelling compression regions (TCRs) detected as moving magnetic imprints of a plasmoid in the lobes (Zong, 2004; Slavin et al., 1995, 2003). A tailward moving plasmoid in the central plasma sheet temporarily compresses the magnetic flux in the tail lobes because the cross-sectional area of the lobe is reduced. In the area between the central plasma sheet and lobe a layer of particles moving parallel to the magnetic field arises from a rapid change of the flux tube volume outside the diffusion region (Schindler, 2007). However, these field-aligned beams could also be of a different origin than reconnection, e.g. due to Fermi acceleration (Vogiatzis et al., 2006; Grigorenko et al., 2009). Thus in the terrestrial magnetosphere two distinct groups of field-aligned beams can be derived:

(1) field-aligned ion beams accompanied with field-aligned electrons and associated with the X-line reconnection;
(2) ion field-aligned beams accompanied by isotropic electrons accelerated by the quasi-steady dawn–dusk electric field.

Substorm-like (or) reconfiguration processes have been observed at Jupiter by the particle and fields instruments onboard the Galileo spacecraft (Krupp et al., 1998; Woch et al., 1998, 1999; Kronberg et al., 2005). It is believed that the reconfiguration processes in the jovian magnetosphere are rather internally driven by ion mass loading from the moon Io and fast planetary rotation, although we cannot fully exclude the influence of the solar wind (Kronberg et al., 2009). This internal driving mechanism leads to a periodic release of plasma in the magnetotail with a repetition period of about 3 days. The thinning of the plasma sheet prior to

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the mass release reminds the growth phase of the terrestrial substorm (Ge et al., 2007). This plasma sheet reconfiguration due to internal energy loading leads to a formation of the X-line in the jovian magnetotail at approximately $80R_J$ (Woch et al., 2002; Vogt et al., 2010). The scale size of downtail released plasmoids was estimated to be about $9R_J$ (Kronberg et al., 2008b).

Reconnection processes at Jupiter seem to play an important role in the reconfiguration process as reported by Nishida (1983), Russell et al. (1998, 2000), Vogt et al. (2010), and Ge et al. (2010). Reconnection conditions in the jovian magnetotail are satisfied just before the energetic particle release (Zimbardo, 1993; Kronberg et al., 2007). Statistical studies of bursty bulk flows and plasmoids were carried out by Kronberg et al. (2008b) and Vogt et al. (2010). Also data from the New Horizons spacecraft during the Jupiter flyby showed evidence of periodic plasma injections possibly caused by reconnection (McNutt et al., 2007; McComas et al., 2007). Some field-aligned beams were discussed in the substorm-like context by Woch et al. (1999).

In this paper, we show for the first time observations of a TCR and plasmoids together with field-aligned beams and consider their features more detailed in the context of X-line reconnection using data from the Galileo Energetic Particle Detector (EPD) (Williams et al., 1992) and from the magnetometer (MAG) (Kivelson et al., 1992). The paper is organized as follows: In Section 2 we introduce shortly the instruments onboard Galileo used to identify field-aligned beam features in the measurements. In Section 3.1 we present a typical jovian reconfiguration event with field-aligned beams and dynamic processes preceding and following the beam. In Sections 3.2, 3.3, 3.4, 3.5 we show examples of four field-aligned beams and their wide spectrum of characteristics. Section 4 discusses results and provides a statistical analysis. Section 5 summarizes the observations.

2. Instrumentation

The EPD was an instrument onboard the Galileo spacecraft designed to measure the characteristics of the charged particle population such as energies, intensities, ion composition and angular distribution to determine, in particular, the configuration of the jovian magnetosphere (Williams et al., 1992). The advantages of the EPD instrument compared to similar instruments on previous missions were the 4π steradian angular coverage for jovian energetic particles and the extended coverage of particle energies.

EPD consisted of two double-headed detector telescopes: the Low Energy Magnetospheric Measurement System (LEMMS) and the Composition Measurement System (CMS). CMS measured the ion fluxes with discriminating ion species using the time-of-flight technique. Its energy ranges were 80–1250 keV (protons), 27 keV/nuc to 1 MeV/nuc (helium ions), 12–562 keV/nuc (oxygen ions), and 16–310 keV/nuc (sulfur ions). On the other hand, LEMMS observed the electron flux in the energy range between 15 and 11,000 keV and the species-integrated ion flux between 22 and 12,400 keV. In this case electrons and ions were separated by a permanent magnet. Although these telescopes have narrow field-of-view (the full opening angles are 18° and 15° for CMS and LEMMS, respectively), an almost full-sphere coverage is achieved by the motion of a turntable combined with the spacecraft spin (the exception is a small solid angle ($\leqslant$0.1 sr) along the spin axis which is blocked to avoid direct sun light in the detector). The unit sphere is divided into 16 (see Fig. 6.2, in Lagg (1998)) or 6 sectors dependent on the energy channel. To study the flow direction we analyze 16-sector resolution data in this work. Data are accumulated within sampling times of ∼11.5 min (for this study) and allocated to the angular sectors. Each sector is ∼±45° wide. In the record time mode EPD/LEMMS count rates are sampled every 1.25 s over up to 64 sectors. The description of LEMMS and CMS energy channels used in our analysis one can find in Table 1.

Table 1
LEMMS and CMS rate channels.

Ions (LEMMS)		Electrons (LEMMS)	
Channel	Energy range (keV)	Channel	Energy range (keV)
a0	22–42	e0	15–29
a1	42–65	e1	29–42
a2	65–120	e2	42–55
a3	120–280	e3	55–93
a4	280–515	f0	93–188
a5	515–825	f1	174–304
a6	825–1680	f2	304–527
a7	1680–3200	f3	527–884
Ions (CMS)			
Species	Channel	Energy range (keV/nuc)	
Protons	tp1	0.08–0.22	
	tp2	0.22–0.54	
	tp3	0.54–1.25	
Oxygen+Sulfur	to1	0.012–0.026	
Oxygen	to2	0.026–0.051	
Sulfur	ts1	0.016–0.030	
	ts2	0.030–0.062	

The first order anisotropies were calculated using technique described by Krupp et al. (2001), and references therein.

The pitch angle distributions (PAD) are presented in the detector frame – Detector Pitch Angles (DPA). The flow is parallel to the magnetic field when DPA is close to 180° and respectively anti-parallel when DPA is close to 0°.

Particle pitch angles are determined with the magnetic field data obtained by the Galileo magnetometer. We discuss pitch angles only when the magnetic field direction varies insignificantly during a sampling time, since otherwise the pitch angle determination is unreliable.

The magnetic field observations have a time resolution of ∼24 s, which is much higher than that of the particle measurements. This does not affect our results, however, as we compare the observed field-aligned beams in the particle data with features in the magnetic field and not the other way around. Still, it is very likely that we miss many events with time scales less than 11 min in the EPD data set.

3. Observations

3.1. An overview event

A typical substorm-like or reconfiguration event in the jovian magnetosphere is shown in Fig. 1. The figure shows the time interval from day 1997 151, 06:00 UT to day 154, 02:00 UT. During this time Galileo was located in the midnight sector of the jovian magnetotail (0116 Local Time (LT)) at about a radial distance $R = 100R_J$. The upper panel displays omnidirectional ion intensities in seven energy channels covering the energy range between 22 keV (a1 channel) and 3.2 MeV (a7 channel). The second panel from the top shows the radial (red[1]) and azimuthal (green) component of the ion directional flow anisotropy as derived from measurements of 65 to 120 keV ions. The lower two panels present the magnitude and components of the measured magnetic field in the SIII-system. In this system the radial magnetic field component is positive in the radially outward direction, the azimuthal component is positive

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[1] For interpretation of color in Figs. 1–6, the reader is referred to the web version of this article.