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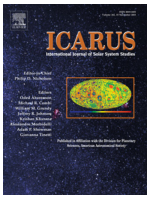

Planetary period oscillations in Saturn's magnetosphere: Further comments on the relationship between post-equinox properties deduced from magnetic field and Saturn kilometric radiation measurements

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ABSTRACT

We discuss the planetary period oscillations (PPOs) observed by the Cassini spacecraft in Saturn's magnetosphere, in particular the relationship between the properties of the PPOs in the post-equinox interval as observed in magnetic field data by Andrews et al. (2012) and Provan et al. (2013, 2014) and in Saturn kilometric radiation (SKR) emissions by Fischer et al. (2014, 2015), whose results are somewhat discrepant. We show that differences in the reported PPO periods, a fundamental property which should be essentially identical in the two data sets, can largely be accounted for by the phenomenon of dual modulation of the SKR emissions in polarization-separated data, in which the modulation associated with one hemisphere is also present in the other. Misidentification of the modulations results in a reported reversal in the SKR periods in the initial post-equinox interval, south for north and vice versa, relative to the magnetic oscillations whose hemispheric origin is more securely identified through the field component phase relations. Dual modulation also results in the apparent occurrence of phase-locked common periods in the northern and southern SKR data during later intervals during which two separate periods are clearly discerned in the magnetic data through beat modulations in both phase and amplitude. We further show that the argument of Fischer et al. (2015) concerning the phase relation between the magnetic field oscillations and the SKR modulations is erroneous, the phase difference between them revealing the local time (LT) of the upward field-aligned current of the PPO current system at times of SKR modulation maxima. Furthermore, this LT is found to vary significantly over the Cassini mission from dawn, to dusk, and to noon, depending on the LT of apoapsis where the spacecraft spends most time. These variations are consistent with the view that the SKR modulation is fundamentally a rotating system like the magnetic perturbations, though complicated by the strong LT asymmetry in the strength of the sources, and rule out a mainly clock-like (strobe) modulation as argued by Fischer et al. (2015), for which no physical mechanism is suggested. We also elucidate the nature of the magnetic periods, criticized by Fischer et al. (2015), which have previously been derived in ~100–200 day post-equinox intervals between abrupt changes in PPO properties, and further show that their argument that the magnetic phase data provide evidence for the occurrence of common phase-locked magnetic oscillations in some intervals is fallacious. The most important consequence of our results, however, is that they demonstrate the essential compatibility of the post-equinox magnetic field and SKR data, despite the contrary results published to date. They also show that due to the dual modulation effect in polarization-separated SKR data, analysis and interpretation may contain more subtleties than previously realized. Joint examination of the combined magnetic and SKR data clearly provides greater insight and enhanced confidence compared with analyses of these data sets individually.

1. Introduction

One of the central focuses of research on Saturn's magnetosphere during the Cassini era has been the phenomenon of the

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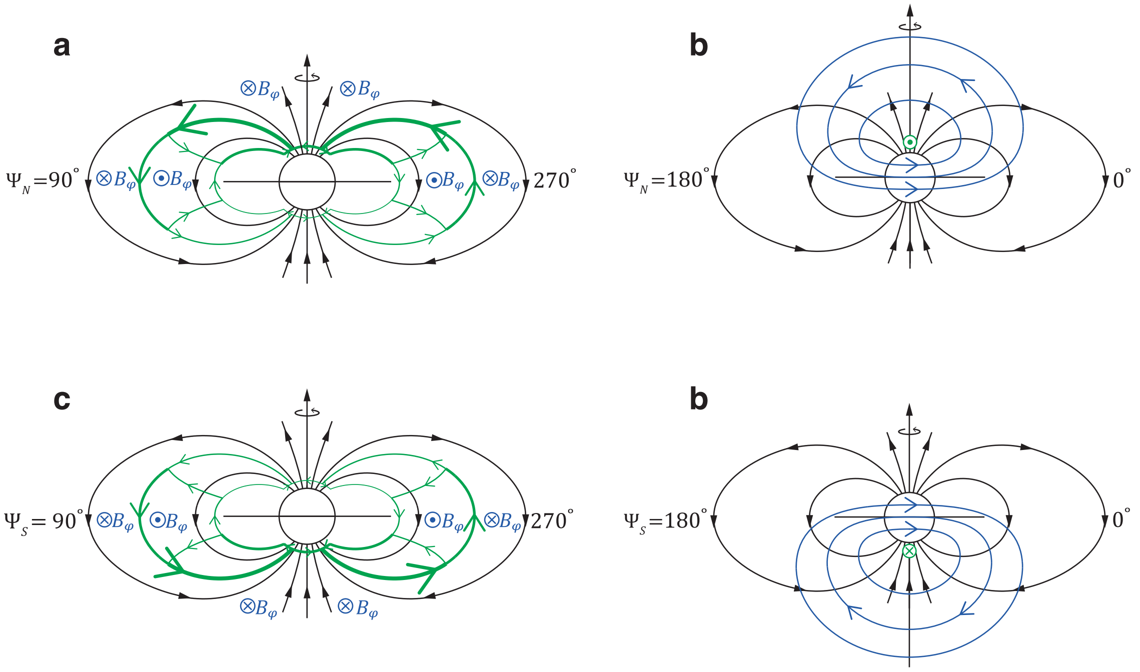

Fig. 1. Sketches showing the form of the electric currents and perturbation magnetic fields associated with the Saturn PPO phenomenon. Black arrowed lines show the background magnetospheric magnetic field, green arrowed lines and symbols the electric currents, and blue arrowed lines and symbols the associated perturbation magnetic field. Circled crosses and dots show vectors pointing into and out of the plane of the diagrams, respectively. Panels (a) and (b) show the northern PPO-related system, where panel (a) shows the $\Psi_N = 90° - 270°$ meridian plane and panel (b) the $\Psi_N = 0° - 180°$ meridian plane. Panels (c) and (d) similarly show the southern PPO-related system, where panel (b) shows the $\Psi_S = 90° - 270°$ meridian plane and panel (d) the $\Psi_S = 0° - 180°$ meridian plane. (Adapted from Hunt et al. (2015)) (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

'planetary period oscillations' (PPOs) (e.g., Cowley et al., 2006; Southwood and Kivelson, 2007; Andrews et al., 2008, 2010a; Carbary et al., 2007; Provan et al., 2009; Burch et al., 2009; Kurth et al., 2008; Ye et al., 2010), in which modulations of the magnetic field, plasma populations, plasma waves, and radio emissions are observed throughout the system near the planetary rotation period of ~10.6 h despite the close axial symmetry of the planetary internal magnetic field (Burton et al., 2010). These studies have shown that modulations at two closely-spaced periods are usually present, one associated with the northern hemisphere and the other with the southern, which consideration of the observed magnetic signatures, together with modeling studies, suggests are due to two rotating current systems as sketched in Fig. 1 (Andrews et al., 2010b; Jia and Kivelson, 2012; Southwood and Cowley, 2014; Hunt et al., 2014). In these sketches (adapted from Hunt et al. (2015)) black lines indicate the axisymmetric background planetary magnetic field, green lines and symbols the electric currents, and blue lines and symbols the resulting perturbation magnetic field. Circled dots indicate vectors pointing out of the plane of the diagram, and circled crosses vectors pointing into the plane of the diagram. The sketches on the left (Fig. 1a and c) show the meridian plane of maximum field-aligned current for each system, while those on the right (Fig. 1b and d) show the resulting magnetic perturbations in an orthogonal meridian plane in which Fig. 1a and c are viewed from the left. In the northern system in Fig. 1a the principal field-aligned currents (thicker green lines) flow into the polar ionosphere on the right and out on the left, closing through the magnetospheric plasma and in oppositely-directed field-aligned currents at lower latitudes, producing a quasi-uniform perturbation field in the equatorial magnetosphere directed to the right in Fig. 1b, together with a quasi-dipolar closure field over the northern polar region. In the southern system in Fig. 1c the principal field-aligned currents flow into the ionosphere on the left and out on the right, similarly producing a quasi-uniform perturbation field in the equatorial magnetosphere directed to the right in Fig. 1d, together with a quasi-dipolar closure field over the southern polar region. The principal field-aligned currents are found to flow mainly on outer closed field lines, from near the open-closed field boundary inwards to ~9 R_S in the equatorial plane, essentially co-located with the main upward field-aligned currents associated with plasma subcorotation (Hunt et al., 2014, 2015). (R_S is Saturn's 1 bar equatorial radius, equal to 60,268 km.)

With increasing time these current systems rotate about the vertical axis with slightly different rotation periods, producing beats in the equatorial magnetosphere where the two quasi-uniform perturbation fields co-exist, but single periods over the two polar regions where the individual quasi-dipolar fields are uniquely present (Provan et al., 2011, 2012; Andrews et al., 2012; Hunt et al., 2015). Position with respect to these systems is defined by the northern (N) and southern (S) magnetic phases $\Psi_{N,S}$ around the spin axis as shown in Fig. 1, defined such that the equatorial quasi-uniform field points radially outward in each system where $\Psi_{N,S} = 0°$ (on the right of Fig. 1b and d), and increases with time at a fixed point as the current system rotates in the sense of planetary rotation, by 360° for a full rotation. Brief study of these diagrams shows that for both systems the radial (r) field component then varies approximately as $\cos\Psi_{N,S}$, while the azimuthal (φ) component varies as $\sin\Psi_{N,S}$ in the equatorial region, in lagging quadrature with the r component, and as $-\sin\Psi_{N,S}$ in the polar regions, in leading quadrature with the r component. We note that these phase relations are characteristic of a quasi-uniform field in the equatorial region and of a transverse dipole in the polar region (Southwood and Kivelson, 2007; Andrews et al., 2008, 2010b, 2012; Provan et al., 2009). The co-latitudinal component, however, varies as $\cos\Psi_S$ in the southern system, in phase with the r component, but as $-\cos\Psi_N$ in the northern system, in antiphase with the r component (Andrews et al., 2008; Provan et al., 2011), a difference that allows separation of the two