Icarus 263 (2016) 94–100

Contents lists available at ScienceDirect

Icarus

journal homepage: www.journals.elsevier.com/icarus

Recurrent pulsations in Saturn's high latitude magnetosphere

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ARTICLE INFO

Article history:
Received 12 May 2014
Revised 17 September 2014
Accepted 16 October 2014
Available online 25 October 2014

Keywords:
Saturn, magnetosphere
Aurorae
Magnetospheres
Ionospheres
Solar wind

ABSTRACT

Over the course of about 6 h on Day 129, 2008, the UV imaging spectrograph (UVIS) on the Cassini spacecraft observed a repeated intensification and broadening of the high latitude auroral oval into the polar cap. This feature repeated at least 5 times with about a 1 h period, as it rotated in the direction of corotation, somewhat below the planetary rotation rate, such that it moved from noon to post-dusk, and from roughly 77° to 82° northern latitudes during the observing interval. The recurring UV observation was accompanied by pronounced ∼1 h pulsations in auroral hiss power, magnetic perturbations consistent with small-scale field aligned currents, and energetic ion conics and electrons beaming upward parallel to the local magnetic field at the spacecraft location. The magnetic field and particle events are in phase with the auroral hiss pulsation. This event, taken in the context of the more thoroughly documented auroral hiss and particle signatures (seen on many high latitude Cassini orbits), sheds light on the possible driving mechanisms, the most likely of which are magnetopause reconnection and/or Kelvin Helmholtz waves.

1. Introduction

Pulsations in auroral hiss as seen by the Cassini Radio and Plasma Wave Science (RPWS, Gurnett et al. (2004)) instrument aboard the Cassini spacecraft have been observed on many occasions, often in association with correlated energetic ion conics, high energy, field aligned electrons, and magnetic signatures of field aligned currents (Mitchell et al., 2009a). These events formed a pulsed subcategory of a broader class of events documented in that work, all of which were associated with downward field aligned currents (FAC). The broader class was thought to represent the Saturn equivalent of similar field-aligned electron beam events observed at Earth in association with downward field-aligned currents in the auroral zone (Klumpar, 1990; Carlson et al., 1998; Marklund et al., 2001), although this subclass of *pulsed* events has not been documented at Earth. Auroral features at high latitudes and local times (i.e., rotating from near noon toward dusk), similar to those found for the series of pulsations presented here, have also been observed on other occasions at Saturn. Radioti et al. (2011, 2013) and Badman et al. (2012, 2013) have showed observations of auroral bifurcations of the main emission, and related them to magnetopause reconnection. Radioti et al. (2013) showed two "rebrightenings" of the bifurcations of the main emissions, with an interval of 1 h, but no other mention has been made of the repeated brightening at about a 1 h period in the auroral data. There has been no association made between these repeated auroral events and the ∼1 h pulsations observed regularly in the radio wave and particle data, for example in Mitchell et al. (2009a), Jasinski et al. (2014), Bunce et al. (2014). Badman et al. (2012) showed the correspondence of similar 1 h pulsations in the in situ data with the presence of conjugate auroral arcs, but did not have the temporal resolution to observe any intensity variations in the auroral emissions. It has been suggested by Radioti et al. (2011, 2013) and Badman et al. (2012, 2013) that repeated magnetopause reconnection may be responsible for the auroral features, where it has also been documented that they significantly subcorotate.

2. Observations

The UV auroral observations of Saturn's northern ionosphere begin just before 0800 UT on May 8 (day 129), 2008, and repeat

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http://dx.doi.org/10.1016/j.icarus.2014.10.028
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at a cadence of four full auroral images per hour until just before 1400 UT. Fig. 1 shows a sequence of polar projections of Saturn's northern aurora obtained with the FUV channel (111–191 nm) of the Cassini UVIS instrument (Esposito et al., 2004) on DOY 129, 2008, one hour per horizontal line of four images. Circles on each figure are drawn at 70° and 80° colatitude, and in white in the upper left panel we show the trajectory of the Cassini spacecraft mapped to the ionosphere, with the interval analyzed in the paper highlighted in pink and labeled with a pink "C".

The images reveal a rotating region of bright arcs moving from near noon through dusk between northern co-latitudes of ~8–13°, whose intensity varies considerably from image to image in a repeating fashion. These arcs are labeled with a white "B" in each frame for which their emission peaks. As in Radioti et al. (2011, 2013), and Badman et al. (2013) this region is closely associated with a strong distortion of the auroral oval into the polar cap just westward of the recurrent brightening. Also apparent, though much fainter, is a recurrent brightening near noon at high colatitudes between 3 and 12°, a region that may be connected with the cusp (Gérard et al., 2005; Bunce et al., 2005). The frames for which this noon, high latitude emission reaches peak intensity are labeled with the word "cusp?".

To quantify the intensity of the emissions associated with these auroral regions, in Fig. 2a and b we construct auroral keograms, as in Mitchell et al. (2014), by averaging the auroral emissions from each panel of Fig. 1 in local time bins of 1 h between colatitudes of 10–15° (a) and 3–10° (b). The former colatitude range captures essentially the entire poleward edge of the auroral oval (e.g., Badman et al., 2014), while the latter includes primarily the polar cap (containing the possible aforementioned cusp-related auroral emission near to noon). These ranges were chosen so as to isolate the "cusp?" signature from the pulsating bifurcated arc signature in the keograms. The top panels of Fig. 2 exhibit the local time keograms obtained the full set of auroral scans in Fig. 1. Also included in Fig. 2a is a blue line that tracks the local time of Saturn's moon, Mimas. The results obtained using this line instead of the white line that was drawn to follow the arcs are indistinguishable from those using the white line, corresponding to an orbital period of 23 h, i.e., approximately 50% of corotation. We have no mechanism to offer to explain this causally, but simply point it out as a curiosity. However, 50% of corotation is a fairly typical magnitude both in the polar auroral region (e.g., Nichols et al., 2014) and for plasma in the outer magnetosphere (Thomsen et al., 2010; Arridge et al., 2011).

Even a cursory inspection of the keograms reveals the time variations of the auroral regions of interest in this study. White lines have been drawn across the each of the keograms that roughly track the relevant auroral features. One can arrive at an estimate of the intensities of the features as a function of time by averaging the intensities, for each scan, within ±2 h of the local times of these lines. These intensities-along-the-lines appear in the bottom panels of Fig. 2.

This event took place during the same time interval discussed in Mitchell et al. (2009b) [see their Figs. 5 and 7 containing MIMI/INCA energetic neutral atom (ENA) images, along with the discussion]. We wish to emphasize that aside from a likely common association with a high pressure solar wind driver, we believe this event to be unrelated with the bright system of arcs beginning post-midnight and rotating through dawn during this same sequence, at somewhat lower latitudes (seen in Fig. 1, as well as in the morning local times in the 10–15° keogram in Fig. 2). That region was discussed in some detail in Mitchell et al. (2009b), and related to probable nightside reconnection and subsequent ring current heating and rotation as imaged in energetic neutral atoms. There was no enhanced ENA emission associated with this pulsating auroral activity, consistent with the high latitude of the auroral features, which most likely map to the dusk side magnetopause, a region where energetic ion intensities are not generally high enough to produce ENA emission above the INCA threshold for detection.

The in situ measurements at Cassini (Fig. 3), however, show very strong correlation with the auroral activity. During the interval shown in Fig. 3, the spacecraft position mapped to the northern hemisphere high-latitude polar cap at approximately constant colatitude of ~8° (as shown by the pink line in Fig. 1). The spacecraft was located at high latitudes off the equator in the middle to outer magnetosphere (between radial distances of ~15 and 17 R_S), near to 13 h LT. The top panel (A) shows the magnetic field components from the Cassini magnetometer instrument (MAG, Dougherty et al. (2004)). The second panel (B) shows the magnetically mapped ionospheric footprint of Cassini relative to the model location of the nominal auroral, using a combination of the internal field model of Dougherty et al. (2005) and the ring current model of Bunce et al. (2007). In addition a model location of the nominal auroral oval at the longitude of the spacecraft is shown based on the northern magnetosphere oscillation phase for this interval (see Andrews et al. (2012)), and a model of the observed amplitude of the oscillation of the auroral oval by Nichols et al. (2010). The third panel (C) shows rates resulting from field aligned energetic electrons (discussed in the following paragraph), and the last panel (D) presents RPWS auroral hiss intensities.

In panel C of Fig. 3, we plot the counting rate from the MIMI/INCA "Stop" microchannel plate (MCP). Whereas INCA is designed to measure ENAs and ions, the MCP detectors used to derive the speed and direction of the ENAs or ions also respond with reasonable efficiency to energetic electrons. Because the "Start" MCP in INCA is not in the particle trajectory path, the signal from electrons in the Start MCP is weak—it relies on secondary electrons generated in the Start entrance foil as primary energetic particles transit the foil on their way through the time of flight (TOF) volume to the Stop foil and MCP. The primary particles penetrate the Stop foil directly in front of the Stop MCP, and collide with the Stop MCP. Although energetic electrons have a low efficiency for generating secondary electrons in the Start foil (<1%), they have a high probability of triggering the Stop MCP (10s of percent). With INCA in ENA imaging mode (as it was throughout this event) only charged particles with $E/q \geqslant 180$ keV/q can get through the high voltage charged particle rejection plates in front of the entrance slit. Of these, the efficiency for proton detection above that energy is roughly 30%, for which we measure the proton TOF and so derive its energy and trajectory. Electrons not only have a low probability of generating a TOF because of the low Start efficiency for electrons, but their TOF is shorter (~1–2 ns) than the minimum TOF analyzed by INCA, and we do not know their energy other than that it is sufficient to enter through the charged particle rejection plates. So the signature of energetic electrons in INCA is simply elevated Stop counting rates without a corresponding increase in Start counting rates. Additional detail on the detection techniques used in INCA measurements can be found in the MIMI instrument paper, Krimigis et al. (2004).

The energetic electron intensity is not steady, but beginning a little before 10:00 UT comes and goes episodically, with fast fluctuations modulated by an envelope with a period of about 1 h. The auroral hiss power (bottom panel) likewise varies quasi-periodically, although the average power varies by about an order of magnitude over the interval between 0600 and 1600 UT. Indications from the MIMI CHEMS instrument are that magnetospheric ion intensities were slightly higher in the interval between 0800 and 1000 UT, consistent with the spacecraft being farther inside the magnetopause at this time than over the rest of the interval. The magnetic field behavior (panel A) is less obviously periodic, but the phi and theta angles vary consistent with Alfvénic structures carrying field-aligned