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Key Points:

- We present simultaneous observations of auroral brightening and plasma perturbations at Saturn
- We show evidence of plasma wave conversion in driving a transient auroral brightening at Saturn
- We propose two potential mechanisms generating the plasma wave and aurora intensification

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Mechanisms of Saturn's Near-Noon Transient Aurora: In Situ Evidence From Cassini Measurements

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Abstract Although auroral emissions at giant planets have been observed for decades, the physical mechanisms of aurorae at giant planets remain unclear. One key reason is the lack of simultaneous measurements in the magnetosphere while remote sensing of the aurora. We report a dynamic auroral event identified with the Cassini Ultraviolet Imaging Spectrograph (UVIS) at Saturn on 13 July 2008 with coordinated measurements of the magnetic field and plasma in the magnetosphere. The auroral intensification was transient, only lasting for ∼30 min. The magnetic field and plasma are perturbed during the auroral intensification period. We suggest that this intensification was caused by wave mode conversion generated field-aligned currents, and we propose two potential mechanisms for the generation of this plasma wave and the transient auroral intensification. A survey of the Cassini UVIS database reveals that this type of transient auroral intensification is very common (10/11 time sequences, and ∼10% of the total images).

1. Introduction

Auroral emission is an important energy dissipation mechanism in planetary magnetospheres and has been identified at Earth (Akasofu, 1964). Substorm aurora is usually considered as the most distinctive auroral feature. During this process, thin auroral arcs (mostly east-west aligned, narrowed in north-south direction) in the most equatorward are usually formed at the beginning and are followed by an explosive auroral intensification and extension (Akasofu et al., 2010; Frey et al., 2004). The auroral activities are often accompanied with wave-like features, which have been revealed as a consequence of plasma instabilities (Lui et al., 2008; Rae et al., 2009). Auroral emissions also commonly exist in other planets, e.g., Saturn (Broadfoot et al., 1981; Gérard et al., 2009; Sandel & Broadfoot, 1981), Jupiter (Clarke et al., 1998; Ingersoll et al., 1998; Mauk et al., 2002; Waite et al., 2001), Mars (Bertaux et al., 2005; Fox, 1992), Venus (Phillips et al., 1986), Uranus (Herbert, 2009; Hill et al., 1983; Waite et al., 1988), and Neptune (Broadfoot et al., 1989; Cheng, 1990; Sandel et al., 1990). Mercury does not have auroral emission due to its tenuous atmosphere, although airglow may still exist (Broadfoot et al., 1974). The generation of aurora strongly relies on the magnetospheric plasma sources that could come from either the solar wind or the moon-induced processes. Moreover, the polar auroral emissions are often affected by boundary interactions at the magnetopause.

The simultaneous measurements of in situ plasma and remote imaging of the aurora is vital in revealing the mechanisms of auroral brightening; however, this is not often available for planetary research. The past few decades have seen the development and launch of a number of terrestrial magnetospheric missions and ground all-sky cameras, which make routine coordinated measurements between Earth aurorae and their magnetospheric sources. Thus, the mechanisms of field-aligned current generation for terrestrial aurorae has been extensively investigated with coordinated measurements (e.g., Angelopoulos et al., 2008; Keiling et al., 2009; Yao et al., 2012). In addition, similar auroral mechanisms may exist at Earth and the giant planets. For example, Yao, Pu, et al. (2017) present similar wave-like auroral structures at Earth, Saturn, and Jupiter, and they show strong evidence that kinetic ballooning instability generates the wave-like aurora at Earth, although it is still unclear whether the auroral structures at Saturn and Jupiter are generated by a similar process.

The main auroral emission at Saturn is suggested to be associated with the open-closed field line boundary on the dayside (Bunce et al., 2008), although uncertainties might be involved in determining the open-closed field line on their aurora images. The intensity of auroral emission has strong dawn-dusk asymmetry (Badman et al., 2006), which may be related to the dawn-dusk asymmetries of field and plasma properties in Saturn's magnetosphere (Jia & Kivelson, 2016; Sergis et al., 2017). As the main aurora rotates with Saturn (e.g., Radioti et al., 2016), the dawnside (duskside) aurora can thus be considered as precompression (postcompression) aurora. It is very likely that the compression from solar wind has a contribution to the dawn-dusk asymmetry in auroral emissions. Besides the main auroral emissions, Saturn's aurora also presents highly dynamic features. It is usually considered that the auroral emissions at Saturn are driven by both internal and external processes (e.g., Mitchell, Carbary, et al., 2009). The highly dynamic aurorae often exist in the region poleward of the main auroral emission where solar wind driven processes are nonnegligible. High-latitude reconnection is suggested to generate a transpolar auroral arc (Radioti et al., 2014) that is usually very dynamic. Reconnections at Saturn's magnetopause (Badman et al., 2013; Radioti, Grodent, Gérard, Milan, et al., 2011) and in the nightside magnetotail are also suggested to cause Saturn's auroral brightenings (Cowley et al., 2005; McAndrews et al., 2008; Mitchell, Krimigis, et al., 2009; Nichols et al., 2014; Radioti et al., 2014). Arridge et al. (2016) present a long-duration (up to ~19 h) magnetic reconnection event in Saturn's magnetotail, which strongly implies the existence of solar wind driven reconnection in Saturn's nightside magnetosphere. In addition to the solar wind driven reconnection, Yao, Coates, et al. (2017) describes a corotating type of magnetic reconnection at Saturn that can only be driven by internal process. Since the magnetic reconnection process at Saturn may be internally or externally driven, we would expect reconnection-related dynamic aurorae to be driven by both internal and external processes. The solar wind and internal drivers on Saturn's magnetospheric dynamics are often discussed in previous studies (e.g., Delamere et al., 2015; Masters et al., 2014).

The studies with simultaneous in situ measurements and remote sensing are few in planetary research. Using Hubble Space Telescope (HST) ultraviolet images and concurrent Cassini measurements, Bunce et al. (2008) presented for the first time near-simultaneous observations of the southern auroras and the corresponding magnetospheric plasma observations at Saturn. Their results directly showed the large-scale upward field-aligned currents (FACs) flowing at the open-closed-field line boundary at Saturn, and they concluded that the main aurora oval is produced by the magnetosphere-solar wind interaction through the shear in rotational flow across the open-closed-field line boundary. More recently, using coordinated measurements from the instruments onboard Cassini and the HST observed aurora, Badman et al. (2016) clearly presented the upward FAC on the nightside auroral arc and the downward FAC in poleward of the upward FAC in an aurorally dark region. Their results thus clearly indicate that the main auroral arc is not adjacent to the open-closed field line boundary, which is different from the conclusion in Bunce et al. (2008), perhaps due to the different local time of their observations, which also implies that the solar wind-magnetosphere interaction is important in modifying the large-scale auroral current system. Jinks et al. (2014) determined that the upward FAC region is clearly below the polar cap boundary by ~1.5–1.8° at both hemispheres. Simultaneous measurements between near-magnetopause conditions and the aurora at Saturn reveal that the compressed magnetosheath field can pile up at the dayside magnetopause boundary to produce a favorable condition for reconnection to occur. This results in bifurcations of the near-noon auroral oval (Badman et al., 2013). Badman et al. (2012) showed the first simultaneous observations of transient reconnection and the corresponding aurora. Mitchell et al. (2016) reported recurrent auroral pulsations, which are inphase with the magnetic field and particle events. They suggested the most likely mechanism for the pulsating aurora to be magnetopause reconnection and/or Kelvin-Helmholtz waves. In addition to the coordinated measurements at Saturn, Radioti, Grodent, Gérard, Vogt, et al. (2011) reported an event with measurements from Galileo magnetic field and HST aurora at Jupiter. Their results suggest a connection between inward moving flow from magnetotail reconnection and the nightside polar auroral brightening. More simultaneous measurements of aurora and in situ plasma environment are needed to understand the mechanisms of aurorae at giant planets, particularly important for understanding the dynamic aurorae, which are directly related to explosive energy release processes (e.g., magnetic reconnection, wave-particle interaction, and flow-ambient plasma interaction).

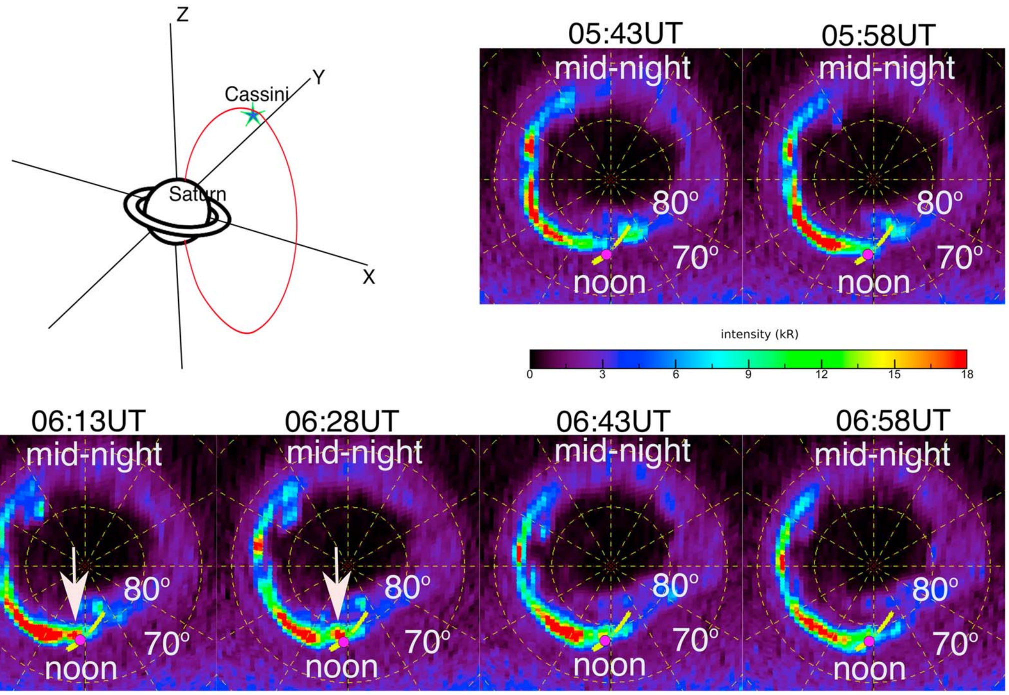

Figure 1. Aurora images on 13 July 2008 (DOY 195) from Cassini/UVIS instrument. Each image was obtained in a time window of ~10 min. The time displayed on the top of each image represents the start time of each window. The location of Cassini is presented on the top left of this figure. The location of the Cassini spacecraft was magnetically mapped to Saturn's polar region. The filled pink circle represents the foot point of Cassini at 0730 UT. The yellow dots show foot points of Cassini's trajectories between 12 July and 14 July 2008. The white arrows indicate the auroral intensification region.

In this study, we present an event with simultaneous aurora, particle and magnetic field measurements, all from the instruments on board the Cassini spacecraft. We reveal the generation of the FACs for a transient auroral intensification for this event, and we survey the Cassini Ultraviolet Imaging Spectrograph (UVIS) database to determine a probability of the transient auroral intensification. We also examine whether or not the physical FAC mechanisms match previous Saturnian magnetospheric models.

2. Observations

2.1. Auroral Sequences From Cassini UVIS Instrument

Figure 1 (top left) shows a schematic plot for the location of the Cassini spacecraft. During these observations, Cassini was located at ~11.7 Saturn local time, at latitudes ~40° north of Saturn's equatorial plane, and radius $R \sim 14R_S$, where $1R_S = 60,268$ km. The relatively high latitude location allows us to simultaneously obtain a good field of view of the polar aurora and the magnetospheric measurements, which is an ideal opportunity to determine the connection between the magnetosphere and auroral emissions. The auroral images shown in Figure 1 are obtained with Cassini UVIS instrument (Esposito et al., 2004) on 13 July 2008 (day of year (DOY) 195) and are part of a longer sequence presented in Radioti, Grodent, Gérard, Milan, et al. (2011). The projections are constructed by combining slit scans, with details presented in Radioti, Grodent, Gérard, Milan, et al. (2011). In that study, the major interest was the bifurcations in the duskside, while in this paper, we focus on the dynamic aurora in the near-noon region, to which the Cassini spacecraft was magnetically connected. The footprint of the Cassini spacecraft between 12 July 2008 and 14 July 2008, marked by the yellow dots, was obtained with a corresponding magnetic model. We used a magnetic field model incorporating a current sheet with half thickness of 2.5 R_S, a magnetopause standoff distance of 22 R_S, the internal magnetic field is from Dougherty et al. (2005), and the current sheet scaling laws from Bunce et al. (2007). The filled pink circle marks the foot point at 07:30 UT on 13 July 2008. From the sequences of auroral images, by eye, we can identify an intensification near the footprint of Cassini spacecraft at 06:13 UT and 06:28 UT (indicated by the white arrows), which became faint at 06:43 UT, indicating that this is a transient auroral intensification. It is noteworthy to mention that the transient auroral intensification was in an extended auroral arc, and this extended

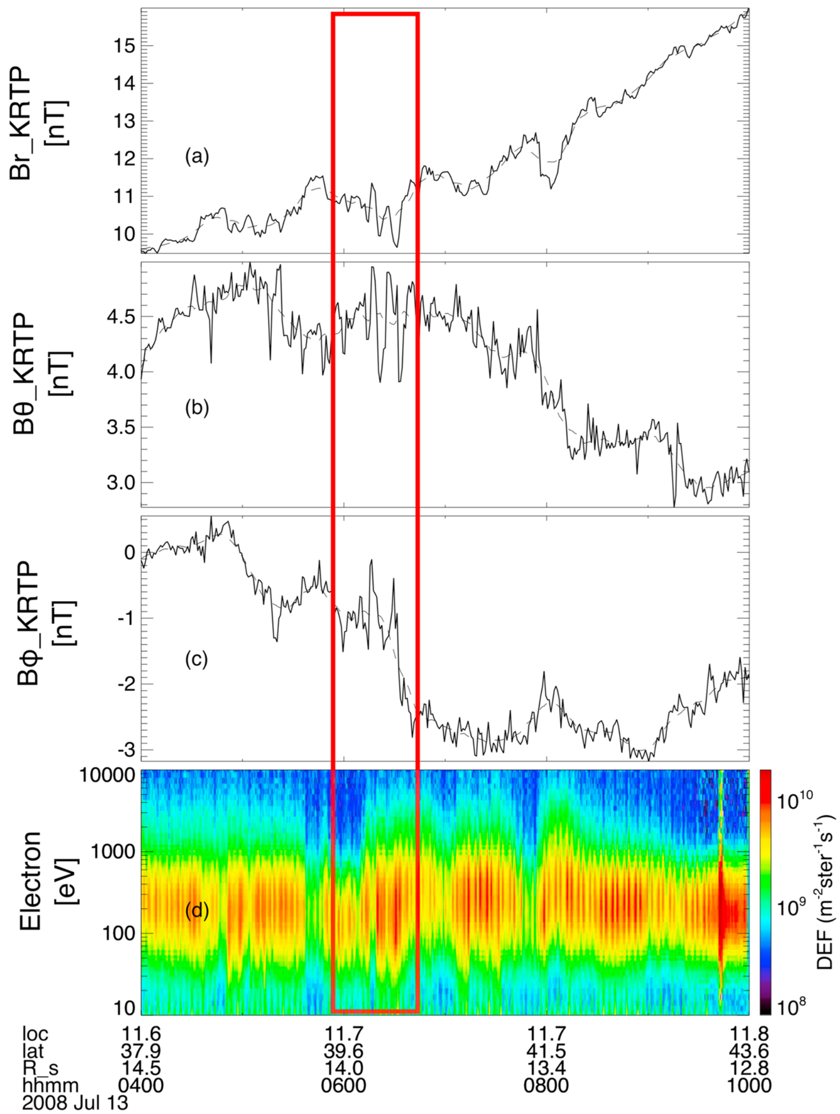

Figure 2. Overview of the in situ measurements from Cassini. (a–c) The components of magnetic field in Kronocentric Radial-Theta-Phi coordinates. (d) Electron differential energy flux from Cassini CAPS-ELS instrument. The red rectangle indicates the perturbations of magnetic fields and plasma corresponding to the auroral intensification.

auroral arc corotates with the planet for a few hours (please also see Radioti et al., 2017). This extended aurora arc is more permanent and should be caused by other mechanisms that we do not discuss in this letter. The location of the Cassini spacecraft was magnetically mapped to the auroral intensification region; thus, the Cassini spacecraft was in ideal position to detect the signatures of magnetic field-aligned currents associated with the auroral intensification. We would like to point out that considerable uncertainty may exist in the magnetic mapping result, as the current sheet thickness is very varied at different radial distance (Thomsen et al., 2010). To evaluate the potential mapping uncertainty, we also tried a half thickness of 1 R_S, and we found that the latitude of the spacecraft foot point decreases 0.8°, which is much smaller than the width of the aurora (i.e., ∼3–4°). Moreover, we compare the time delay between in situ perturbation and auroral intensification with Alfvén transit time from the spacecraft to the ionosphere and found that the two times are highly consistent. Thus, we suggest that this mapping uncertainty would not seriously affect our analysis.

2.2. In Situ Measurements of Magnetic Field and Plasma

In this section, we show the detailed in situ measurements associated with the auroral intensification shown in Figure 1. Figures 2a–2c show the magnetic field data (1 min resolution) from the Cassini magnetometer (Dougherty et al., 2004) in Kronographic Radial-Theta-Phi coordinates between 04:00 UT and 10:00 UT on

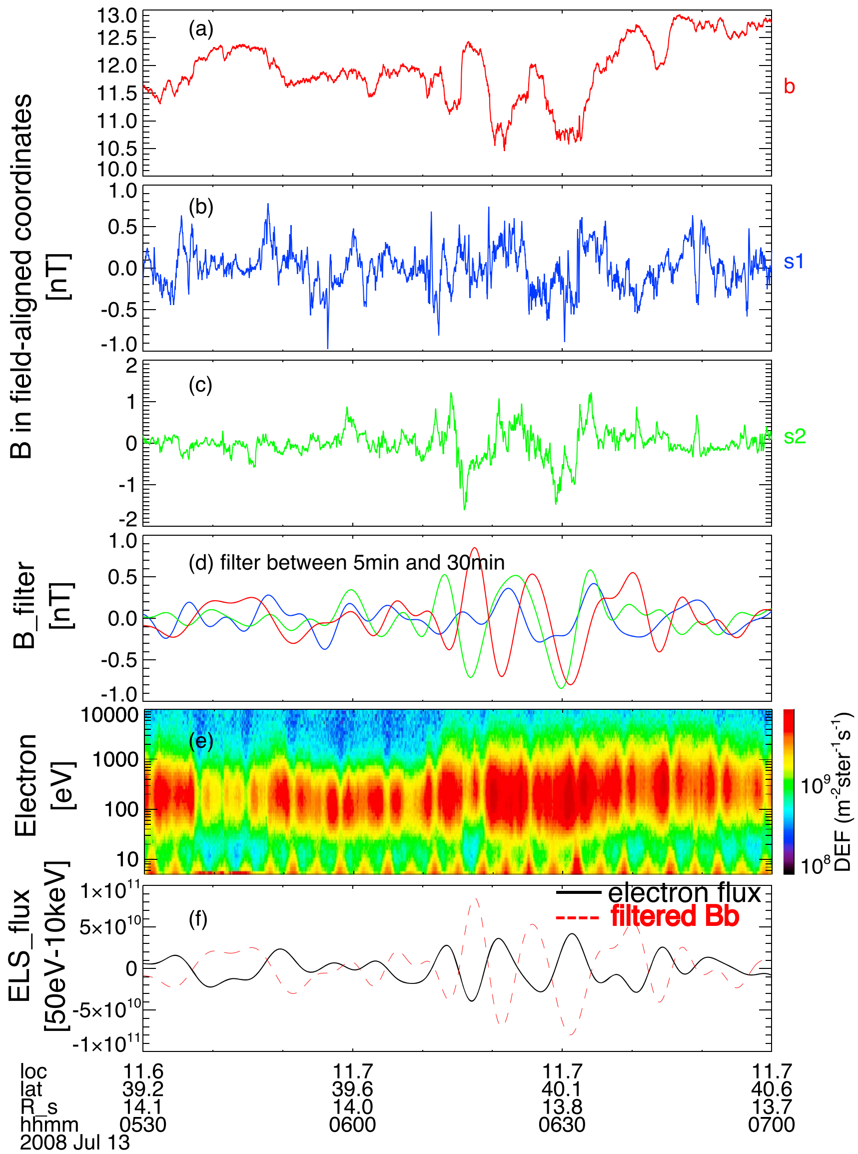

Figure 3. The results of wave analysis of in situ measurements. (a–c) Three components of the magnetic field in mean field-aligned (MFA) coordinate system. (d) The results of a band-pass filter (5 min to 30 min) of the three magnetic components (Figures 3a–3c). (e) Electron differential energy flux. (f) The total flux of the electron differential energy flux at energies between 50 eV and 10 keV. The red dashed line if the filtered the compressional component magnetic field as shown in Figure 3d.

13 July 2008. The dashed curves are smoothed over 20 min, which represent a large-scale variation of magnetic field. The deviation between the measured magnetic field and the smoothed data shows magnetic perturbations within a time scale of 20 min. Figure 2d shows the electron differential energy flux from the Cassini electron spectrometer (CAPS-ELS) (Young et al., 2004).

A significant magnetic perturbation was detected between ~ 06:10 UT and ~ 06:50 UT, while the electron flux was slightly enhanced (indicated by the red rectangle). The magnetic perturbation show a period of ~15 min, which is likely a wave feature. The plasma and wave activities are very likely related to the auroral intensification shown in Figure 1 (06:13 UT and 06:28 UT), because they are magnetically connected and occurred almost simultaneously. The resolution of the auroral images is ~15 min, and the wave has a period of ~15 min, so we are not able to determine more accurately (better than 15 min) aurora and wave onset times.

Figure 3 shows the results of wave analysis between 05:30 UT and 07:00 UT. We transformed the magnetic field into a mean field-aligned (MFA) coordinate system to investigate the nature of the plasma wave (e.g., Du et al., 2011). The mean field is determined by the low pass filtered data with a shortest period of 20 min. The MFA coordinates applied in this paper are defined as follows: the **b** component is parallel to the mean field, **s2** is perpendicular to the plane determined by mean field and the line from Saturn to the spacecraft (negative rotationward), and **s1** completes the right-handed set. Figures 3a and 3c show the vector magnetic components in MFA coordinates. The variations in Figure 3d are obtained by band-pass filter of the data (Figures 3a–3c) with a period of 5 to 30 min, which should well represent the major magnetic variations that can be visually identified. The magnetic perturbations presented in MFA coordinates allow us to distinguish the transverse (δB_{S1} and δB_{S2}) and the compressional component δB_b. The wave amplitude on both the transverse δB_{S2} and compressional δB_b components were prominently enhanced at ~06:15 UT. We also notice that the differential electron energy flux in Figure 3e shows anticorrelation with the magnetic compressional component δB_b. To quantify the relation between the electron flux and the compressional magnetic perturbation, we sum the electron flux from 50 eV to 10 keV and filter the total flux with the same period as for the magnetic field in Figure 3d (5 and 30 min). As presented in Figure 3f, the variation of electron flux is clearly out of phase with δB_b(the red dashed curve). It is very likely the plasma pressure was also out of phase with δB_b, although we cannot directly obtain the plasma pressure from Cassini measurements (the temporal resolution of full energy coverage ion measurements is not sufficient for this study). Mirror mode and slow mode wave are well known for the out-of-phase relation between plasma pressure and magnetic field. Considering that mirror mode is driven by strong pressure anistropy ($T_{\rm perp} > T_{\rm par}$), the mirror mode is usually constrained near equator where the temperature anisotropy is maximum (e.g., Rae et al., 2007). In this event, the Cassini spacecraft was at high latitude (~40°), we thus suggest that the compressional magnetic perturbation in this event is a slow mode wave.

We would like to point out that there are photoelectron pollution at the energies up to 20 eV in Figure 3e, as we can clearly identify from their periodic enhancements. We believe that the photoelectron pollution would not affect the anticorrelation between electron flux and magnetic field strength for two reasons:

1. The peak energy of the photoelectrons is ~20 eV, while we calculate the total electron flux of electrons with energies starting from 50 eV. It is thus not likely that our calculation of electron flux is affected by photoelectrons.
2. The photoelectrons are also modulated by actuations, as the anode at the sunward looking and antisunward looking would measure different fluxes, and this modulation is 3 min. This actuation modulation period is significantly smaller than the period of compressional wave discussed in the present study, and this period would be filtered out by our band-pass filter analysis. Hence, photoelectron pollution does not likely lead to a problem in our study.

3. Summary and Discussion

Alfvén transit time from the Saturn equator to ionosphere is suggested to be ~20–30 min (Bunce et al., 2005; Roussos et al., 2016). Considering that Cassini was at high latitude, the transit time from the spacecraft to the ionosphere will be <20 min in this event. The auroral intensification was recorded for the image taken between 06:15 UT and 06:25 UT, and the plasma wave activity started at ~06:10 UT. The time delay between the wave activity and auroral intensification is 5 to 15 min, consistent with the expected Alfvén transit time, which suggests that we directly measured a magnetospheric mechanism for the dynamic auroral intensification at Saturn's polar region.

From the features of magnetic and plasma perturbations, we suggest the plasma wave is a slow mode compressional MHD wave. Slow mode waves are often generated near the dayside magnetopause (Song et al., 1992; Southwood & Kivelson, 1992; Yan & Lee, 1994). In the present study, we report the slow mode perturbation detected inside the magnetopause by Cassini spacecraft. Coexistence of Alfvénic perturbation suggests a coupling process of compressional mode and transverse mode. The coupling between slow mode wave and Alfvénic wave often exist at curvature and nonuniform plasma (Nakamizo & Iijima, 2003). The coupling of slow mode wave and Alfvénic wave in flow braking region (e.g., the near-Earth region where magnetotail reconnection outflow brakes, at $x \sim -10R_E$) is suggested to play an important role in forming FACs that couple the magnetosphere and ionosphere at Earth (Du et al., 2011; Keiling et al., 2014; Nakamizo & Iijima, 2003; Ohtani et al., 1989; Southwood & Saunders, 1985).

In our event, the wave period is significantly smaller than the eigenperiods of Saturn's magnetic field line resonance. The eigenperiod strongly depends on the magnetic field model. At ~14 R_S, the eigenperiod is usually a few hours (e.g., Cramm et al., 1998). More recently, the quasiperiodic ~1 h fluctuations have been suggested to be Alfvén waves standing between the northern and southern ionospheres in Saturn's outer magnetosphere (see Yates et al., 2016, and references therein). In this event, the wave period is ~15 min, significantly shorter than the field line resonance period. The Alfvén wave, even though it is not a standing wave, still provides the communication between the magnetosphere and ionosphere and causes the precipitation. We suggest that the Alfvén wave is not a standing wave in this event and this is also supported by the fact that the corresponding auroral intensification quickly became faint, although we could not fully exclude a possibility of higher harmonic resonance.

We suggest that the plasma wave is not likely a fast mode compressional wave based on the anticorrelation of magnetic and electron flux. However, drifting mirror mode structure also shows this anticorrelation, and mirror mode couples with an Alfvén wave as well (Klimushkin, 2006). Rae et al. (2007) indicate that mirror mode structure in Earth's magnetosphere are limited to the equatorial plane (±20°), as the ion temperature anistropy (T_{perp}/T_{par}) peaks at the equatorial plane. In Saturn's magnetosphere, ion temperature anistropy $T_{perp}/T_{par} > 1$ is common in the inner magnetosphere (e.g., Lazarus & McNutt, 1983) and becomes less anisotropic as distance increases, but still not isotropic by 10 R_S (Wilson et al., 2008). The ion anisotropy at the location of Cassini in this event is unclear. Nevertheless, based on the results in Wilson et al. (2008), $1 < T_{perp}/T_{par} < 2$ at $R \sim 10R_S$, we would expect T_{perp}/T_{par} to be close to 1 at 14 R_S. The anisotropy is very likely negligible in this event particularly considering that Cassini was at a high-latitude region, where the anisotropy is smaller than the near equator region. Moreover, no notable ion anisotropy was found from the Cassini CHarge Energy Mass Spectrometer (CHEMS) instrument (Krimigis et al., 2004), although only very limited pitch angles were available (not shown in this paper). We thus suggest that the magnetic and plasma perturbation is not a mirror mode wave.

We also note that the slow mode wave is very similar to the Pi2 band magnetic perturbation in Earth's inner magnetosphere (Keiling & Takahashi, 2011). Pi2 is defined as the magnetic perturbation with period between 40 s and 150 s, which is a key feature of magnetospheric substorm activity (Keiling & Takahashi, 2011). Previous studies have shown that Pi2 wave is a combination of compressional and Alfvénic perturbations (Wang et al., 2015), and the compressional perturbations are mostly slow mode (Xing et al., 2015). The Earthward magnetotail reconnection outflows are considered as the mechanism to generate compressional magnetic perturbation near equatorial plane, which may convert to Alfvénic perturbations at higher latitude. In this case, Cassini was not near Saturn's equatorial plane, so it is natural that the magnetic perturbation is a combination of compressional slow mode wave and an Alfvénic wave.

To test our hypothesis that the auroral intensification was caused by the observed Alfvénic wave, we compare the wave Poynting flux with the inferred auroral electron fluxes. The brightness of the transient aurora was about 20–30 kR, which requires precipitating electron fluxes of 2–3 mW/m^2 (see Gérard & Singh, 1982; Waite et al., 1983). It has been a major difficulty to calculate the Poynting flux without a direct measurement of electric field. Here we use an indirect method to roughly estimate amplitude of the perturbed electric field and the associated Poynting flux. From the electron measurements (CAPS-ELS), we adopt the plasma density of 0.028 cm^{-3}, $B \sim 11.5$ nT, and obtain an Alfvén speed of 1,500 km/s. Considering that the amplitude of perturbed magnetic field was ~1 nT, we thus estimate a perturbed electric field of 1.5–15 mV/m. Here, we assume the Poynting flux to increase proportionally with the phase speed of the kinetic Alfven wave and the wave speed to be 1–10 times of the Alfvén speed, which is a nature of kinetic Alfvén wave. Thus, the Poynting flux in the magnetosphere is 0.0012–0.012 mW/m^2, which corresponds to 7.3–73 mW/m^2 in the ionosphere. The magnetosphere to ionosphere relation was based on the relation of magnetic field strength at magnetosphere (the Cassini location, 11 nT) and ionosphere (at 1,100 km (Gérard et al., 2009), 6,800 nT, see Nichols et al., 2009). We need to point out that Poynting flux is not always proportional to the phase speed of the kinetic Alfvén wave. Moreover, kinetic Alfvén waves might be the end product of a turbulent cascade where dissipation occurs, so it would be impossible to increase Poynting flux. So the upper limit of the Poynting flux is likely overestimated. Obviously, the Poynting flux associated with this Alfvénic wave is sufficient to generate the corresponding auroral intensification, although we have no information how much energy would be eventually converted from wave to plasmas.

The simultaneous observations of auroral intensifications and their corresponding plasma perturbations are pivotal in understanding the physical processes. To further understand the potential importance of this mechanism in planetary magnetosphere-ionosphere coupling dynamics, we survey the aurora data set from Cassini UVIS to obtain occurrence of the transient auroral intensification. The results are shown in Table 1. Note that

Table 1
List of the Transient Auroral Intensifications From Cassini UVIS

YYYY-DOY	Event (Yes/No)	Number of transiently brightened images	Number of images	References
2008-129	Y	2–3	24	Mitchell et al. (2016) and Palmaerts et al. (2016)
2008-195	Y	2	24	Radioti, Grodent, Gérard, Milan, et al. (2011) and Radioti et al. (2017)
2008-197	Y	2	14	Radioti et al. (2015)
2008-201	Y	1–2	54	Badman et al. (2013)
2008-238	Y	1* (the first image of the sequences)	5	Radioti et al. (2017)
2008-304	N	0	6	
2008-334/335	Y	4–5	28	Radioti, Roussos, et al. (2013)
2009-021	Y	2	10	Radioti, Grodent, et al. (2013)
2013-109(1)	Y	1* (the first image of the sequences)	18	Radioti et al. (2017)
2013-109(2)	Y	2–4		
2013-128	Y	2* (the first and second images of the sequences)	15	Palmaerts et al. (2016)
In total	10/11	19–24	198	

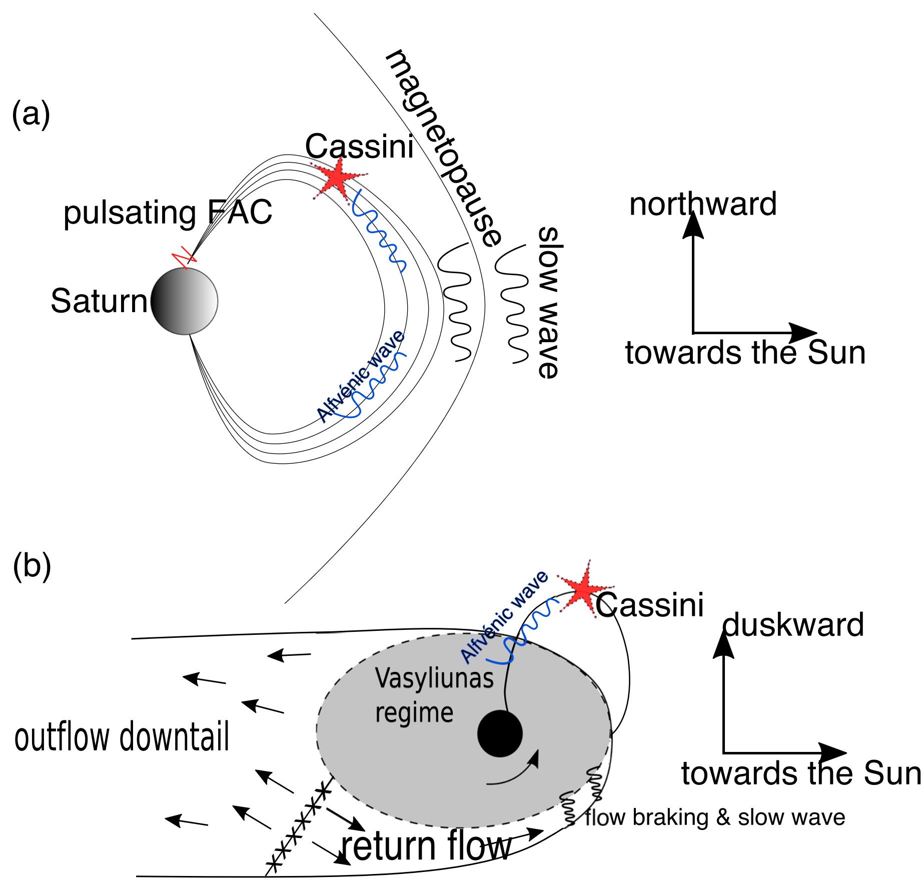

Figure 4. Illustration of two physical pictures for the generation of the plasma wave observed in this study. (a) Slow mode wave generated in magnetosheath propagates into magnetosphere and converts to Alfvénic wave that carries FAC to ionosphere and generate a transient aurora. (b) The return flow from the nightside Dungey cycle reconnection experiences a blockage in the equatorial plane, which generates slow mode compressional wave within the magnetosphere. The slow mode wave converts to Alfvénic wave and generate aurora intensification. The picture of flow cycle is adapted from Radioti et al. (2017) (originally from Southwood & Chané, 2016).

the resolution for auroral images is ∼15 min (i.e., every 15 min per image), and we only survey the auroral sequences with at least five continual images. Eleven events are selected, with in total 198 images. Ten events with 19–24 images are identified as transient intensification as in the case study. We thus consider that the transient auroral intensification is a frequent phenomenon (10/11 time sequences, and ∼10% of the total images) in Saturn's polar aurora region. Most of the events in Table 1 are described in detail in previous studies. In Table 1, we have provided these relevant references that we are aware of.

In Figure 4, we propose two potential physical pictures for the generation of the plasma wave and aurora intensification in our event. In Figure 4a, we suggest that the slow mode wave propagates from the magnetosheath into the magnetosphere, and the slow mode compressional wave converts to Alfvénic wave that carries FAC to ionosphere and generates a transient aurora. The second picture shows a hypothesis that describes the FAC and waves at the flow blockage of the plasma circulation theory (see Southwood & Chané, 2016 for details). They suggest that the return flow from the nightside Dungey cycle reconnection experiences a blockage in the equatorial plane and cannot rotate through noon. The blockage of return flow at noon is similar to the interaction of flow braking at the near-Earth magnetotail (Birn et al., 1999; Shiokawa et al., 1997; Yao et al., 2013), which thus may generate the slow mode compressional wave (Kepko & Kivelson, 1999; Kepko et al., 2001; Xing et al., 2015), and consequently coupled with Alfvén wave at high latitude that carries FAC. We would like to point out that mode conversion is only one hypothesis in explaining the Alfvénic wave, it is also possible that both the compressional mode wave and Alfvénic wave were both simultaneously excited. For example, the coupled Kelvin-Helmholtz instability can also potentially generate compressional and Alfvénic perturbations near the magnetopause (Delamere et al., 2011; Masters et al., 2009; Pu & Kivelson, 1983). The blockage of return flow at noon (described in Figure 4b) may also directly excite both compressional and Alfvénic wave. Slow mode wave itself can only modulate electron flux but do not lead to field-aligned current or parallel acceleration (Yao, Rae, et al., 2017), until it converts to Alfvénic wave (e.g., Johnson et al., 2001). It is also noteworthy that the two physical pictures in Figure 4 can be well connected to the recent progress on local time-dependent transient and turbulent magnetic field signatures (Kaminker et al., 2017; Papen & Saur, 2016).

Our main results are summarized below:

1. We show simultaneous measurements of Saturn's dynamic dayside aurora and in situ plasma perturbation in the magnetosphere.
2. We found evidence for slow mode wave and the coexisting Alfvénic wave in Saturn's magnetosphere near magnetopause.
3. We suggest that the dynamic aurora reported in this paper corresponds to a pulsating FAC that is generated by a traveling wave instead of a steady FAC forming as a standing wave.
4. We survey the Cassini UVIS database and reveal that the transient auroral intensification is a very common phenomenon (10/11 time sequences, and ∼10% of the total images) near Saturn's polar noon region.
5. We propose two potential mechanisms for the generation of the plasma waves and the consequent transient auroral intensification.

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