# Dawn auroral breakup at Saturn initiated by auroral arcs: UVIS/Cassini beginning of Grand Finale phase

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**Key Points:**

- Identification of a novel type of auroral arc at Saturn: 'azimuthally-extended polar to equator arc'
- The arc could be ionospheric signature of moving plasma flow released from tail reconnection, similar to the terrestrial auroral streamer
- Dawn auroral enhancements and poleward expansion could be initiated by the auroral arc

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## Abstract

We present Cassini auroral observations obtained on November 11, 2016 with the Ultraviolet Imaging Spectrograph at the beginning of the F-ring orbits and the Grand Finale phase of the mission. The spacecraft made a close approach to Saturn's southern pole and offered a remarkable view of the dayside and nightside aurora. With this sequence we identify, for the first time, the presence of dusk/midnight arcs which are azimuthally spread from high to low latitudes, suggesting that their source region extends from the outer to middle/inner magnetosphere. The observed arcs could be auroral manifestations of plasma flows propagating towards the planet from the magnetotail, similar to terrestrial 'auroral streamers'. During the sequence the dawn auroral region brightens and expands poleward. We suggest that the dawn auroral breakup results from a combination of plasma instability and global scale magnetic field reconfiguration, which is initiated by plasma flows propagating towards the planet. Alternatively, the dawn auroral enhancement could be triggered by tail magnetic reconnection.


## 1 Introduction

The aurora at Saturn displays several different morphologies, each of them related to different dynamical behaviours [*Grodent*, 2015] and connected to the magnetosphere by different current systems. The main auroral emission at Saturn is suggested to be related to the shear in the rotational flow which is present in the boundary between open and closed field lines [*Bunce et al.*, 2008]. Field aligned-currents, which give rise to the auroral emissions, are generated by the difference in plasma angular velocity between high-latitude open field lines that strongly sub-corotate with respect to the planet, and closed outer magnetosphere field lines at lower latitudes that near rigidly corotate. Apart from the currents related to solar wind interaction with the planet, there is also a current system related to subcorotation of the magnetospheric plasma [*Cowley et al.*, 2004], which was shown not to account for the auroral field aligned current intensities or their co-latitude location. Finally, there is another system associated with the planetary period oscillation phenomenon at Saturn [*Southwood and Kivelson*, 2007]. It is suggested that the main auroral field-aligned current system at Saturn is a combination of two systems: one rotating system associated with the planetary period oscillation system and one static related to the subcorotation of the magnetosphere near the open-closed field lines [*Hunt et al.*, 2014].

The main auroral emission is often observed to brighten in the dawn region as hot tenuous plasma carried inward in fast moving flux tubes returns from tail reconnection site to the dayside [*Clarke et al.*, 2005; *Mitchell et al.*, 2009; *Nichols et al.*, 2014; *Radioti et al.*, 2015; *Radioti et al.*, 2016; *Badman et al.*, 2016]. These fast moving flux tubes may generate intense field-aligned currents that would cause aurora to brighten [*Cowley et al.*, 2005; *Jia et al.*, 2012]. As a result the dawn sector of the main auroral emission brightens and expands poleward. *Mitchell et al.* [2009] suggested that intensifications of Saturn's dawn auroras and simultaneous enhancement of ENA emission and Saturn Kilometric Radiation (SKR) are reminiscent of the initiation of several recurrent acceleration events, related to tail reconnection events. Prior to the intensifications of dawn auroras, poleward auroral intensifications were observed in the nightside and interpreted as signatures of dipolarizations in the tail [*Jackman et al.*, 2013]. Additionally, *Radioti et al.* [2016] observed multiple small-scale auroral intensifications followed by enhanced auroral activity with irregular wave-like structure, rotating at 45% of rigid corotation. The authors related them to internally driven reconnection events operating on closed field lines, in accordance with the Vasyliunas type reconnection [*Vasyliūnas*, 1983]. Another example of auroral intensifications and poleward expansions in the dawn auroral sector was reported by *Nichols et al.* [2014]. They showed a case where the auroral emission was supercorotating at ~330% of rigid corotation and was associated with ongoing, bursty reconnection of lobe flux in the magnetotail. It was recently shown that the main dawn auroral emission at Saturn, as it rotates from midnight to dusk via noon, occasionally stagnates near noon over a couple of hours [*Radioti et al.*, 2017]. The authors discussed this behaviour in terms of local time variations of the flow shear close to noon or/and of a plasma circulation theory suggested by *Southwood and Chané* [2016].

Polar auroral arcs have been previously reported in the aurora of Saturn and related to various dynamical events. In the dayside region auroral arcs are reported to bend towards the pole (bifurcations of the main emission) and are related to dayside reconnection events [*Radioti et al.*, 2011]. Additionally, a nightside polar auroral arc [*Radioti et al.*, 2014] , which resembles a terrestrial transpolar arc [*Milan et al.*, 2005], has been observed to extend from the nightside auroral emission into the region of open flux and was related to tail reconnection.

One of the new results of this study is the report of dusk/midnight azimuthally-aligned polar arcs, with poleward edges located close to the ionospheric location of the open-closed field line boundary. Dusk/midnight polar arcs at the terrestrial aurora have been associated with moving plasma flows, often described as 'auroral streamers', that are released from tail reconnection and move towards the Earth [*Sergeev et al.*, 1996; *Nakamura et al.*, 2001; *Yao et al.*, 2017a]. The plasma bubble ejected from tail reconnection moves towards the planet along longitudinally localised regions of fast flow, usually named flow channels [*Lyons et al.*, 2013] and via field-aligned currents give rise to auroral emissions. Such auroral streamers (auroral counterpart of inward moving flow) at Earth have been argued to trigger substorm onset intensifications [*Nishimura et al.*, 2011]. Auroral streamers at Earth are usually observed prior to substorm onset, and thus suggested to play an important role in triggering a substorm onset [*Nishimura et al.*, 2011; *Yang et al.*, 2014; *Yao et al.*, 2017a]. Post-onset auroral streamers are also observed at Earth [*Cao et al.*, 2012] and a comparison between the pre and post onset streamers, revealed that the post-onset streamer is much brighter than the streamer in the growth phase. In this study we present for the first time auroral observations of dusk/midnight arcs at Saturn which are azimuthally extended from high to low latitudes. We suggest that they are inward moving flows and we relate them to the terrestrial auroral streamers. Additionally, we propose that they initiate dawn auroral intensifications and poleward enhancements at Saturn.

## 2 November 2016 auroral observations during the Cassini F-ring orbits

Ten months before the end of its mission, Cassini reduced its periapsis and came close to the 'F-ring' for 20 orbits before it begun its final series of dives between the planet and the inner edge of the rings. Here we present Cassini Ultraviolet Imaging Spectrograph (UVIS) [*Esposito et al.*, 2004] auroral observations at the beginning of the F-ring orbits and Grand Finale phase of the mission. Figure 1 shows a sequence of polar projections of Saturn's southern aurora obtained with the FUV channel of the UVIS instrument onboard Cassini on November 11, 2016 DOY 316. The spacecraft made a close approach to the planet, its altitude changing from 4.6 to 5.8 $R_S$ between the start of the first image and the end of the last one. The sub-spacecraft planetocentric latitude increased from -22° to -57° and offered a detailed view of the dayside and nightside regions of Saturn's southern pole, which allows us to investigate the evolution of localised features as well as the global auroral response. In order to construct the polar projections we consider that the auroral emission peaks at 1100 km above the surface [*Gérard et al.*, 2009]. The FUV emission displayed in the projections is restricted to 120-163 nm range, so that the contrast between the auroral signal and the dayside planetary background is maximised. Each image consist of two or three subimages, each subimage is taken over ~ 30 min and the starting time of each image is indicated on the top left of the panels. The emission brightness in kiloRayleighs (kR) of $H_2$ is indicated by the colorbar at the right of Figure 1. The polar projection procedure does not preserve photometry; therefore, the color table may only be used as a proxy for the projected emission brightness. More details in the method can be found in *Grodent et al.* [2011].

The auroral emission during this very close approach of Cassini displays several features. A polar projection of the sequence is shown in Figure 1. An emission at lower latitudes (outer emission), at 70°, is observed during the whole sequence and indicated in panel A. This outer emission is observed to corotate while remaining at the same latitude during the ~ 8 hours of the sequence. The outer emission has been suggested to be related to the inner magnetospheric region (7-10 $R_S$) and caused by pitch angle scattering of electrons into the loss cone or/and to layers of upward and downward field aligned currents [*Schippers et al.*, 2012; *Grodent*, 2015]. While the outer emission is observed to corotate, the part of the main emission in the pre-noon sector, marked as Region 2 (R2) remains stagnant close to noon, while it brightens and expands poleward with time. This behavior of the aurora has been recently discussed by *Radioti et al.* [2017] in terms of local time variations of the flow shear close to noon or/and of a plasma circulation theory [*Southwood and Chané*, 2016]. Additionally, we observe a high latitude emission in the prenoon sector from the beginning of this sequence, indicated by the yellow arrow. This feature remains at constant local time, while at the second half of the sequence as the main emission expands poleward the high-latitude feature merges with the main emission or disappears. This type of high latitude emissions has been previously discussed and related to high latitude reconnection [*Bunce et al.*, 2005; *Gérard et al.*, 2005; *Palmaerts et al.*, 2016].

In this work, we report a novel type of arc the 'dusk/midnight auroral arc' and discuss its relation to the evolution of the dawn auroral emission. In panel A (at 0642 UT) we observe two dusk/midnight arcs extending from the poleward edge of the main emission almost to the outer emission (indicated by the two red arrows). Their equatorward edge reaches ~70° and their poleward one is located at ~78°, near the region where the polar plasma sheet boundary layer is mapped to. The equatorward edge of the auroral arc would map to 15 $R_S$ and the poleward at 38 $R_S$ in the magnetosphere using a current sheet model, considering a magnetopause standoff distance of 22 $R_S$, a current sheet half thickness of 2.5 $R_S$ and the current sheet scaling laws from *Bunce et al.* [2007]. We name these auroral features 'azimuthally-extended polar to equator arcs'. Two hours later in panel B (at 0847 UT) the two arcs rotated in the corotation direction at 50% of rigid corotation speed, intensified and merged into one large and intense arc (red arrow) extending from 78° to 70°. In panel A at the beginning of the sequence there is a region devoid of emission in post midnight sector (00 - 06 LT) close to the arcs, marked as Region 1 (R1) in panel A and included in the ellipse. R1 which was empty of auroral emission started to brighten two hours later (panel B). In the last two panels the morphology of the aurora changes remarkably. In panel C (1120 UT) there is not any dusk/midnight arc which extends from high to low latitudes, instead in the midnight region we observe a longitudinal extended intense emission located between 75° and 80° of latitude (pink arrow). The emission displays an irregularly shaped structure. At the same time the dawn aurora emission is intensified and R1 cannot be distinguished from R2, as it possibly rotated and merged with R2. In panel D (at 1452 UT) the longitudinal extended emission is less intense and takes a thin regular elongated shape at the same latitude, while the dawn emission (R2) expands poleward. As mentioned in the introduction the main auroral field-aligned current system at Saturn is suggested to be a combination of a rotating system associated with the planetary period oscillation system and a static one related to the sub-corotation of the magnetosphere near the open-closed field line [*Hunt et al.*, 2014, 2016]. The elongated shape (crossing several degrees of latitude) of the azimuthally-extended polar to equator arc reported in this work, as well as its location do not suggest that it is controlled by the planetary period oscillation currents. This is based on the estimation of the direction of the maximum equatorward displacement for our observed interval following private communication with G. Provan (southern hemisphere: towards 9 LT for the first image and towards 3.5 LT for the last one; northern hemisphere: towards 2 LT for the first image and towards 8 LT for the last one), and considering the azimuthal direction of the effective dipole and according to the method described in *Badman et al.* [2012]. The azimuthal directions of the effective dipoles are taken from the empirical model by *Provan et al.* [2013]. We believe that the above description of the evolution of the auroral features is reasonable, even though it cannot be absolute, since we are not monitoring continuously the aurora but every 2-3 hours.

The observations of the azimuthally-extended polar to equator arcs in the dusk sector presented here is not a unique observation. Similar arcs in the dusk sector have been observed in previously published datasets (for example: 2008 DOY 129 in *Mitchell et al.* [2016], 2013 DOY 109 in *Radioti et al.* [2017]) however their importance was not recongnised. In the *Mitchell et al.* [2016] study an azimuthally-extended polar to equator arc is observed in the first 5 panels (from ~ 0800 to 0900 UT) of Figure 1 from midnight to early postmidnight region and is followed by dawn enhancement, as in the case reported in this work. In the work of *Radioti et al.* [2017] an azimuthally-extended polar to equator arc is observed in the first two panels (from ~ 0340 to 0430 UT) of Figure 2 at midnight. However, in that case the arc disappears without being followed by a dawn enhancement.

This dusk/midnight arc observed here should not be mistaken for the 'nightside polar arc' reported by *Radioti et al.* [2014] and suggested to be related to tail reconnection. The nightside polar arc extends into the region of open flux up to ~ 82° of latitude while keeping one end on the main emission. Its poleward part moves dawnward during the 3-hour interval. The observations here present 'polar to equator' arcs which extend from the main emission latitude to much lower latitudes (panel B, Figure 1) and within two hours of observations take an elongated shape at the same latitude (panel C and D, Figure 1).

## 3 Auroral arc and large scale changes of the dawn aurora

Here we discuss the interpretation of the two main observations of this auroral sequence: the evolution of the 'azimuthally extended polar to equator auroral arc' (referred to just 'arc' later on) in the first half of the sequence and the enhancement of the poleward expansion of the dawn aurora in the second half. The two dusk auroral arcs observed in panel A (at 0642 UT) extend from the poleward edge of the main emission to lower latitudes and their presence is followed by auroral poleward enhancements. The latitudinal extent of the arcs suggests that they are related to a magnetospheric source region spanning from the outer to middle/inner magnetosphere. In the terrestrial aurora this is a typical auroral morphology called 'auroral streamers', related to earthward moving flows that are released from tail reconnection and move towards the planet [*Sergeev et al.*, 1996; *Nakamura et al.*, 2001; *Nishimura et al.*, 2011]. We suggest that the arcs at Saturn reported here, given their latitudinal extent and local time position, are possibly auroral manifestations of planetward propagating plasma flows in the magnetotail similar to the terrestrial auroral streamers. Evidence of subcorotating planetward moving flow in the dusk-midnight sector possibly released from tail reconnection was provided by Cassini plasma observations [*Thomsen et al.*, 2013]. More specifically, in their Figure 9 they show a reconnection generated inward plasma flow with strong corotating component, which ionospheric footprint would be consistent with our polar to equator auroral arc structure. Apart from the observations, simulations have also clearly indicated sunward accelerated flows returning to the inner postmidnight magnetosphere from the tail reconnection site [*Jia et al.*, 2012]. In particularly they suggested that tenuous plasma carried inward in rapidly moving flux tubes from the tail reconnection site may generate significant disturbances in the magnetosphere and the ionosphere, especially on the dawn side, such as producing intense field-aligned currents that would be expected to cause aurora to brighten.

The asterisk on panel A and B of Figure 1 indicates the ionospheric location of the reconnection site that possibly gave rise to the inward moving plasma flow. From the reconnection site the plasma is transported towards the planet forming an azimuthally narrow flow channel. There are two possible mechanisms that could created field aligned currents related to inward moving flows. As the depleted plasma flow bursts move towards the planet, charged particles are accumulated at their flanks and they become electrically polarised [*Sergeev et al.*, 1996]. Following the polarisation, Alfvén waves are launched so that an upward field-aligned current is created at the dawnward edge in a similar way as the terrestrial current wedge [*Chen and Wolf*, 1993]. Alternatively, when the bubble moves towards the planet, field lines located closer to the planet are pushed outward out of the way of the planet, leading to a vortex flow outside the bubble. The shear created between these azimuthally narrow fast flow channels and the surrounding slower flow region results in the creation of field-aligned currents and thus auroral emission in the polar region [*Birn et al.*, 2004; *Keiling et al.*, 2009; *Yao et al.*, 2012]. The proposed scenario is illustrated in the bottom panel of Figure 2. In a similar scenario, inward moving flow bursts have been related to auroral activities also at Jupiter [*Radioti et al.*, 2010]. In the case under study, we suggest that planetward magnetic reconnection flow moves towards Saturn and interacts with the local plasma. As a result the auroral arc intensifies, indicated in panel B with the red arrow. It should be noted that the equatorial flows are strongly influenced by the planetary rotation. Thus due to radial variations of the corotation rate the shape of the 'auroral streamers' at Saturn are expected to bend toward the rotation-direction at the equator side. At Earth auroral streamers have a 'north-south aligned' shape (i.e. *Nishimura et al.* [2011]).

Apart from the morphological evolution of the arc from panel A and B, we observe additional large scale changes of the aurora in the dawn region. The enhancement, the poleward expansion of the aurora, as well as its irregular shape shown in panel C (at 1120 UT) R2 are indicative of a large-scale dynamic event. Similar enhancements and poleward expansions of the aurora, sometimes accompanied by irregular shaped structure have been reported previously in the aurora of Saturn (i.e. *Radioti et al.* [2016]; *Badman et al.* [2016]; *Nichols et al.* [2014]) and related to magnetic reconnection (solar wind or internally driven) and/or global reconfiguration events (i.e. magnetic dipolarisation). It is worth noticing that the portion of the aurora that was devoid of emission at panel A (0642 UT) R1 (ellipse), two hours later at panel B (0847 UT) slightly brightens, suggesting enhanced electron precipitation, which could imply an enhancement of a large scale field aligned current and the beginning of a global magnetic reconfiguration. The presence of the arcs is possibly related to the subsequent enhancement of the aurora, the beginning of which is observed in panel B. We suggest that, as the new plasma intrudes near the inner edge of the plasma sheet, a plasma instability might be triggered [*Pu et al.*, 1997; *Yao et al.*, 2017b], or flux is piled up in this region [*Hesse and Birn*, 1991]. This could cause an auroral brightening initially within the ionospheric footprint of this instability and thus at the equatorward edge of the arc at low latitudes (70°) as it is shown in panel B (at 0847 UT), R1. The proposed scenario is illustrated in the top panel of Figure 2. Additionally, we suggest that, as the inward moving flows (auroral arcs) interact with the ambient plasma, they cause a current redistribution dipolarization which changes the magnetic field topology and results in poleward auroral expansion, which is observed in R2 panel C (1120 UT). The term 'current redistribution dipolarization' is used to represent a global magnetic field topology change caused by large-scale magnetotail current redistribution and is recently reported for Saturn on the basis of Cassini magnetic field and electron observations [*Yao et al.*, 2017a]. As a result of the reconfiguration of the magnetic field, the ionospheric footprint of the magnetospheric source maps to higher latitudes [*Chu et al.*, 2015], which explains the contraction of the observed nightside emission in panel C and D.

While the above scenario of the poleward auroral expansion to be initiated by the auroral arc is novel at Saturn, it has been previously proposed for the terrestrial case. *Nishimura et al.* [2011] proposed for the Earth a model according to which auroral streamer (auroral counterpart of inward moving flow) initiated from Earth's poleward auroral boundary propagates equatorward and triggers a substorm expansion. The irregular shaped auroral structure of the emission, which is evident at panel C (1120 UT), is also consistent with this scenario. Wave-like irregular shaped structures are observed to be formed in the terrestrial nightside main auroral arc at the arrival of an auroral streamer [*Nishimura et al.*, 2011; *Yao et al.*, 2017b] and they are explained as a consequence of plasma instability development; for example ballooning instability [*Pu et al.*, 1997; *Saito et al.*, 2008] or cross-field current instability [*Lui et al.*, 1991; *Lui*, 2004]. It should be noted that not all auroral streamers are necessarily followed by auroral enhancements and poleward expansions, as this depends on the system's free energy [*Nishimura et al.*, 2011]. The system's free energy describes a status of ambient plasma environment prior to the flow arrival. If there is little free energy stored in this region, an interaction with flow arrival would not lead to a significant energy dissipation. Thus the auroral streamers might disappear without initiating a global auroral intensification. This is consistent with the case presented in *Radioti et al.* [2017] (2013 DOY 109) where an azimuthally-extended polar to equator arc is observed in the midnight without being followed by an auroral dawn enhancement.

Alternatively to the current redistribution (initiated by the auroral streamer) scenario, the magnetic field topology could have been triggered by magnetic reconnection which took place between panel B and C (0847 to 1120 UT) and caused the auroral brightening and poleward expansion in the second part of the sequence. Magnetic reconnection (internally or externally driven) could have begun in the dusk sector prior to the beginning of the sequence, which created the auroral streamers. The trigger of tail reconnection could have been solar wind compression [*Cowley et al.*, 2005] or internally driven processes (fast planetary rotation and internal plasma loading) [*Vasyliūnas*, 1983]. Then reconnection proceeded onto post-midnight open field lines, which have their footprints at higher latitudes and resulted in the dawn poleward expansion observed in panel C and D. Solar wind driven magnetic reconnection events have been previously suggested to result in poleward expansion of the dawn aurora and closure of flux [*Nichols et al.*, 2014; *Badman et al.*, 2016].

It should be noted that we do not have any observational evidence of what happened between panel B and C (from 0847 and 1120 UT). Therefore, both the above described scenarios are possible.

## 4 Summary and conclusions

In this work we present UVIS/Cassini auroral observations obtained on November 11, 2016 during the beginning of the F-ring orbits and the Grand Finale phase of the mission. The position of the spacecraft provided us with detailed views of the dayside and nightside southern auroral region and allowed us to relate for the first time dusk/midnight arcs to dawn auroral intensifications and poleward enhancements at Saturn. The analysis of this auroral sequence presents two major findings: i) this is the first identification of an auroral feature at Saturn that is related to the terrestrial auroral streamers , ii) we suggest for the first time at Saturn that such a feature could be the precursor to a global auroral activity. In particular, in this sequence we observe dusk/midnight auroral arcs with a large latitudinal extent, from ~70° to ~78°, suggesting that they are related to a magnetospheric source region extending from the outer to the middle/inner magnetosphere. Given their latitudinal extent and local time position we propose that the arcs are auroral signatures of planetward propagating plasma flows in the magnetotail, similar to the auroral streamers at Earth (illustration at the bottom of Figure 2). The flow as it moves towards Saturn interacts with the local plasma and results in the intensification of the arc observed in panel B (red arrow). We also report the presence of a region devoid of auroral emission in the midnight-dawn region (R1, ellipse) at the beginning of the sequence in panel A, which slightly brightens in panel B. This auroral brightening which appears initially within the ionospheric footprint of the equatorward edge of the arc at low latitudes (illustrated in Figure 2, top panel) could be initiated by the inward moving flow which triggers a plasma instability [*Pu et al.*, 1997; *Yao et al.*, 2017b] or flux is piled up in that region [*Hesse and Birn*, 1991].

We further suggest that the inward moving flows, as they interact with the ambient plasma, cause a global scale magnetic field reconfiguration (current redistribution dipolarization [*Yao et al.*, 2017a]), which changes the magnetic field topology and results in poleward auroral expansion observed in panels C and D of Figure 1. A similar scenario is reported for the terrestrial case according to which auroral streamer initiated from Earth's poleward auroral boundary propagates equatorward and triggers a substorm expansion [*Nishimura et al.*, 2011]. Additionally, irregular auroral structures, such as those observed in this sequence at panel C in Figure 1, are observed to be formed in the terrestrial aurora at the arrival of an auroral streamer (*Nishimura et al.* [2011]; *Yao et al.* [2017b]). Alternatively to the above suggested scenario of the global scale magnetic field reconfiguration initiated by the inward moving flow, the poleward auroral expansion could have been trigged by reconnection on post-midnight open field lines, which have their footprints at higher latitudes.

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**Figure 1.** A sequence of polar projections of Saturn's southern aurora obtained with the FUV channel of UVIS onboard Cassini at the beginning of the F-ring orbits and the Grand Finale phase of the mission. The first image starts at 0642 UT and the last one at 1452 UT on DOY 316, 2016. Noon is to the bottom and dusk to the right. The grid shows latitudes at intervals of 10° and meridians of 40°. The yellow dashed circle stands for the 75° latitude. The asterisk on panel A and B of indicates the ionospheric location of the reconnection site that possibly gave rise to the inward moving plasma flow. The red arrows indicate the azimuthally-extended polar to equator arc at the dusk/midnight side, one of the main focus of this paper, while the pink one the arc when it takes an elongated shape at the same latitude in panels C and D. The yellow arc indicates a high latitude dawn emission. R1 and R2 stands for region 1 and 2, respectively of the main emission in the dawn sector. The ellipse in panel A indicates a region devoid of emission. The color bar at the right gives a correspondence between the color table and the emission brightness in kiloRayleighs (kR) of $H_2$. The polar projection procedure does not preserve photometry; therefore, the color table may only be used as a proxy for the projected emission brightness.

**Figure 2.** Illustration depicting the plasma flow, released from tail reconnection, which is transported towards Saturn forming an azimuthally narrow flow channel. The shear between the fast moving flow channel and the surrounding slower flow region results in the creation of field-aligned currents and thus auroral emission in the polar region adapted from *Birn et al.* [2004]. The red line indicates the closed field line boundary in the magnetosphere. Top: zoom in the auroral region, (a) the dusk/midnight arc is the auroral counterpart of the flow burst moving towards the planet, the red line indicates the poleward boundary and the green scattered line the location of the main emission, the 'x' symbol indicates the ionospheric region where the reconnection occurred and released the flow, (b) as the new plasma intrudes near the edge of the electron plasma sheet a plasma instability or flux pile up might be triggered, which in turn causes an auroral brightening initially at the equatorward edge of the arc at low latitudes.

**figure 1.**

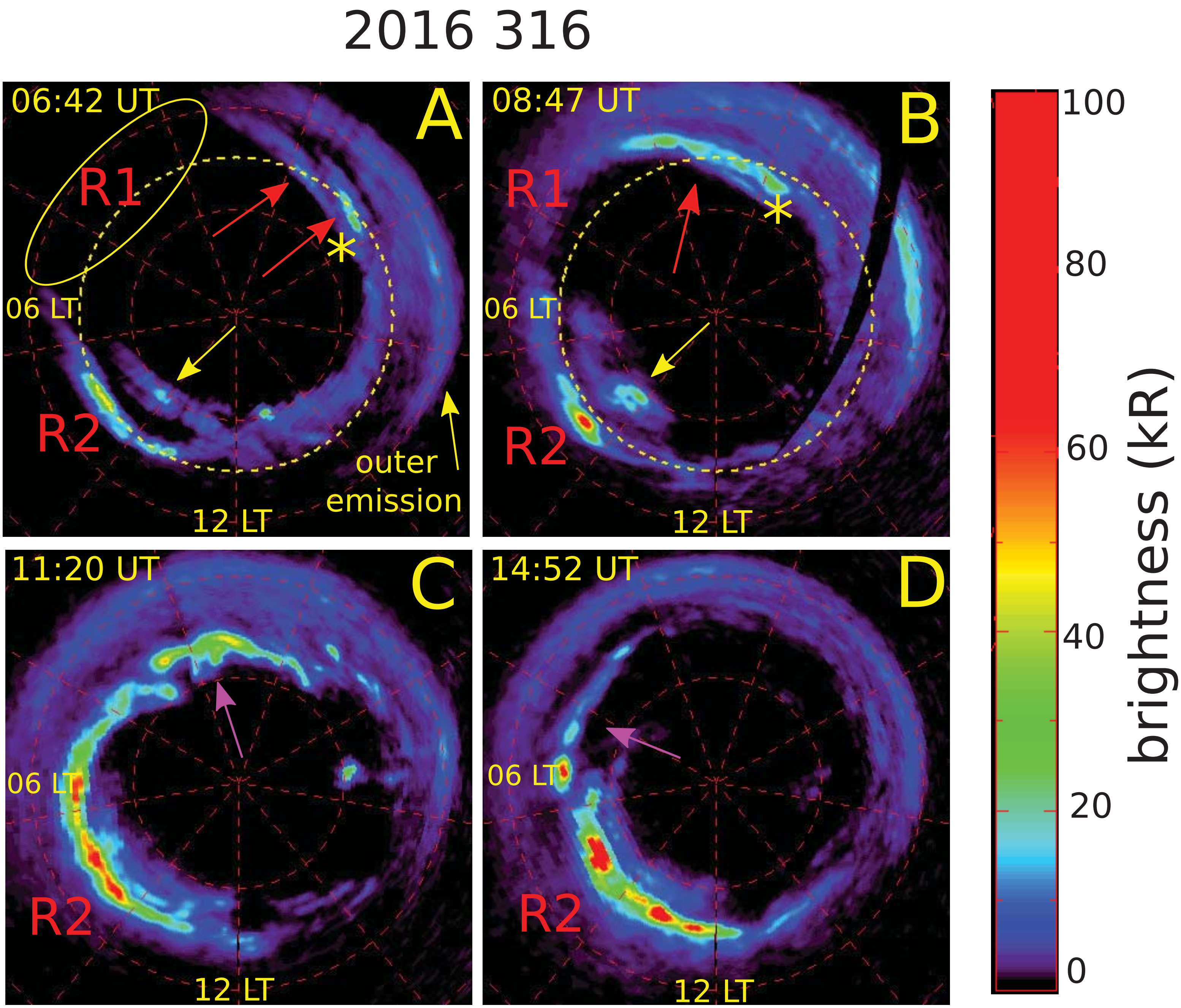
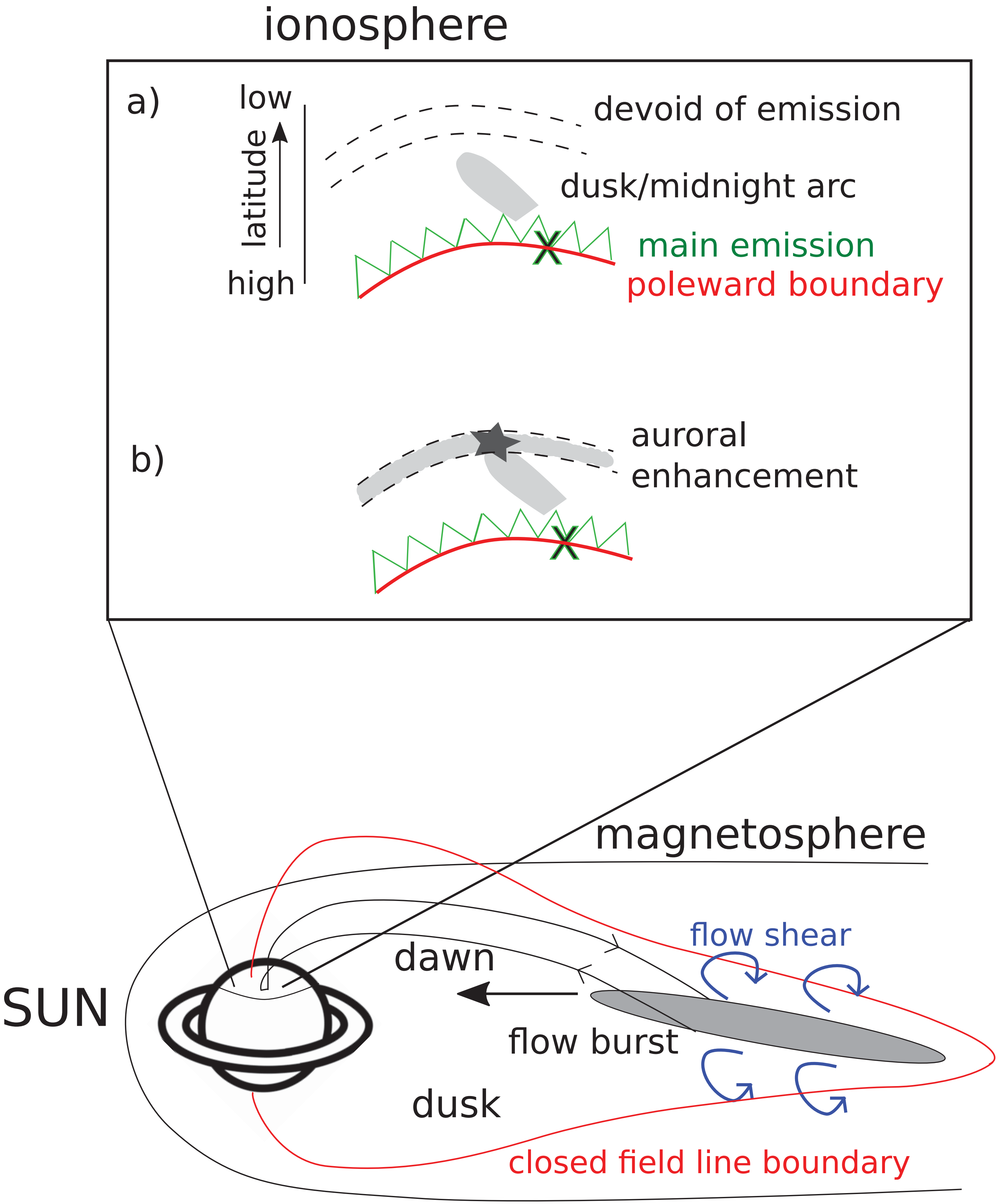

2016 316
06:42 UT
A
R1
*
06 LT
R2
outer
emission
12 LT
08:47 UT
B
R1
*
06 LT
R2
12 LT
11:20 UT
C
06 LT
R2
12 LT
14:52 UT
D
06 LT
R2
12 LT
100
80
60
40
20
0
brightness (kR)

**figure 2.**


ionosphere
a)
low
latitude
high
devoid of emission
dusk/midnight arc
main emission
poleward boundary
b)
auroral
enhancement
magnetosphere
SUN
dawn
flow shear
flow burst
dusk
closed field line boundary