Jupiter's aurora observed with HST during Juno orbits 3 to 7

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Abstract

A large set of observations of Jupiter's ultraviolet aurora was collected with the Hubble Space Telescope concurrently with the NASA-Juno mission, during an 8-month period, from 30 November 2016 to 18 July 2017. These Hubble observations cover Juno orbits 3 to 7 during which Juno in situ and remote sensing instruments, as well as other observatories, obtained a wealth of unprecedented information on Jupiter's magnetosphere and the connection with its auroral ionosphere. Jupiter's ultraviolet aurora is known to vary rapidly, with timescales ranging from seconds to one Jovian rotation. The main objective of the present study is to provide a simplified description of the global ultraviolet auroral morphology that can be used for comparison with other quantities, such as those obtained with Juno. This represents an entirely new approach from which logical connections between different morphologies may be inferred. For that purpose, we define three auroral subregions in which we evaluate the auroral emitted power as a function of time. In parallel, we define six auroral morphology families that allow us to quantify the variations of the spatial distribution of the auroral emission. These variations are associated with changes in the state of the Jovian magnetosphere, possibly influenced by Io and the Io plasma torus and by the conditions prevailing in the upstream interplanetary medium. This study shows that the auroral morphology evolved differently during the five ~2-week periods bracketing the times of Juno perijove (PJ03 to PJ07), suggesting that during these periods, the Jovian magnetosphere adopted various states.

1. Introduction

The NASA Juno spacecraft began its prime mission on 4 July 2016 when it started orbiting Jupiter on a highly elliptical 53-day polar trajectory (Bolton et al., 2017; Connerney et al., 2017). Near perijove, Juno skims above Jupiter's atmosphere at an altitude as low as 3500 km above the cloud tops, while at the most distant point of its orbit, Juno reaches distances in excess of 100 RJ (1 RJ = 1 Jupiter Radius = 71492 km). On every orbit, it rapidly passes over both polar regions at an altitude of a few Jovian radii, which is providing us with unprecedented viewing geometries of Jupiter's auroral emissions, while simultaneously measuring the particles and fields from whence the emissions originate. The HST campaign that is analyzed in the present study not only supports the Juno mission payload (particles, waves, magnetic field and remote imaging/spectroscopy) and its science goals, but it also provides crucial synergistic measurements and additional opportunities to augment the Juno mission science return relating to solar wind-magnetosphere-ionosphere coupling.

Jupiter's ultraviolet aurora comprises at least four components (e.g.: Grodent, 2015 and references there in): Galilean satellite footprints; main emission (ME); emissions equatorward of the ME; and emissions poleward of the ME. It should be noted that the poleward and equatorward (anti-poleward) directions that we are using throughout this study for both hemispheres relate to the position of the magnetic pole, which we consider to be close to the geometric center of the ME contour. All these emissions relate to specific processes taking place in Jupiter's enormous magnetosphere. Since they are all observed simultaneously with HST, they are indirectly providing a global and dynamic picture of the Jovian magnetosphere. This HST campaign completes the local in situ information captured by Juno particles and fields instruments and complements the Juno remote sensing instruments (see Bagenal et al., 2014; Bolton et al., 2017; Connerney et al., 2017 and references therein for the MAG, Waves, JADE, JEDI, JIRAM, JunoCam and MWR instruments), particularly the Ultraviolet Spectrograph (UVS, Gladstone et al., 2014).

During each Juno science orbit, UVS acquires science data for two short periods: near perijove for approximately 8 hours, and near apojove for about 1 day but with low spatial resolution. For the remaining ~51 days of the orbit, that is more than 96% of the time, UVS is not observing the Jovian aurora. Therefore, for the majority of the time there is no simultaneous ultraviolet observation of Jupiter's aurora with UVS, while other Juno in situ instruments are sampling the complex electromagnetic and particle environment to which the aurora is directly connected.

A similar HST campaign was executed in 2016 (GO-14105), at the time of orbital insertion of Juno, while its in situ instruments were measuring the conditions prevailing in the interplanetary medium. This campaign allowed HST observations of Jupiter's auroras in response to upstream solar-wind conditions, along with the first simultaneous in situ magnetic field and plasma measurements within the dawn side outer Jovian magnetosphere. The main results of this campaign were reported by Nichols et al. (2017a) and show that the interplanetary medium (IM) likely triggers magnetospheric activity and subsequent auroral displays, but in a more complex way than previously thought. This is supported by the results presented by Kimura et al. (2015), Yoshikawa et al. (2017) and Bonfond et al. (2012) that the volcanic activity on Io is likely to significantly modify Jupiter's magnetosphere and generates recurrent strong transient auroral brightenings. However, it should be noted that we are still missing a clear connection between the enhancement of the activity of some volcanoes and the mass and energy balance of Jupiter's giant magnetosphere. These external and internal drivers appear to affect the auroral morphology differently. For the IM events, like the arrival of a compression region of a corotating interaction region or a coronal mass ejection, the main emission and some features poleward of the ME are affected. For internal events related to

Io and its plasma torus, it is mainly the emissions equatorward of the ME that show significant variations.

The main scope of the present study is to provide a simplified description of the global ultraviolet auroral morphology that can be used for comparison with other quantities, especially those obtained concurrently with various instruments on board the Juno spacecraft, as well as with other space-based and Earth-based observatories. It is also meant to be used as a background, or starting point, for more detailed studies of specific auroral processes, such as the temporal behavior of some particular auroral features. We are taking advantage of the different responses of the aurora to external and internal conditions to link the morphology with the presumable state of the magnetosphere at the time of the HST observations.

In the following, we consider the HST dataset that was collected concurrently with Juno during orbits 3 to 7. Section 2 describes this dataset spanning an ~8-month period from 30 November 2016 to 18 July 2017. In section 3, in order to characterize the auroral activity, we define three subregions dividing the aurora according to its distance from the magnetic pole. The auroral emitted power is evaluated in these subregions as a function of time. In section 4, we define six morphological families that allow us to quantify the variations of the spatial distribution of the auroral emission. We relate these variations with the likely state of the Jovian magnetosphere, possibly influenced by the volcanic activity of Io and by the state of the upstream interplanetary medium. For the latter, no instrument was measuring the solar wind conditions prevailing near Jupiter at the time of the present HST observations. Therefore we can only estimate these characteristics from models propagating the solar wind measured near Earth to Jupiter, when the Sun, the Earth and Jupiter are almost on the same line (e.g. Tao et al., 2005). The evolution of these auroral markers are then discussed in section 5 for each individual Juno orbit, from 3 to 7, with special focus on the 2-week period bracketing the times of perijove referred to as PJ03 to PJ07.

2. Observations

All observations were obtained within the frame of HST program GO-14634. This large HST program takes advantage of the unique capabilities of the Space Telescope Imaging Spectrograph (STIS) UV camera, which provides a plate scale of 0.024 arsec^2 over a ~25x25 arsec^2 field of view. All observations shown here were made through the FUV-MAMA (Multi-Anode Microchannel Array) channel in time-tagged imaging mode with the F25SRF2 filter (~130-182.5 nm), which is used to prevent Ly-α contamination by geocoronal emission when HST is not in full occultation, and to reduce the amount of sunlight reflected by the Jovian planetary disk. Jupiter was positioned such that only the auroral region and a small portion of the Jovian disc illuminate the field of view of STIS. This ensures that the count rate always remains well below the bright-object limit. We obtained time-tagged exposures entirely filling the available HST orbital visibility period (~41 min), from which images integrated over smaller intervals (e.g. 10-100 s) are extracted to produce high-resolution movies of the Jovian auroral activity. For Jupiter, a time interval of 10 sec is usually the shortest time globally providing sufficient contrast between the auroral signal and the planetary disk background. A 100 sec interval increases the contrast for faint auroral structures but at the expense of temporal resolution. As a result, a 100 sec interval is preferred to produce small size preview movies and still images. All images are calibrated and corrected for instrumental effects and background emissions, including planetary disk, by using the procedure described by Bonfond et al. (2011) and conversion factors provided by Gustin et al. (2012).

HST program GO-14634 is allocated 151 orbits, each of which usually consists of one visit. Some of these orbits are used to obtain spectrally resolved pseudo-images of Jupiter's aurora, while others are designed to observe atmospheric emissions of Jupiter's moons Io, Ganymede and Europa. The spectral observations are not included in the present study and will be presented elsewhere. About

3/4 of this HST program was dedicated to Juno orbits 3 to 7 and comprises the 118 visits reported here. The detailed characteristics of these visits are listed in Table 1 and in its more detailed version (Table S1 in the supporting information section). For the sake of clarity, each visit is assigned an index corresponding to the 3 middle characters of the official HST archive root name (for example, index « k01 » for root name « od8**k01**r0q »). We note that these indices are not necessarily attributed in alphabetical order.

The present dataset covers approximately 8 months, spanning the 2016-2017 visibility period of Jupiter from HST. For the sake of time consistency, we subtracted 366 days to the "day of year 2017" (DOY) of data obtained in 2016, giving rise to negative DOY values in 2016. The first observation took place soon after HST's solar-avoidance period, during which the Sun is within 50° of Jupiter, on DOY -30, eleven days before perijove 3 (DOY -19). The last observation was obtained before HST's next solar avoidance, on DOY 199, one week after perijove 7 (DOY 192), when Jupiter was close to the opposite quadrature. Several observations were obtained close to Jupiter's opposition (DOY 97), near perijove 5 (DOY 86), when Jupiter was closest to Earth and STIS spatial resolution was highest (~80 km per pixel).

3. Auroral Power and Subregions

One of the most important characteristics of the aurora is its brightness. In the case of the UV aurora, the energy radiated by the auroral region is proportional to the energy that the atmosphere receives from charged particles, mainly electrons with energy exceeding 10 eV, impinging the top of Jupiter's atmosphere (e.g. Grodent et al., 2001). Therefore, there is a complex connection between the auroral brightness and magnetospheric processes that energize these incoming particles. The auroral brightness is highly dynamic, in both space and time. Brightness variations of several orders of magnitude are the norm for the Earth, but especially so for Jupiter's aurora, which fills a volume corresponding to several tens of times the volume of Earth, assuming the vertical extent of Jupiter's auroral emission covers at least 1000 km. Accordingly, it would be inappropriate to characterize the whole auroral region with one single brightness value representative of a particular region of the aurora, that also depends on the viewing geometry, especially near the planetary limb (e.g. Gustin et al., 2016). This was dramatically illustrated during the previous HST program (Nichols et al., 2017a) in which images with strikingly different morphology exhibited similar total power values. For these reasons, we prefer to consider the auroral power emitted in each hemisphere, which informs us of the amount of energy received from the magnetosphere at a given time. In parallel, we define six typical auroral morphological families (section 4) allowing us to characterize the overall distribution of brightness with one single descriptor. The emitted power is plotted in the different panels of **Figure 1** and is discussed in section 3.5.

We also define three auroral subregions containing emission features of similar type and presumably sharing common magnetospheric origins. In the present analysis, there is no point in considering a larger number of smaller subregions, for instance isolating the footprint of one particular satellite, since we aim to understand the global picture. (1) *The main emission* (ME) is often referred to as the main oval, even though it never really forms a complete oval, especially in the northern hemisphere. (2) The *poleward region*, also known as the polar region, is bounded by the poleward boundary of the main emission. (3) The *equatorward region* is defined by the equatorward boundary of the main emission and the auroral footpath of Io, inclusive. They are named after their location in the ionosphere relative to the ME and they are magnetically connected to different regions of the magnetosphere (e.g.: Khurana et al., 2004), the usual names of which are inverted with regard to that of the subregions: the poleward subregion corresponds to the outer magnetosphere, the equatorward subregion corresponds to the inner magnetosphere and the ME subregion corresponds to the middle magnetosphere.

These three subregions are illustrated in **Figure 2** for the northern hemisphere; another set of subregions is defined for the southern hemisphere in the same way. They form three contiguous surfaces on Jupiter's ellipsoid, approximately centered on the geometrical center of the main emission. The color code used in Figure 2 is the same as for Figure 1 (and Figures S1.1, S1.3 - S1.7), with the equatorward emission in yellow, the ME in red and the poleward region in green. The addition of these three regions encompasses the majority of the auroral emission in each hemisphere and is used to determine the total emitted power.

We set the width of the main emission ribbon, the 2D contour on Jupiter's surface roughly containing the main emission, to 3,000 km (~2.5° on the surface of Jupiter) to make sure that the region encompasses the majority of the emission associated with the main aurora, while at the same time avoiding contamination by other types of emissions, that are ideally fully represented within the other subregions. This width is 5 to 10 times the typical width of the dawn-side arc forming the main emission. The efficiency of the subregion slicing largely depends on the quality of the definition of the contour best fitting the main emission. Since the location of the main aurora may significantly change over a Jovian rotation, each visit is considered separately and we define a separate set of subregions for each observation. This approach is simpler than the method used by Nichols et al. (2017a) who further discriminate portions of these regions according to local time.

The ME contour was also used to estimate the size of the aurora by assuming that it is reasonably represented by the area on the Jovian surface limited by the contour.

Since Jupiter's magnetic axis is tilted by only ~10° with respect to the spin axis, Earth-orbiting observatories can only capture one portion of Jupiter's aurora at the time. Therefore, we follow the methodology described by Bonfond et al. (2015) in which the closure of the contour is achieved with a Fourier series. This effect was also accounted for in **Figure 1** and **Table 1**, where the emitted power is corrected for the viewing geometry by a time-dependent factor equal to the ratio between the total area of the subregion of interest and the area of its portion visible from Earth (Nichols et al., 2009a).

3.1. Uncertainties on the emitted power

The intrinsic variability of the auroral emission power is well illustrated in **Figure 1** by the vertical distribution of the data points over one HST visit (~41 min). During this time the subregion or total power may change by as much as 1/3. This level of variation is comparable to the estimated uncertainty on the emitted power, which is mainly influenced by three processes: the background subtraction, the conversion from STIS counts per second to emitted power, and the correction for the viewing geometry. The background subtraction procedure described by Bonfond et al. (2011) is based on the generation of a model planetary disk simulating the reflected sunlight. A conservative uncertainty of 25% on this simulation gives rise to ~6% inaccuracy on the auroral power. This inaccuracy is systematic and remains constant over an HST visit. Therefore, it is not affecting the relative variability of the emission. The conversion factor from STIS counts to emitted power depends on the emission spectrum passing through STIS + F25SRF2 filter optical assembly. It is affected by the amount of methane absorption, related to the energy of the impinging electrons through the H_2 UV color ratio described by Gustin et al. (2012). In the present study, we have assumed a constant color ratio of 2.5, while, following Gérard et al. (2014) and Bonfond et al. (2017b), this color ratio is found to vary significantly with space and time. We note that a color ratio of 1.5, corresponding to a weak level of absorption would decrease the conversion factor by 7% and a color ratio of 5, corresponding to a relatively strong absorption by methane, would increase the factor by about the same amount. Finally, as a result of the viewing geometry from Earth orbit, we usually capture around 2/3 of the auroral region. This is corrected by a geometry factor assuming that the average emission brightness in the hidden part of the auroral subregions, defined above, equals the average brightness measured in the visible portion of the corresponding subregions. The uncertainty brought by this correction may be estimated by assuming that the power emitted by the 1/3 of the aurora that is not visible to HST is affected by a variability of 33%, like the rest of the emission, leading to an imprecision of ~10%. Like the background disk subtraction, this uncertainty is rather systematic and does not alter the intrinsic variability of the auroral emission over one HST visit. The total (quadratic) uncertainty is thus on the order of 14%, smaller than the intrinsic auroral variability. The measured variability of the emission during one HST visit is thus real and the dispersion of the data points over one visit in **Figure 1** is, in most cases, a relatively good indicator of the inaccuracy on the inferred auroral emission power.

3.2. The ME subregion

The ME subregion contains the emission likely associated with the process of corotation breakdown in the middle magnetosphere (e.g.: Hill, 2001; Cowley and Bunce, 2001). It is tightly linked to the magnetic field topology and the subregion remains fixed in the System 3 (S3) frame of reference, rotating with it. It should be noted that while the bulk of the auroral emission and therefore the subregions, are fixed in S3, the emission inside these subregions may not be strictly corotating with the planet and display local time morphological variations giving rise to redistribution of the emission along the subregions (Grodent et al., 2003a, 2003b). Bonfond et al. (2015) showed that, statistically, the ME is brighter on the duskside than on the dawnside. As already suggested above, this emission does not form a continuous ribbon of emission but rather an assemblage of extended features influenced by the position of the Sun. On the dawn side, these features usually form a well-defined main emission often taking the form of a narrow arc. In the pre-noon sector, the brightness rapidly drops, giving rise to a discontinuity (Radioti et al., 2008; Chané et al., 2013), often followed by a brighter spot (Palmaerts et al., 2014; Nichols et al., 2017b). In the afternoon sector of the northern hemisphere, the ME takes a more dynamic form, presumably influenced by the presence of a potential high-latitude magnetic anomaly (Grodent et al., 2008; K. Moore et al., 2017) acting like a magnifying glass and revealing the intricate morphology of the ME. This anomaly is fixed in S3 but for observations from Earth orbit, the viewing geometry is such that it appears in the afternoon sector. In the southern hemisphere, it is likely that no such anomaly exists and the ME consists of more regular arc-like features. We emphasize that the magnetic field of Jupiter is far from symmetric and N-S auroral asymmetries have been reported by Gérard et al. (2016). It is in this anomaly sector that the ME is more likely to be contaminated by, or to contaminate the features of the other subregions. The ME emission is usually stable in time, at least for the duration of an HST visit, but at times, strong brightenings of the dawn side ME, often referred to as dawn storms (Clarke et al., 1998; Gustin et al., 2006), occur with shorter timescales. The ME power is plotted in **Figure 1** and discussed in section 3.5, along with the other subregions. According to the different studies of Nichols et al. (2007, 2009a, 2017a), it is expected that the ME subregion power is measurably sensitive to the conditions in the interplanetary medium. Specifically, the power of the dawn sector of the ME was shown to increase significantly following compression region onset. According to the three-dimensional one-fluid MHD global simulations of Chané et al. (2017), such an enhancement of the dawn emission during the solar wind compression could be a result of larger magnetic stresses exerted on the magnetosphere caused by increased solar wind ram pressure.

3.3. The poleward subregion

The poleward subregion contains the most variable components of the Jovian aurora (Grodent et al., 2003b). Their poleward location suggests that they are associated with the outer magnetosphere, extending to the magnetopause, and possibly with open magnetic field lines (Vogt et al., 2015), although it is still unclear how the solar wind exchanges momentum and energy with Jupiter's magnetosphere (Delamere et al., 2014, 2015). Grodent et al. (2003b) divided this subregion into three smaller regions (dark, swirl and active) characterized by different auroral dynamical behaviors and the boundaries of which are affected by the sub-solar longitude. In that regard, Nichols et al. (2017a) recently refined the selection with the dusk and noon active regions (DAR, NAR, respectively). Bonfond et al. (2016) performed a detailed analysis of the active region and reported quasi-periodic brightness variations on a 2-minute timescale as well as propagation of fast wave-like auroral features, the origin of which is still uncertain. The poleward subregion also contains a recurrent polar auroral filament (PAF, Nichols et al., 2009b), which is superficially similar to terrestrial transpolar auroral arc (or "theta" aurora). At Earth, their generation is usually associated with magnetic reconnection process (e.g. Fear et al. 2014). Nichols et al. (2017a) suggested that the dusk active region (DAR) is affected by the IM activity, with significantly enhanced and pulsing emission features, arcs and patches, which affects the power in the poleward region accordingly. Since in the present study we are interested in the global auroral morphology, we do not address the details of the very complex ingredients that are filling the poleward subregion. Instead, we focus on the longer-timescale power variations.

3.4. The equatorward subregion

The equatorward subregion contains the rest of the auroral emission bounded by and including the auroral footpath of Io. This includes the satellite footprints and their different components (Bonfond et al., 2017a), the diffuse secondary emission (Radioti et al., 2009; Gray et al., 2017) and the auroral signatures of magnetospheric plasma injection (Dumont et al., 2014; Gray et al., 2016, Bonfond, 2012, Kimura, 2015). It is therefore likely that the equatorward subregion corresponds to the dynamics from the inner to middle magnetosphere. Very often, these three types of equatorward auroral features mix together, which raise difficulties in discriminating them. This is particularly unfortunate for the studies of the weak footprints of Ganymede and Europa, whose signatures are often drowned out by the secondary emission and/or the injection signatures. In addition, Bonfond et al. (2012) showed that under some conditions, the main emission may move equatorward of the footprint of Ganymede, the latter thus contributing to the ME subregion. However, the total power emitted by the satellite footprints is small in comparison with the other components, and such change would remain unnoticed in **Figure 1**. This is also true for the short quasi-periodic variations of the satellite footprint. In general, the substantial enhancements of the equatorward subregion power may be attributed to the injections. Bonfond et al. (2012) and Yoshikawa et al. (2017) suggested that there is an indirect link between the volcanic activity of Io and the occurrence rate of such large injection signatures, where an enhanced volcanic activity would be associated with an increased plasma loading of the middle magnetosphere which in turn favors flux tube interchange and increases the rate of injection of sparse hot plasma in the inner-middle magnetosphere.

3.5. Power variations during the campaign

Several pieces of information may be drawn from the busy light curves displayed in the upper left panel of **Figure 1**. First, no clear long-term trend emerges from this plot. The corrected total power (solid black line for the north, dashed black line for the south) usually varies by a factor of 3 and remains between ~1 and 3 TW in each hemisphere, with the exception of two rare events on DOY

109.806 (visit k81) near apojove 5, observed in the northern hemisphere, and DOY 139.478 (visit k06) near perijove 6, in the southern hemisphere. During these events, the total power reached extreme values in excess of 3.5 TW (see also power values in Table S1 in the supporting information). In both cases, the large emission power resulted from an episode of very strong injection signatures within the equatorward subregion (yellow line, solid for the north, dashed for the south in **Figure 1**) combined with enhanced emissions in the ME subregion (red line, solid for the north, dashed for the south). In both cases, the poleward subregion was not particularly bright (solid and dashed green lines), suggesting that the aurora in the poleward subregion is disconnected from the other components. In general, the contribution from the three subregions (i.e. ME, poleward, equatorward) to the total power is on the same order of magnitude, and as a rule of thumb, it may be stated that during unperturbed periods, each subregion approximately contributes one third of the total power. This rule breaks down during extreme events such as during visit k06, described above, where the distribution was 15% (poleward), 30% (ME), 55% (equatorward). Within one visit (~41 min.) the power changes very rapidly, by amounts of a few 100s GW over ~100 sec., up to 500 GW during events characterized by enhanced contribution from the poleward subregion, which contains the most variable auroral features (Bonfond et al., 2016).

Interestingly, variations of the area of the surface subtended by the main emission contour (upper blue lines in Figure 1, dotted in the north, dashed in the south) is anti-correlated with variations of the total power, suggesting that stronger power is associated with smaller auroral region (Nichols et al., 2009a; Badman et al., 2016). The linear correlation coefficient is -0.36 in the northern hemisphere and -0.33 in the southern hemisphere, corresponding to moderate anti-correlations.

Comparison of the total power in the northern and southern hemispheres, when we captured both close in time, that is for the 8 pairs of visits taken less than 5 hours apart, shows no clear systematic trend, which is partly expected from the very large variability of the aurora. However, we note that the power in the poleward subregion is systematically smaller in the south than in the north, with south-north power ratios ranging from 0.28 to 0.83, even for the cases where the ratio is reversed for the other subregions (south more powerful than north). At present, this discrepancy remains unexplained.

In the following, we introduce the typical auroral morphologies that have been recorded during this first part of the HST-Juno campaign.

4. Typical Morphologies and auroral families

The bulk morphology of Jupiter's UV aurora is known to change rapidly, usually within one Jovian rotation and sometimes during a period of time as short as a few hours. In addition, the features of smaller scale structures such as the satellite footprints or isolated auroral patches within the polar region can also display substantial variations on the minute or even shorter timescales.

As a result, it would be deceptive to select an image that is fully representative of a whole Juno orbit (53 days), a particular day, or even of a perijove sequence (~6 hours). Instead, we selected one visit for each Juno orbit, in the northern hemisphere, for a CML close to 143 degrees S3, which is offering a relatively complete view of the various auroral components. The choice of CML was dictated by two criteria. First: the availability of an HST visit at that particular CML +/- 3 degrees, in order to compare auroral morphologies captured with almost exactly the same viewing geometry. Second: the variety of morphologies, in order to display an indicative sample of typical morphologies.

Figure 3 shows six sample frames displayed with the same logarithmic color table so that they may be directly compared with each other. The six selected visits all show the same basic auroral ingredients, but with different proportions. In some cases, these differences may be dramatic and sudden, suggesting that the magnetosphere and the coupled ionosphere are regularly undergoing large-scale changes. The complexity of the auroral morphology is such that no two observations are alike and they seem to display an ever-changing auroral landscape. Still, in this apparent chaos some recurrent patterns emerge and these selected morphologies allow us to define six auroral ''families''. However, we note that the discrimination between these families carries some elements of subjectivity and in some cases, the observed morphology may fit several families or eventually none. As discussed below, each auroral family (Q, U, N, i, I, X) may tentatively be related to a certain state of the magnetosphere, which itself is influenced by internal and external drivers, such as the amount of plasma transport from the Io torus or the local dynamic pressure of the interplanetary medium, respectively. These family name codes are used in **Table 1** (and Table S1). With the light curves displayed in **Figure 1**, they allow one to easily trace the evolution of the auroral morphology during the period covered by this HST campaign. Again, since most of the data were collected during ~one-week periods centered on the times of Juno perijove, and considering the important variability of the aurora, the morphological tracing is obviously limited to these periods. Similar families were defined for the southern hemisphere, for which the viewing geometry is usually less favorable than for the northern hemisphere. Accordingly, categorization in southern families is less reliable, although images taken close in time in both hemispheres turn out to belong to the same family. The following paragraphs describe the main characteristics of each family, based on a sample of data in the northern hemisphere. These characteristics are also conveniently summarized in Table 2.

4.1. The Q (''Quiet'') family

The Q family example displayed in upper left panel **of Figure 3** appeared in visit k18 (**Table 1**), on 12/12/2016 (DOY -018), about one day after perijove 3. The main characteristic of this morphology is the very low emission power (total less than 1 TW) of most auroral components, especially those filling the ME and equatorward subregions. Comparison with the upper middle panel reveals that in this case, even the auroral footprint of Io is dimmer. The main emission is barely visible (marked "1" in Figure 3) so that the ME is not well defined. In particular, there is no apparent arc feature on the dawn side of the main emission, but a rather diffuse and wide ribbon of emission. As a result, the faint ME discontinuity can hardly be discriminated, although we observe the expected continuous dimming of the emission from dawn to noon. The ME contour is particularly extended, as indicated by the peaking value of the area of the surface it subtends (blue top curves in **Figure 1**). We note that, although the power in the poleward subregion is also very low, the associated time tagged movie shows that there is still a lot of polar activity with successive spot flashings and wave-like propagating features. As expected, the main contribution to the total power is coming from the poleward and equatorward subregions. However, the power in the equatorward subregion remains small, compared to other visits, suggesting that there is no ongoing large-scale injection. Overall, the low power and the absence of a sharp dawn ME suggest that a large portion of the magnetosphere was likely in an undisturbed state (see discussion in section 5.4 and correlation of such morphology with observed low upstream solar wind activity by Nichols et al., 2017a), presumably with very little plasma to bring back to corotation. This family occurs about 11% (13 out of 118) of the HST visits and spreads over all Juno orbits.

4.2. The U (''Unsettled'') family

The U family is illustrated with case k0k in upper middle panel of **Figure 3**, on 05/26/2017 (DOY 146), one week after perijove PJ06. It is intermediate between the Q and N families as the dawn ME sector emission is relatively wide and faint. On the contrary, in the afternoon sector the ME is usually brighter and narrower. The equatorward emission is also faint, sometimes forming a distinct secondary emission, parallel and equatorward of the ME. According to Radioti et al. (2009), this secondary emission (SE) is not necessarily associated with signatures of plasma injections, but could be caused by a dipolarization of the magnetic field beyond the orbit of Europa, creating the conditions for producing whistler-mode waves that are able to scatter the plasma sheet electrons in the loss cone and produce aurora. The poleward subregion aurora is similar to what is observed for the N family, suggesting that, apart from the X family, this subregion behaves independently from the rest of the emission. The U family has a frequency of 14.5%, comparable to Q and I. Like the Q family the ME contour of the U family is extending more equatorward and subtends a rather large surface, which, according to Nichols et al. (2017a), may be associated with a rarefaction region in the IM.

4.3. The N (''Narrow'') family

The N family example displayed in the upper right panel of **Figure 3** corresponds to visit k39, obtained on 02/01/2017 (DOY 032), one day before perijove PJ04. The total power is also relatively low, but in this case the morphology is characterized by a very narrow dawn side ME arc (marked "2" in Figure 3) with a width (Gaussian fit FWHM) on the order of 200-300 km, very close to STIS' Point Spread Function. The rest of the main emission also consists of relatively narrow arcs, giving rise to a quasi-continuous ME. Brightness values along the ME are average, leading to a sharp discontinuity in the 10:00-12:00 LT sector. The activity in the poleward subregion is somewhat similar to that observed for the Q family, but the power increases proportionally with the ME subregion power. The power in the equatorward subregion is relatively low as it mainly contains faint auroral signatures of injections, possibly remnants of previous stronger emissions. Most N family members show an expanded main emission. 29.5% of the visits match this family, making it the most frequent one. Like Q family, the N family may also correspond to a quiet magnetosphere but with a slow mass loading increase that may lead to the need for moderate plasma acceleration and a corresponding slight enhancement of the field aligned currents related to the ME aurora through the process of corotation enforcement.

4.4. The I (''strong Injections'') family

The lower left panel of **Figure 3** shows an example of the ''strong Injections'' family, or I family, with k88, obtained on 05/16/2017 (DOY 136), three days before perijove PJ06. The unmistakable characteristic of the members of this family is the very strong enhancement of the emission near longitude 150° S3, equatorward of the ME (marked "3" in Figure 3) and associated with the dynamics in the inner magnetosphere, which is likely associated with magnetospheric plasma injections and is worth a more detailed description. These emissions are the main contributor to the equatorward subregion, the power of which can easily surpass the power in other subregions. Hence, the most noticeable feature of this enhancement is its non-uniform meridional distribution, which contrasts with the statistical analysis of Dumont et al. (2014) who show that this emission is, on average, evenly distributed in longitude and does not show preferential local time. For the I family, the emission often forms a recurrent pattern (mostly in the northern hemisphere) with an accumulation in the 140-170° S3 region, resulting in a low latitude corner shaped feature ("3" in Figure 3) contrasting with the rest of the emission. This morphology may therefore be only associated with the few episodes of very strong plasma injection. We note that in the southern hemisphere, this region is located at lower S3 longitudes ranging from 40 to 100°. This emission is almost fixed in S3, with a very slight drift in longitude and latitude. Within this structure, there are sharp brightness discontinuities and the brightness itself is either increasing or decreasing with time, with different time scales for different sub-structures. A second characteristic of the I family is the broken appearance of the ME and the presence of localized, short-lived (less than a Jovian rotation) dawn brightenings (marked "4" in Figure 3), sometimes very strong. The latter have often been referred to as "dawn storms", although there is still no clear definition of these recurrent features. In the present family, these slightly sub-corotating brightenings are found on the ME. Yao et al. (2017) suggested that similar auroral features observed at Saturn are consistent with a process of internally driven corotating reconnection. On the afternoon side, contrary to the X family, the ME is not particularly well defined. In some cases, it is even totally absent.

This family is reminiscent of the sudden auroral brightenings discussed by Kimura et al. (2015) and of the morphology discussed by Bonfond et al. (2012), Badman et al. (2014), Gray et al. (2016) and Nichols et al. (2009a), suggesting that it is rather common, as confirmed by the measured frequency of 18%. This is compatible with Kimura et al. (2015), who derived a frequency of one such event every 4.7 days. In the present sample, the poleward subregion of the I family is not particularly bright or dim, suggesting that the poleward and equatorward subregions are disconnected. Kimura et al. (2015) showed that these strong equatorward subregion emissions may occur during periods of quiet solar-wind activity. Bonfond et al. (2012) tentatively associated periods of repeated strong equatorward emission events every few days over periods of several weeks. Using Hisaki observations, Yoshikawa et al. 2017 showed that the brightness of short lived events (~10h) associated with equatorward emissions increased ~2 weeks after the beginning of an intense volcanic event on Io. Such enhancements probably result from the progressive ionization of Iogenic volcanic material, which increased the amount of outward moving heavy flux tubes that must be replaced by hot plasma, therefore increasing the occurrence rate of large features associated with bright injection signatures. During its first perijove sequence, Juno UV observations showed the progressive development of intense equatorward emissions possibly associated with injections, followed by the emergence of a protrusion inside the main emission possibly related with internal reconnection in the tail (Bonfond et al. 2017b). Yoshikawa et al. (2017) and Bonfond et al. (2017b) thus suggest that injections of hot plasma precede internally driven reconnection events.

4.5. The i (''moderate injections'') family

The i family is represented in lower middle panel of **Figure 3** with k1g, captured on 07/16/2017 (DOY 197), five days after perijove PJ07. The morphology resembles that of family I. The major difference stems from the lower brightness of the equatorward subregion features ("5" in Figure 3) and the absence of equatorward ME brightenings, resulting in narrow dawn ME arcs ("6" in Figure 3), often bright, somewhat similar to what was observed in the X family. It is likely that the i family represents a later or earlier stage of the I family, where the signatures of plasma injections continuously increased then decreased, down to the point where the power in the equatorward subregion may be smaller than in the other subregions. Like in the I family, the afternoon side ME is not well defined and sometimes absent. The power in the poleward subregion is equivalent to that in the I family, with occasional very strong brightenings in the afternoon sector of the polar region. 18.5% of the present sample fit in the i family. Put together with the I family, these injection cases represent more than 1/3 of the dataset.

4.6. The X (''eXternal perturbation'') family

A member of the X family is shown in lower right panel **of Figure 3**. Visit k57 was taken on 03/19/2017 (DOY 78), more than a week before perijove PJ05. This family is distinguishable mostly for its very strong dawn-side main emission (marked "7" in Figure 3), which forms a very bright and narrow arc that has a sharp boundary with the discontinuity region, near 10:00 LT. In this regard, in case of a compressed magnetosphere, the MHD model of Chané et al. (2017) generates larger magnetic stresses and associated modified field-aligned electric currents, which are consistent with a more pronounced discontinuity. In more than half of the cases, the afternoon side of the ME is also bright and narrow, leading to a strong ME. As a result, the power in the ME subregion is usually the largest contributor to the total emitted power. However, in more than 70% of the cases the poleward subregion is also filled with bright polar emissions, mainly on the dusk side, corresponding to features marked "8" and "9" in Figure 3, suggesting a possible connection between the brightenings in these two subregions. Nichols et al. (2017a) suggested that such brightening of the ME and dusk side polar region is a response to an external perturbation taking the form of a compression region in the interplanetary medium (IM), but the physical mechanism remains poorly understood. The typical auroral morphology observed during these periods also comprises "bright, strongly pulsing patches or arcs parallel" to the main emission in the dusk sector of the poleward subregion (the DAR region defined by Nichols et al., 2017a). We note that the majority of the X family members also exhibit this typical auroral feature. Therefore, we suggest that the X family is representative of Jovian auroral response to enhanced IM activity. On the contrary, the equatorward subregion power is low compared to the other two regions, indicating that it is probably independent from the IM activity, as expected from an internal origin, indicating that the stress exerted by the IM activity acts less in the inner magnetosphere. The frequency of the X family is 8.5%, close to that of the Q family, suggesting that they are both rather exceptional conditions.

A few visits defy any categorization. For three of them (k46, k49, k93) the poor viewing geometry prevents us from seeing enough auroral features to select a family. In the case of k24, the diffuse morphology approximately fits the Q family, but the total emitted power is large (a factor of ~2) compared to the rest of the family. Those visits were not included in this analysis.

5. Discussion on the evolution of the auroral morphology and power

A graphical representation of the evolution of the auroral morphology over Juno orbits 3 to 7 is given in **Figure 4** (see also individual parameters in **Table 1** and characteristics in **Table 2**, and enlarged versions of Figure 4 panels in the supporting information). Each family was assigned a qualitative index: Q=1; U=2; N=3; i=4; I=5; X=6. This index somewhat reflects the typical power level measured in the families and is also such that the indexes of related families, like i and I, differ by 1 unit and very different morphologies, like X and Q, have very different values. This qualitative index allows us to provide a graphical representation of the importance of the morphological changes of the aurora with time. Morphologies observed in the north are marked with a diamond and those observed in the south are marked with a star. Interestingly, some trends emerge from this plot as the typical morphologies observed around the times of perijove 3 to 7 change noticeably. These differences presumably stem from global variations of the internal (Iogenic) and external (IM) conditions, so that the present HST dataset indeed provides one with a global auroral context during this 8-month period, from which the magnetospheric backdrop may be inferred.

5.1. Juno orbit 3

During the 2-week period including perijove PJ03 (DOY = -19.26), the auroral morphology rapidly and repeatedly changed from the extreme X to Q families, through all other families (**Figure 4** and S4.3). Very close to perijove, the X auroral morphology was typical of a magnetosphere perturbed by an IM compression, while the day after the aurora had dropped to the opposite Q morphology, presumably corresponding to an unperturbed magnetosphere and stayed in that state for a day or two, followed by a new episode of strong injections. During the week that preceded PJ03, the magnetosphere might have encountered more than one IM compression regions and saw several episodes of strong injections, both of which contributed to a rapidly changing morphology. These morphological changes have an impact on the emitted power, as shown in **Figure 1** (and S1.3). During the same period, the total emitted power varied by a factor of ~3 from 0.7 TW to 2.4 TW. The largest power was emitted during the week preceding PJ03, when the very strong emissions in the equatorward subregion combined with the enhancement of the ME subregion. The smallest power was observed for the Q family members. Near the time of perijove, the total power peaked to 1.36 TW and rapidly dropped to its minimum at 0.7 TW, which is also the smallest value measured during the period covered by this study. It is interesting to note that the power emitted in the poleward subregion followed the same trend as in the ME subregion. This is surprising since these two subregions are presumably mapping to very different regions of the magnetosphere and, so far, were expected to behave independently. We cannot ignore the possibility that there is some level of contamination near the boundaries between the three subregions, but this contamination does not give rise to the systematic effects observed throughout the period displayed in **Figure 1**.

5.2. Juno orbit 4

As suggested in the previous **section**, the global auroral morphology observed during the 2 to 3-week period around PJ04 (DOY 33.57) is different from PJ03. **Figure 4** (and S4.4) shows that for at least 16 days, the morphology was continuously influenced by injection signatures and/or characterized by a narrow dawn-side ME. As a result, only the I, i and N families are present. This strongly suggests that during that period, the inner-to-middle magnetosphere was probably adjusting to an enhanced Iogenic plasma production. This might have affected all auroral components, as shown in **Figure 1** (and S1.4), where the power in the 3 subregions evolved in parallel. The influence of the poleward subregion is more pronounced than in the case of PJ03, and the power values observed in it around PJ04 are among the largest ones of the present campaign. If one assumes that the contamination between the subregions is only marginal, this would mean that the internal plasma production has profound effects, not limited to the inner magnetosphere, but extending down the distant magnetosphere. Near perijove, the auroral morphology belonged to the i family and the total emitted power was around 1 TW, which is in the lower part of the range of power values measured around PJ04. Around the time of apojove of orbit 4 (DOY 59) two HST visits captured one i family member and two days later, a X family member. However, it should be noted that the emitted power is similar for both, suggesting that there is an uncertainty on the actual family of the X member, which may also fit the N family. Fortunately, this kind of ambiguity is relatively unusual and in most cases the power measured in the three subregions is in agreement with the selected morphological family.

5.3. Juno orbit 5

The 2-week period around perijove PJ05 (DOY 86.4) is characterized by auroral morphologies that evolved differently from orbits 3 and 4. In the case of orbit 5, about ten days before perijove, the aurora showed signatures of magnetospheric compressions for almost three days (X family). It was then followed by a week of moderate injection signatures (i) that rapidly increased to strong injection signatures (I) just at the time of perijove PJ05. One day after, these equatorward subregion emissions decreased and gave way to 4 days of narrow dawn-side ME (N family). The total emitted power shown in **Figure 1** (and S1.5) followed the same trend as in **Figure 4** (and S4.5), with values peaking above 2.4 TW, especially as a result of the enhanced equatorward-subregion emissions during the episodes of injection. The largest value, 2.6 TW, was reached when the morphology was in the X family and all three subregions were displaying large power values. Near perijove (I family), the total power reached 2.25 TW in the southern hemisphere and rapidly decreased (all subregions) to less than 2 TW in the northern hemisphere. Two HST visits were obtained near the time of apojove of orbit 5 (DOY 112). Both were characterized by extremely strong equatorward subregion emissions (I), giving rise to a total emitted power as large as 3.36 TW, which is the second highest power measured during the present HST campaign (the first highest, 3.52 TW, was during PJ06, as discussed below).

5.4. Juno orbit 6

For 20 days around perijove PJ06 (DOY 139.28), HST observed a great deal of variability in the morphology. All families are well present, with the notable exception of X. For one week, the morphology seems to have 'hesitated' between the Q and U families, both characterized by rather low and diffuse emissions (**Figure 4** and S4.6). We estimate solar-wind conditions upstream of Jupiter with the 1-D MHD model developed by Tao et al. (2005) and available from the on-line AMDA science analysis system. The accuracy of this propagation model largely depends on Earth-Sun-Jupiter angle, which we limited to about 20° in order to narrow down the uncertainty in the arrival times to less than 24 h. The HST observations matching these limitations were mainly obtained during the ~one-week period before the time of perijove PJ06. The weak and diffuse emissions (Q, U) that were observed at that time perfectly correlate with the continuously low solar wind dynamic pressure (<0.05 nPa) that persisted during that week, suggesting that the Q and U morphological families indeed correspond to episodes of low IM activity.

This low auroral period was interrupted by a short enhancement of the equatorward subregion (I) emission that was followed by two more quiet days (U). This temporary auroral enhancement occurred while the solar wind dynamic pressure was still below 0.05 nPa, suggesting that it was driven by processes taking place inside the magnetosphere. Approaching the time of PJ06, the morphology grew more complex (N) and just after perijove, the southern hemisphere showed an extremely strong enhancement of the equatorward emission (I), about twice as much as what was observed during apojove 5. Again, this strong auroral event took place when the solar wind was relatively quiet. Contrary to other cases, the ME and poleward subregions did not follow the same dramatic increase and the total power 'just' peaked around an extreme value of 3.52 TW **(Figure 1** and S1.6**)**. This extreme event suggests that a major reconfiguration event might have taken place in the inner magnetosphere. During the days that followed, the auroral morphology gradually returned to a more undisturbed state (U, N). It is noteworthy that all along this period, the power emitted in the equatorward subregion was about twice the power in the poleward subregion, which itself was characterized by a power about twice that of the main emission subregion. This clearly demonstrates how important it is not to restrict Jupiter's aurora to its main 'oval', but to properly consider all the emissions equatorward and poleward of it. Near the time of apojove of orbit 6 (DOY 165), one HST visit captured a X family member for which the power distribution changed in comparison with the previous cases, since the main emission surpassed the other subregions.

5.5. Juno orbit 7

The 20-day period containing perijove PJ07 (DOY 192.11) is reminiscent of what was observed during orbit 6 (see above), at least for the week around perijove (**Figure 4** and S4.7). After a 3-day period of relatively quiet auroral activity (Q, U), the complexity of the morphology index increased to N and then to I in just a couple of days. A strong, localized, injection occurred just at the time of PJ07. It was observed by HST in the southern hemisphere and resulted in a peak total power of 1.6 TW (**Figure 1** and S1.7). The northern i family case that followed presents a similar total power since the loss of power in the equatorward subregion is almost entirely balanced by the 4 times larger emission power in the poleward subregion. During the week that followed PJ07, the auroral emission remained influenced by episodes of injection signatures interrupted by N family cases, and a second I family case took place on DOY 197 that reached 2.2 TW.

5.6 Connections between the families

The six morphological families that we identified in section 4 allow us to see how the auroral distribution is changing during different phases of the Juno mission. They also make it possible to determine how these typical morphologies relate to each other. **Figure 5** shows the connections between all families. For example, the upper left "Q" panel describes how the Q family is connected with other ones. The red arrows, pointing to "Q" correspond to the transition(s) from the family observed during the visit directly preceding an Q case. The numbers next to the arrows indicate how many times such a transition was observed during the campaign between two adjacent visits separated by less than 2 days, amounting to 53 transitions. The number in parenthesis is limited to visits separated by less than a Jovian rotation. The blue arrows pointing away from "Q" correspond to direct transitions from an Q case to any other family. The numbers follow the same rule as for the red arrows. The next panels show the other transitions, such that all branches appear twice in the figure. Numbers in parentheses are significantly smaller since there are fewer visits separated by less than 1 Jovian rotation, amounting to 17 transitions, and for which we can assume that the overall morphology is not drastically changing in the interval. We note that in most cases they show the same trend as with the less-than-2-days numbers. Panel "Q" is dominated by U-Q and Q-U transitions. This is somewhat expected because both Q and U morphologies are very close, with Q being dimmer than U. These transitions thus correspond to a gradual change of the brightness of the auroral features contained in the ME subregion. Panel "N" reveals several transitions N-i i-N and N-I I-N, suggesting that the N family, characterized by a very narrow dawn side ME, is following or preceding episodes of plasma injections (I, i). Panel "I" then shows that there is probably a link between I and i families, which may show different stages of the evolution of the auroral signatures associated with plasma injections, although their characteristic time is usually less than one Jovian rotation. In panel "X", only one type of transition emerges; from X to i, suggesting that the X family, associated with IM compression, is often followed by plasma injections, implying that the disturbance caused by IM compression may trigger episodes of plasma injections in the middle magnetosphere, a scenario supported by Galileo particles and radio observations and reported by Louarn et al. (2014). Interestingly, no typical family precedes an IM compression event, meaning that these events are indeed independent from the state of the magnetosphere, as expected for an external driver. **Figure 5** also suggests that the N and i families could often change from one to the other. If these connections represent a systematic evolution, then it may challenge fundamental physics for which a non-adiabatic process cannot be reversible. Here, we propose that the process from N family to i family is a natural evolution of the magnetospheric system involving processes like magnetic dipolarization, wave-particle interaction, and so on. This is contrary to the case of the i family to N family evolution, which would require an interruption of the system. Such an interruption may take place during the interaction between Jupiter's magnetosphere and the interplanetary medium, for example, in the form of reconnection driven plasmoid release.

In parallel to **Figure 5**, a close inspection of **Figure 4** suggests that episodes of plasma injection (I, i families) immediately following episodes of enhanced IM activity (X) are rather rare, with only 4 cases separated by less than a Jovian rotation (5 cases if we extend this separation to 2 days). For the remaining 13 cases (48 if we count all cases separated by less than 2 days) these episodes appear disconnected, suggesting that the IM activity has a limited direct influence on the inner Jovian magnetosphere. On the contrary, the N family (narrow ME arc) almost systematically follows a period of injection (I and i families), which is compatible with the idea that during these periods of plasma injection, more plasma needs to be brought to corotation. Quiet periods (Q, U families) can last for as long as a week until they are interrupted by injection events. It is clear that the uneven temporal sampling of the aurora meant that we missed isolated events. Accordingly, there are probably gaps in the above scenarios.

Finally, it should be noted that the morphological evolution depicted in Figure 5 is only showing observed transition between two different families; it does not necessarily represent a physical or logical connection. Two families connected by an arrow could either suggest a natural evolution from one to the other, such as the development of plasma instability, or represent two irrelevant processes. For example, if we assume that family X is a consequence of IM compression, then it is possible to coincidentally have any other family prior to this family, as the appearance of IM compression is controlled by solar activity and obviously does not depend on the present condition of Jupiter.

6. Summary and Conclusions

In the present study, we report on observations of Jupiter's ultraviolet aurora with the STIS instrument onboard the Hubble Space Telescope during Juno orbits 3 to 7. The 118 selected STIS observations, or visits, of HST program GO-14634 are principally designed to complement Juno's remote-sensing instruments and to provide a longer monitoring of Jupiter's aurora, spanning a couple of weeks around each perijove, for Juno's in situ instruments. The morphology of Jupiter's aurora is known to be very complex and highly variable. It consists of several components, each of which represents a signature of physical processes taking place in different regions of the magnetosphere. As such, each image of Jupiter's aurora may be seen as an instantaneous snapshot of Jupiter's magnetospheric activity. However, the translation of variations of the auroral morphology to magnetospheric activity is far from obvious. One of the difficulties stems from the complexity of the aurora, especially in the northern hemisphere. In order to simplify things, we define three auroral subregions for each visit; main emission, poleward and equatorward, in which we measure the auroral emitted power as a function of time. We then define six auroral morphological families (**Figure 3**, **Table 2**), representative of the morphologies that are typically observed during this campaign and which help us to quantify the morphological variations. Following previous similar auroral studies, we tentatively associate these families with magnetospheric activity.

1. The ''Quiet'' Q family is characterized by very low emission power of most auroral components, especially those filling the ME and equatorward subregions, and a rather large latitudinal extension. This morphology presumably corresponds to a quiet, undisturbed magnetosphere.
2. The ''Narrow'' N family also shows relatively low power, but with a very narrow dawn-side ME arc. The rest of the main emission also consists of relatively narrow arcs, together forming a relatively expanded ME. It very often follows a i family case and may correspond to a

magnetosphere that returned to a quiet state after episodes of injections.

3. The ''Unsettled'' U family is intermediate between the Q and N families, with relatively wide and faint dawn-side main emission, while the ME afternoon sector is usually brighter and narrower. It may then represent an intermediate stage in terms of magnetospheric configuration. The narrow and brightened auroral arc may be a signature of storage of large amounts of free energy, for example in the form of plasma pressure gradient, stretched magnetic topology, or current sheet thinning. The magnetospheric configuration corresponding to the U family is likely to evolve in such a way as to release this energy through plasma instabilities like, for example, the development of interchange instabilities, which are potentially associated with plasma injections.
4. The ''strong Injections'' I family is easily recognized by its strong enhancement of the equatorward emissions and the corner shaped distribution near 150° S3 longitude in the north (70° in the south). These equatorward emissions are likely associated with injection of hot plasma resulting from an enhanced plasma transport from the Io torus. They often follow "quiet magnetosphere" Q and N family members.
5. The ''moderate injections'' i family is similar to the I family but with significantly lower power, suggesting that the injected plasma is either in a more advanced stage of assimilation by the ambient plasma or in a developing stage.
6. The dawn side main emission of the ''eXternal perturbation'' X family is very strong, and the afternoon side of the ME is also often bright and narrow. The dusk sector of the poleward subregion usually contains bright and highly variable auroral patches or arcs parallel to the ME. This family may result from an enhanced influence of the interplanetary medium, such as the arrival of an IM compression region.

With the subregions power and morphological families, we show that the auroral and magnetospheric activities were different for each Juno orbit, from 3 to 7. This suggests that during these periods internal factors (i.e. related to Io) and external factors (related to the interplanetary medium) largely and unevenly influenced Jupiter's magnetosphere. The results presented here demonstrate that the auroral morphology is changing very rapidly, within one Jovian rotation, suggesting that the magnetosphere itself is rapidly adapting to the internal and external constraints. This study also demonstrates that it is imperative not to restrict Jupiter's aurora to its main 'oval', but to address all the emissions both equatorward and poleward of it.

The two-week period around PJ03 was the most influenced by the IM, while during the 2 weeks around PJ04 HST only caught several episodes of plasma injection. The 2-week period around PJ05 started with 3 days of high IM activity, followed by on week of moderate internal activity, and then by strong injections near perijove, followed by several days of N family aurorae. At the beginning, orbits 6 and 7 roughly follow similar trends, with one week of relatively quiet activity followed by strong injections near the time of perijove. The injection activity stops the day after in orbit 6 while it continues for several days at a moderate level in orbit 7. HST observations can be connected with the in situ and remote sensing of Juno in order to better establish the observational relationship between magnetospheric and auroral activity. In addition to our examination of the relationship of our results with the upstream solar wind, for PJ6, it will be helpful to determine whether any relationship can be established between increased Io activity or Io torus density for their potential influence on the evolution of auroral properties as noted between PJ03 and PJ07. This is possible with several ongoing studies of Io and the Io torus that are cross-referenced with the work presented here in a full description of Juno-supporting observations that are summarized at a web site maintained by the Juno mission: https://www.missionjuno.swri.edu/planned-observations. A more complete picture of the processes of energy transport associated with auroral phenomena and their evolution in time can be obtained by additional cross-referencing of X-ray emission (e.g. Dunn et al. 2017), auroral emission from H_3^+ in the near-infrared from the Jupiter Infrared Auroral Mapper (JIRAM) among Juno's instrumentation (e.g. Mura et al. 2017) as well as supporting ground-based observations of H3+ emission (e.g. L. Moore et al. 2017) and their associated influence on temperatures of Jupiter's upper stratosphere (e.g. Sinclair et al. 2017). The timing and scope of these observations are also summarized on the Juno-maintained web site listed above.

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Figure captions

Figure 1

Auroral emitted power (TW) corrected for the viewing geometry as a function of time during the period covering Juno orbits 3 to 7; from 30 November 2016 to 18 July 2017. The time is given in decimal Day of Year 2017 (DOY). For observations obtained in 2016, we subtracted 366 days, resulting in negative DOY 2017. The times of perijoves 3 to 7, corrected for the Juno-HST light travel time, are marked with a vertical bar at the top of the plot. The upper left panel presents all the data in a single plot. A reduced version of Figure 2, depicting the color codes used for the poleward, equatorward and ME subregions is overlaid in order to facilitate the reading of the different curves. Subsequent panels show the results for each individual orbit. The individual panels are also available in the supporting information (Figures S1.1, S1.3-S1.7). The total power (white symbols and lines) is the sum of the power in the ME (red), poleward (green) and equatorward (yellow) subregions. Power values within each HST visits (~41 min) are averaged over 100 seconds, giving 24 data points per visit. The area of the planetary surface limited by the ME contour is represented with blue symbols and lines. We consider only one average value of the area per HST visit. The numerical value of the area was transformed in order to obtain numbers close to but larger than the total power, so that they can be conveniently displayed on the same logarithmic plot. The displayed value corresponds to $6 \mathrm{x} \mathrm{Log}_{10}(\mathrm{Area}/7 \mathrm{x} 10^8\ \mathrm{km}^2)$. The actual value of the area is given in **Table S1** (supporting information) in units of $10^9\ \mathrm{km}^2$. All numbers referring to the northern hemisphere are marked with diamond symbols and connected with solid lines. Numbers referring to the southern hemisphere are marked with stars and connected with dashed lines. No definite long-term trend emerges from the general plot (upper left panel of **Figure 1**, see also Figure S1.1 in the supporting information). The corrected total power usually varies by a factor of 3 over time and remains between ∼1 and 3 TW in each hemisphere. The dispersion of the total auroral power during one HST visit may be used as a proxy for the inaccuracy on the inferred emitted power.

Figure 2

Definition of the three auroral subregions, for the northern aurora, containing emission features of similar type and presumably sharing common magnetospheric origins. We use the same color code as in Figure 1 to represent each subregion: (1) *Main emission* (ME, red), often referred to as the main oval; (2) *Poleward region* (green), also known as the polar region, it is bounded by the poleward boundary of the main emission; (3) *Equatorward region* (yellow), defined by the equatorward boundary of the main emission, and includes the auroral footprint of Io. They form three contiguous surfaces on Jupiter's ellipsoid, approximately centered on the geometrical center of the main emission. The addition of these three regions encompasses the majority of the auroral emission in each hemisphere and is used to determine the total emitted power. The poleward subregion corresponds to the outer magnetosphere, the equatorward subregion corresponds to the inner magnetosphere and the ME subregion corresponds to the middle magnetosphere. Another set of three subregions is defined for the southern hemisphere in the same way. We set the width of the main emission ribbon, the 2D contour on Jupiter's surface roughly containing the main emission, to 3000 km (∼2.5° on the surface of Jupiter). The blue cross marks the location of the magnetic dipole.

Figure 3

Illustration of the six morphological auroral families defined for Jupiter's northern aurora. The aurora, accumulated for 100 sec., is projected on a polar map with 10° spaced S3 meridians (180° to the bottom, 90° to the right) and parallels, assuming an emission altitude of 400 km. The same saturated log-scale blue hues color table is used in each individual panel and adjusted to increase the contrast of the different auroral components. A color bar saturating at 2 MRayleighs is overlaid to the upper left panel. The six selected visits (k18, k39, k57, k88, k1g, k0k) all display the same basic auroral ingredients but with different proportions. Each auroral family: Q, U, N, J, i, X, displayed in the corresponding panel is potentially representative of a certain state of the magnetosphere, which itself is influenced by internal and external drivers. These family codes are used in **Table 1** and repeated in **Table 2**, they allow one to easily trace the evolution of the auroral morphology during the period covered by this HST campaign. Similar families were defined for the southern hemisphere, for which the viewing geometry is usually less favorable than for the northern hemisphere.

We selected at least one visit for each Juno orbit, in the northern hemisphere, for a CML close to 143 S3 degrees, which is offering a relatively complete view of the various auroral components. The availability of observations at this CML (+/- 3°) makes it possible to compare auroral morphologies captured with almost exactly the same viewing geometry. Auroral features characterizing different morphologies are highlighted with red dashed lines and ellipses and red numbers from "1" to "9". For example, the corner-shaped feature marked "3" in the lower left panel is typical of the strong injections (I) family.

Figure 4

Graphical representation of the evolution of the auroral morphology over Juno orbits 3 to 7 (see also detailed parameters in **Table 1**). Like Figure 1, the upper left panel presents all the data in a single plot, while the subsequent panels show the results for each individual orbit. The individual panels are also available in the supporting information (Figures S4.1, S4.3-S4.7). Each family is assigned a qualitative index: Q=1; U=2; N=3; i=4; I=5; X=6. This index reflects the typical power level measured in the families and is also such that the indexes of related families, like I and i, differ by 1 unit. Morphologies observed in the north are marked with a diamond and those observed in the south are marked with a star. The time is given in decimal Day of Year 2017 (DOY). For observations obtained in 2016, we subtracted 366 days, resulting in negative DOY 2017. The times of perijoves 3 to 7, corrected for the Juno-HST light travel time, are marked with a vertical bar at the top of the plot. The horizontal dashed lines are guiding lines. The upper one separates the X family, influenced by the external perturbations, from the strong and moderate injections I and i families, influenced by plasma injections. The lowest line separates the Narrow and Unsettled (N, U) families, corresponding to the most frequent auroral morphologies, from the Quiet (Q) family, characterized by very low emitted power.

Figure 5

Graphical representation of the connections between all families. The upper left “Q” panel describes how the Q family (highlighted in green) is connected with other ones. The red arrows, pointing to “Q” correspond to the transition(s) from the family observed during the HST visit directly preceding an Q case. The numbers next to the arrows indicate how many times such a transition was observed during the campaign between two adjacent HST visits separated by less than 2 days. The number in parenthesis is limited to visits separated by less than a Jovian rotation. The blue arrows pointing away from “Q” correspond to direct transitions from a Q family case to any other family. The numbers follow the same rule as for the red arrows. Cases where no transitions occur are not represented for clarity. The other panels show the other transitions, such that all branches appear twice in the figure. Numbers highlighted in bold and with thicker arrows correspond to the most likely transitions between families (highlighted in yellow).

Table 1: List of various parameters characterizing the 118 HST visits considered in this study. The different columns of the table provide: the index, the HST archive root name, the time at the start of the exposure (mm/dd/yyyy hh:mm:ss format), the same time converted in decimal day of year (DOY) 2017, we subtracted 366 to observations made in 2016; the corresponding time at Juno corrected for light travel time (using the latest Juno trajectory kernels in SPICE), the observed hemisphere (N or S) Jupiter's central meridian System III (S3) longitude (CML) in degrees at the start of the exposure; and the morphological family. See also a more detailed version of this table in the supporting information (Table S1)

index	rootname	HST time (mm/dd/yyyy)	HST DOY(2017)	Juno time(light corr.)	hemisphere	CML start	family
k01	od8k01r0q	11/30/2016 15:47:26	-30.3421	11/30/2016 14:57:23	N	146.100	X
k02	od8k02r4q	11/30/2016 17:22:48	-30.2758	11/30/2016 16:32:45	N	203.746	X
k05	od8k05vnq	12/01/2016 17:13:28	-29.2823	12/01/2016 16:23:32	S	348.537	X
k07	od8k07vrq	12/01/2016 18:48:52	-29.2161	12/01/2016 17:58:56	S	46.2033	i
k22	od8k22czq	12/02/2016 17:03:31	-28.2892	12/02/2016 16:13:41	N	132.958	N
k23	od8k23d1q	12/02/2016 18:38:54	-28.2230	12/02/2016 17:49:05	N	190.614	N
k26	od8k26q4q	12/04/2016 13:34:28	-26.4344	12/04/2016 12:44:51	S	307.470	Q
k11	od8k11fuq	12/05/2016 19:46:26	-25.1761	12/05/2016 18:56:58	S	322.756	X
k19	od8k19fwq	12/05/2016 21:21:49	-25.1098	12/05/2016 20:32:22	S	20.4128	I
k12	od8k12j9q	12/06/2016 14:51:43	-24.3808	12/06/2016 14:02:21	S	295.052	X
k20	od8k20jhq	12/06/2016 16:25:38	-24.3155	12/06/2016 15:36:16	S	351.822	i
k21	od8k21jtq	12/06/2016 18:01:00	-24.2493	12/06/2016 17:11:39	S	49.4689	i
k08	od8k08q5q	12/07/2016 16:16:40	-23.3218	12/07/2016 15:27:26	N	136.849	I
k03	od8k03t0q	12/08/2016 11:21:03	-22.5270	12/08/2016 10:31:54	N	108.604	N
k04	od8k04yuq	12/09/2016 12:46:53	-21.4674	12/09/2016 11:57:53	S	310.940	U
k06	od8k06ejq	12/10/2016 18:58:50	-20.2091	12/10/2016 18:10:00	S	326.231	U
k09	od8k09dmq	12/11/2016 17:14:00	-19.2819	12/11/2016 16:25:18	S	53.3173	U
PJ03		-19.2550					
k10	od8k10dxq	12/11/2016 19:18:02	-19.1958	12/11/2016 18:29:20	N	128.294	X
k17	od8k17e1q	12/11/2016 20:24:44	-19.1495	12/11/2016 19:36:02	N	168.613	i
k18	od8k18ljq	12/12/2016 15:29:12	-18.3547	12/12/2016 14:40:35	N	140.426	Q
k13	od8k13lus	12/12/2016 17:03:59	-18.2889	12/12/2016 16:15:22	N	197.721	Q
k15	od8k15qdq	12/13/2016 12:10:09	-17.4930	12/13/2016 11:21:37	N	170.564	Q
k14	od8k14vrq	12/14/2016 16:45:51	-16.3015	12/14/2016 15:57:27	N	127.685	I
k16	od8k16yrq	12/15/2016 08:39:04	-15.6395	12/15/2016 07:50:44	S	343.896	Q
k27	od8k27ghq	01/07/2017 01:57:08	7.08134	01/07/2017 01:11:38	S	322.353	U
k28	od8k28gpq	01/07/2017 03:32:30	7.14757	01/07/2017 02:47:00	S	20.0052	U
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k25	od8k25jlq	01/22/2017 15:31:08	22.6466	01/22/2017 14:47:45	N	192.688	i
k29	od8k29fiq	01/23/2017 20:07:50	23.8388	01/23/2017 19:24:37	N	150.543	N
k30	od8k30i4q	01/24/2017 15:11:42	24.6331	01/24/2017 14:28:35	N	122.086	I
k31	od8k31iaq	01/24/2017 16:47:04	24.6994	01/24/2017 16:03:58	N	179.742	I
k33	od8k33xwq	01/26/2017 18:04:03	26.7528	01/26/2017 17:21:14	N	167.442	i
k34	od8k34apq	01/27/2017 13:08:24	27.5475	01/27/2017 12:25:42	N	139.284	N
k35	od8k35f8q	01/28/2017 09:48:08	28.4084	01/28/2017 09:05:33	N	168.793	N
k36	od8k36kkq	01/29/2017 14:24:36	29.6004	01/29/2017 13:42:11	N	126.527	I
k37	od8k37l0q	01/29/2017 15:59:58	29.6666	01/29/2017 15:17:33	N	184.183	I
k38	od8k38h7q	01/31/2017 07:43:57	31.3222	01/31/2017 07:01:47	N	185.487	I
k39	od8k39s3q	02/01/2017 12:20:26	32.5142	02/01/2017 11:38:26	N	143.240	N
PJ04		33.5687					
k44	od8k44ycq	02/02/2017 13:46:13	33.5738	02/02/2017 13:04:23	S	345.702	i
k45	od8k45yeq	02/02/2017 15:21:35	33.6400	02/02/2017 14:39:46	S	43.3592	i
k47	od8k47c1q	02/03/2017 08:50:35	34.3685	02/03/2017 08:08:50	S	317.568	i
k48	od8k48d2q	02/03/2017 13:36:40	34.5671	02/03/2017 12:54:56	N	130.530	N
k50	od8k50fqq	02/04/2017 10:16:26	35.4281	02/04/2017 09:34:48	N	160.076	N
k51	od8k51igq	02/05/2017 06:56:14	36.2891	02/05/2017 06:14:41	N	189.644	N
k52	od8k52diq	02/06/2017 11:32:56	37.4812	02/06/2017 10:51:31	N	147.544	i
k53	od8k53isq	02/07/2017 06:40:55	38.2784	02/07/2017 05:59:35	N	121.605	i
k54	od8k54iuq	02/07/2017 08:12:51	38.3423	02/07/2017 07:31:32	N	177.187	i
k55	od8k55tnq	03/01/2017 15:56:39	60.6643	03/01/2017 15:17:38	N	171.661	i

k56	od8k56o2q	03/05/2017	18:29:08	64.7702	03/05/2017	17:50:28	N	146.514	N
---------									
k32	od8k32anq	03/17/2017	08:39:23	76.3607	03/17/2017	08:01:34	N	158.011	X
k42	od8k42fiq	03/18/2017	14:52:23	77.6197	03/18/2017	14:14:38	N	174.219	X
k57	od8k57itq	03/19/2017	09:57:00	78.4146	03/19/2017	09:19:18	N	146.298	X
k58	od8k58eaq	03/20/2017	16:09:14	79.6731	03/20/2017	15:31:36	N	162.043	i
k59	od8k59huq	03/21/2017	11:13:44	80.4679	03/21/2017	10:36:09	N	134.051	i
k60	od8k60i1q	03/21/2017	12:49:06	80.5341	03/21/2017	12:11:31	N	191.713	i
k61	od8k61lyq	03/22/2017	07:53:33	81.3289	03/22/2017	07:16:01	N	163.691	i
k65	od8k65y9q	03/25/2017	05:49:37	84.2428	03/25/2017	05:12:14	N	180.793	N
k66	od8k66e3q	03/26/2017	15:12:12	85.6335	03/26/2017	14:34:54	S	311.630	i
k67	od8k67bfq	03/27/2017	03:55:05	86.1633	03/27/2017	03:17:49	S	52.8983	I
k68	od8k68bxq	03/27/2017	05:30:26	86.2295	03/27/2017	04:53:10	N	110.550	I
k70	od8k70crq	03/27/2017	08:41:10	86.3619	03/27/2017	08:03:54	N	225.875	I
PJ05	86.3952								
k71	od8k71ctq	03/27/2017	10:16:32	86.4281	03/27/2017	09:39:17	S	283.537	I
k73	od8k73d1q	03/27/2017	13:27:15	86.5606	03/27/2017	12:50:00	S	38.8517	I
k72	od8k72g9q	03/28/2017	03:45:30	87.1566	03/28/2017	03:08:15	N	197.782	N
k74	od8k74hnq	03/28/2017	11:42:24	87.4878	03/28/2017	11:05:09	N	126.133	N
k75	od8k75hpq	03/28/2017	13:17:40	87.5539	03/28/2017	12:40:25	N	183.735	N
k76	od8k76lqq	03/29/2017	08:22:00	88.3486	03/29/2017	07:44:46	N	155.641	N
k77	od8k77opq	03/30/2017	03:26:22	89.1433	03/30/2017	02:49:08	N	127.567	N
k78	od8k78orq	03/30/2017	05:01:44	89.2095	03/30/2017	04:24:30	N	185.229	N
k79	od8k79u1q	03/31/2017	09:38:20	90.4016	03/31/2017	09:01:07	N	143.147	N
k81	od8k81roq	04/19/2017	19:27:01	109.810	04/19/2017	18:49:41	N	121.642	I
k82	od8k82ovq	04/23/2017	14:00:08	113.583	04/23/2017	13:22:41	N	166.553	I
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k41	od8k41ixq	05/09/2017	06:42:14	129.279	05/09/2017	06:03:58	N	151.523	U
k63	od8k63neq	05/10/2017	06:32:53	130.273	05/10/2017	05:54:33	S	296.450	Q
k62	od8k62ogq	05/10/2017	11:19:00	130.472	05/10/2017	10:40:39	N	109.427	Q
k86	od8k86oiq	05/10/2017	12:53:48	130.537	05/10/2017	12:15:27	N	166.740	U
k64	od8k64rfq	05/11/2017	07:58:51	131.333	05/11/2017	07:20:26	N	138.998	U
k84	od8k84c6q	05/13/2017	09:15:18	133.386	05/13/2017	08:36:44	N	126.357	Q
k85	od8k85c8q	05/13/2017	10:50:40	133.452	05/13/2017	10:12:06	N	184.012	U
k87	od8k87d1q	05/15/2017	12:06:56	135.505	05/15/2017	11:28:13	N	171.244	Q
k87	od8k87d1q	05/15/2017	12:06:56	135.505	05/15/2017	11:28:13	N	171.244	Q
k88	od8k88hbq	05/16/2017	07:11:14	136.299	05/16/2017	06:32:27	N	143.034	I
k89	od8k89msq	05/17/2017	03:50:54	137.160	05/17/2017	03:12:03	N	172.476	U
k90	od8k90tpq	05/18/2017	08:27:19	138.352	05/18/2017	07:48:23	N	130.134	U
k91	od8k91txq	05/18/2017	10:02:40	138.419	05/18/2017	09:23:44	N	187.777	U
k94	od8k94x3q	05/19/2017	05:06:55	139.213	05/19/2017	04:27:56	N	159.529	N
PJ06	139.278								
k95	od8k95xgq	05/19/2017	06:42:17	139.279	05/19/2017	06:03:17	N	217.182	N
k97	od8k97xzq	05/19/2017	09:52:59	139.412	05/19/2017	09:13:59	S	332.469	I
k0a	od8k0ay5q	05/19/2017	11:28:19	139.478	05/19/2017	10:49:18	S	30.1020	I
k0b	od8k0bzxq	05/20/2017	01:46:31	140.074	05/20/2017	01:07:26	N	188.921	i
k0c	od8k0cgpq	05/21/2017	06:22:53	141.266	05/21/2017	05:43:41	N	146.535	N
k0h	od8k0hpgq	05/24/2017	04:18:33	144.180	05/24/2017	03:39:03	N	162.965	N
k0i	od8k0isyq	05/24/2017	23:22:50	144.974	05/24/2017	22:43:15	N	134.720	N
k0j	od8k0jt8q	05/25/2017	00:58:12	145.040	05/25/2017	00:18:37	N	192.372	U
k0k	od8k0kahq	05/26/2017	05:34:44	146.232	05/26/2017	04:55:01	N	150.064	U
k0l	od8k0le9q	05/27/2017	00:39:08	147.027	05/26/2017	23:59:20	N	121.883	N
k0m	od8k0meiq	05/27/2017	02:14:30	147.093	05/27/2017	01:34:42	N	179.534	N
k0n	od8k0nh8q	05/27/2017	21:18:55	147.888	05/27/2017	20:39:02	N	151.360	U
k69	od8k69idq	06/18/2017	09:55:28	169.414	06/18/2017	09:13:04	N	168.608	X
---------									
k0p	od8k0pg8q	07/04/2017	02:38:03	185.110	07/04/2017	01:53:41	N	150.776	N
k0q	od8k0qldq	07/05/2017	08:50:08	186.368	07/05/2017	08:05:37	N	166.062	Q
k0r	od8k0rniq	07/06/2017	02:19:12	187.097	07/06/2017	01:34:36	S	80.1525	U
k0s	od8k0sotq	07/06/2017	10:16:03	187.428	07/06/2017	09:31:24	S	8.37583	U
k0e	od8k0eqaq	07/07/2017	00:34:21	188.024	07/06/2017	23:49:38	N	167.159	Q
k0t	od8k0twqq	07/08/2017	05:13:19	189.218	07/08/2017	04:28:27	N	126.153	Q
k0f	od8k0fwuq	07/08/2017	06:46:16	189.282	07/08/2017	06:01:24	N	182.335	Q
k0u	od8k0uzgq	07/09/2017	01:50:36	190.077	07/09/2017	01:05:38	N	154.002	N
k0v	od8k0vfzq	07/10/2017	23:55:23	191.997	07/10/2017	23:10:12	S	25.1068	I
k0w	od8k0wgcq	07/11/2017	01:31:19	192.063	07/11/2017	00:46:08	S	83.0911	I
PJ07	192.107								
k0x	od8k0xhrq	07/11/2017	07:52:45	192.328	07/11/2017	07:07:31	S	313.638	i
k0y	od8k0yjqq	07/11/2017	23:46:17	192.990	07/11/2017	23:00:58	N	169.976	N
k0z	od8k0zs2q	07/13/2017	21:51:32	194.911	07/13/2017	21:05:57	S	41.3495	i
k1a	od8k1asqq	07/14/2017	01:02:15	195.043	07/14/2017	00:16:39	N	156.622	i
k1b	od8k1bubq	07/14/2017	05:48:18	195.242	07/14/2017	05:02:40	S	329.516	N

k1c	od8k1cuiq	07/14/2017 07:23:40	195.308	07/14/2017 06:38:02	S	27.1576	N
k1d	od8k1dwvq	07/15/2017 00:52:33	196.036	07/15/2017 00:06:49	S	301.121	N
k1e	od8k1ex2q	07/15/2017 02:27:54	196.103	07/15/2017 01:42:09	S	358.753	N
k1f	od8k1fx8q	07/15/2017 04:03:16	196.169	07/15/2017 03:17:31	S	56.3938	N
k1g	od8k1gbkq	07/16/2017 02:18:14	197.096	07/16/2017 01:32:21	N	143.270	i
k1i	od8k1igpq	07/18/2017 03:34:19	199.149	07/18/2017 02:48:10	N	129.968	N

Table 2: Main characteristics of the six morphological families used in this study.

Name	Code	Index	Frequency	Auroral Characteristics
"**Q**uiet"	Q	1	11%	Overall low auroral power, expanded broad ME
"**U**nsettled"	U	2	29.5%	Intermediate between Q and N
"**N**arrow"	N	3	8.5%	Very narrow ME, average power
"**i**njections"	i	4	18%	Moderate injections signatures, continuous ME
"strong **I**njections"	I	5	18.5%	Strong injections signatures, corner shape, disrupted dawn side ME
"e**X**ternal perturbation"	X	6	14.5%	Strong dawn side ME, contracted ME, poleward strong parallel arcs

Figure 1.


6 x Log10(Area/7x10^8 km^2)
Equatorward
Poleward
ME
Total
Equatorward
ME
Poleward
PJ03
PJ04
PJ05
PJ06
PJ07
Log10 (Corrected Power [TW])
DOY of 2017

Figure 2.

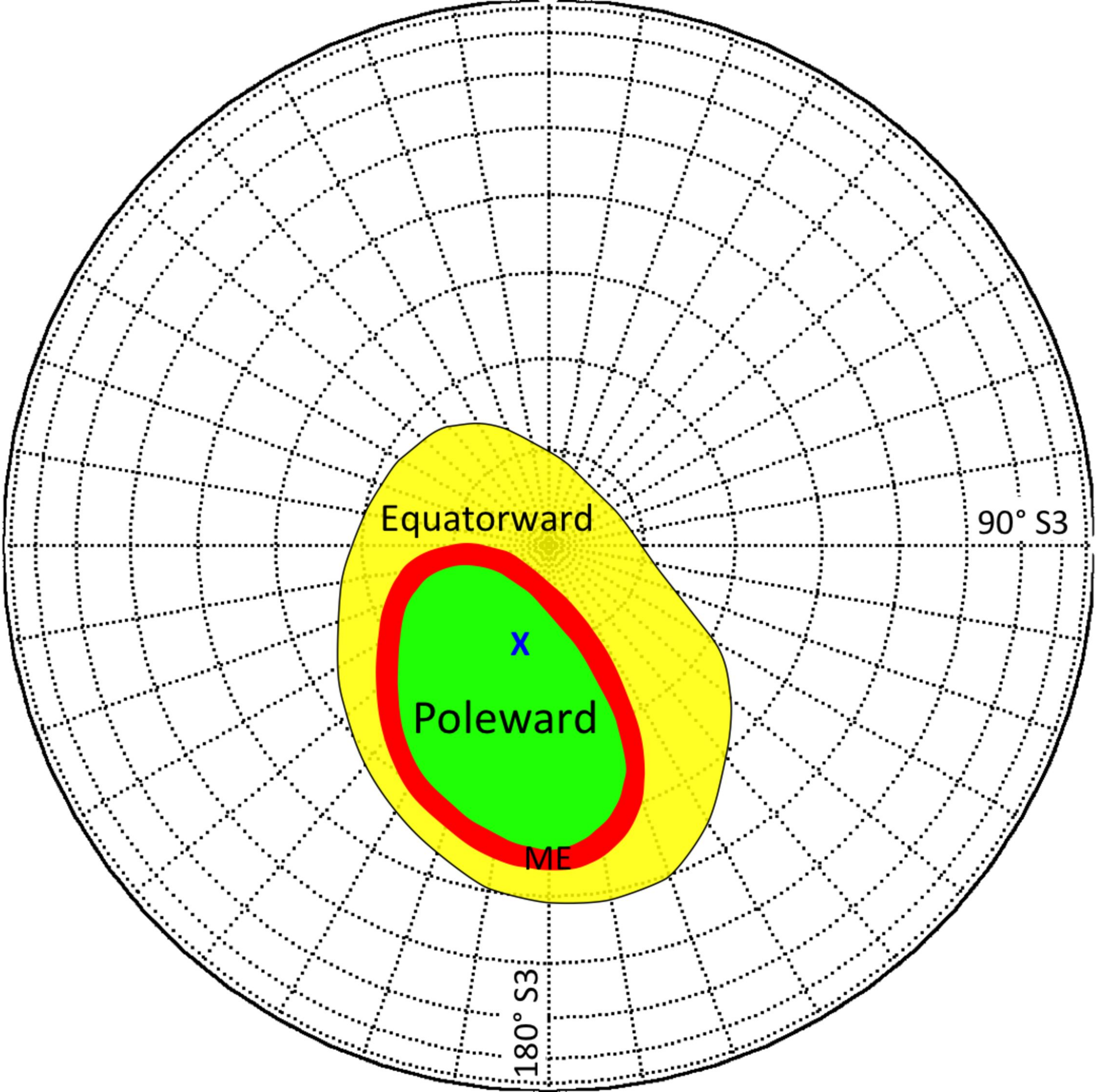

Equatorward
90° S3
X
Poleward
ME
180° S3

Figure 3.

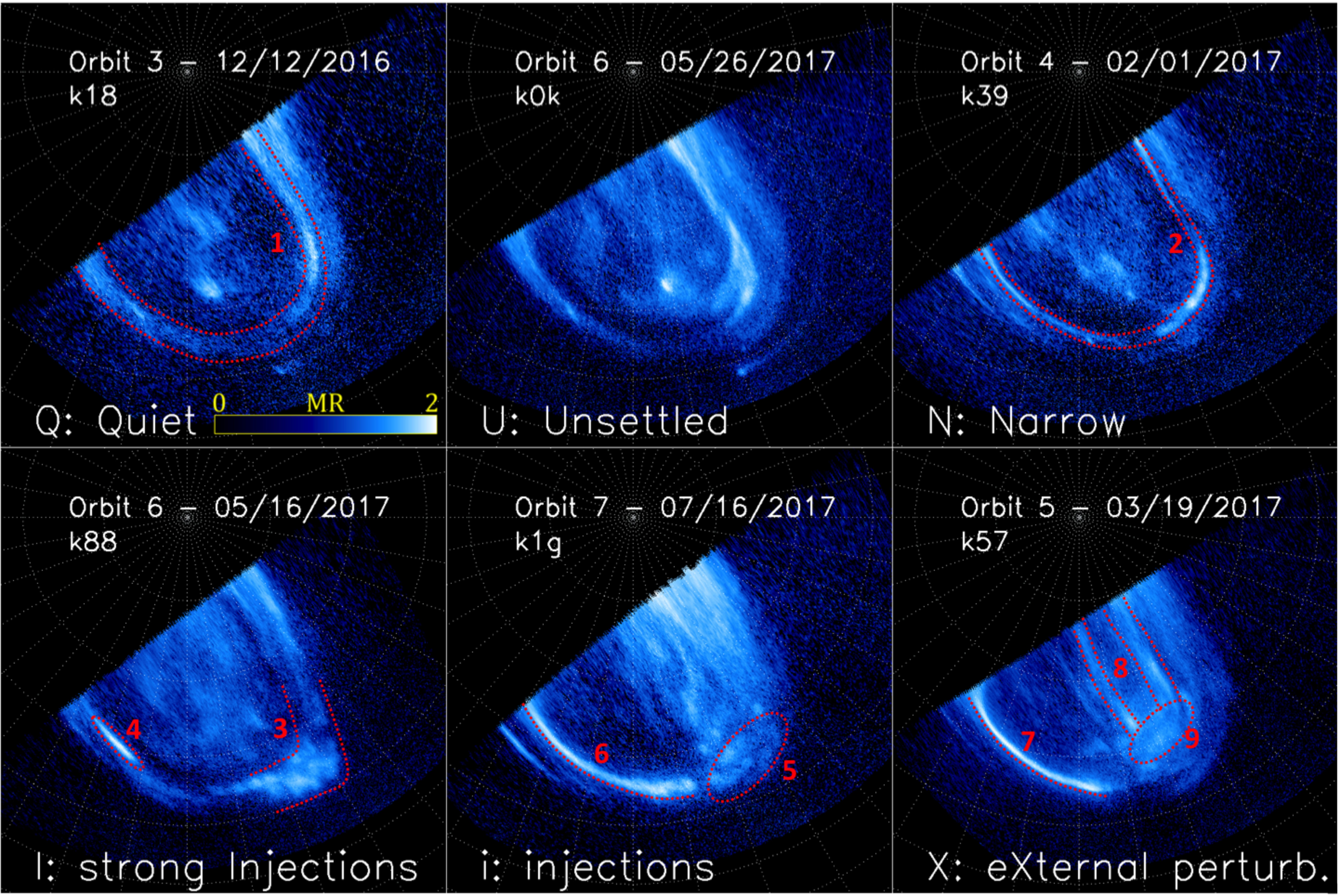
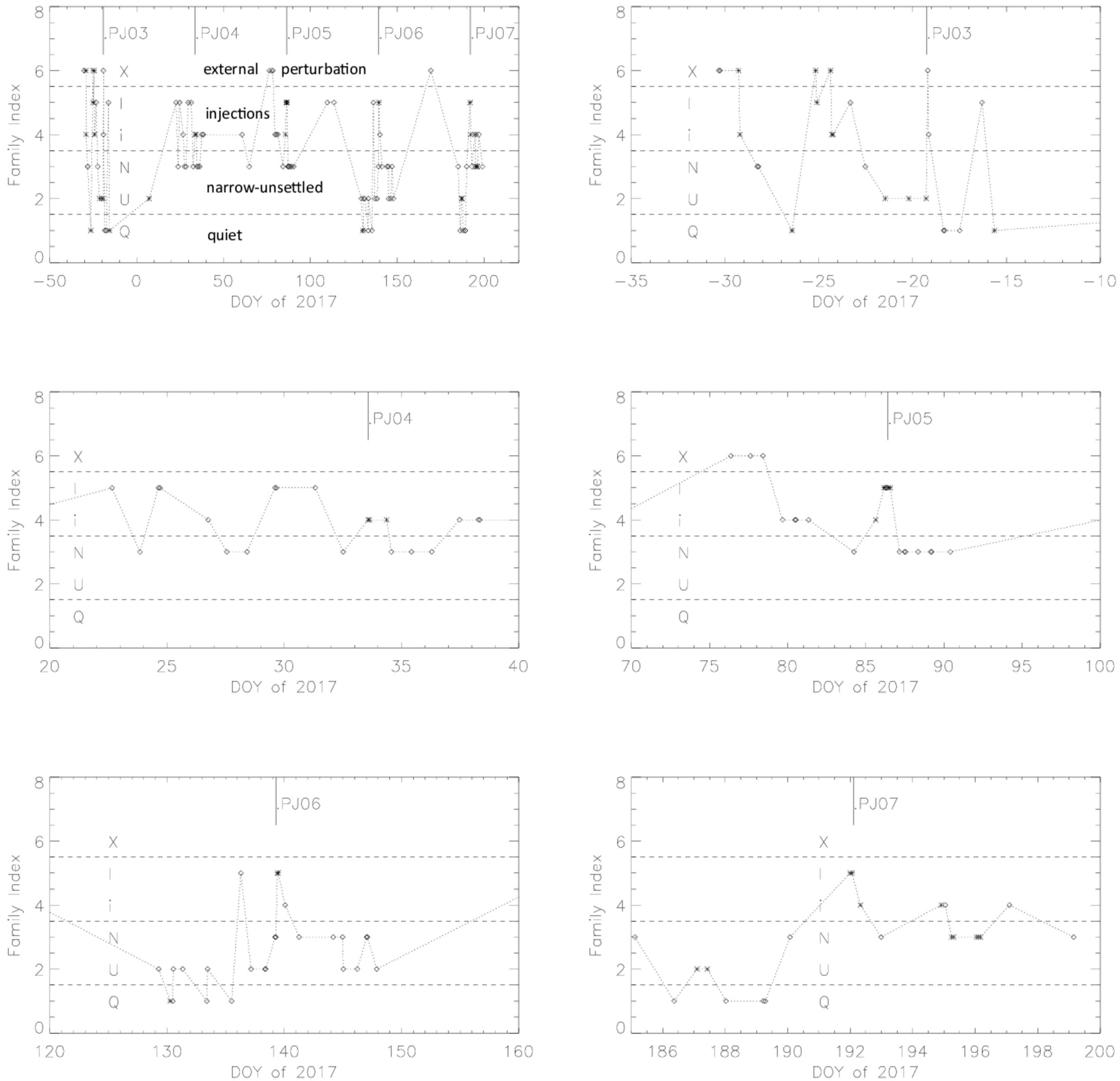
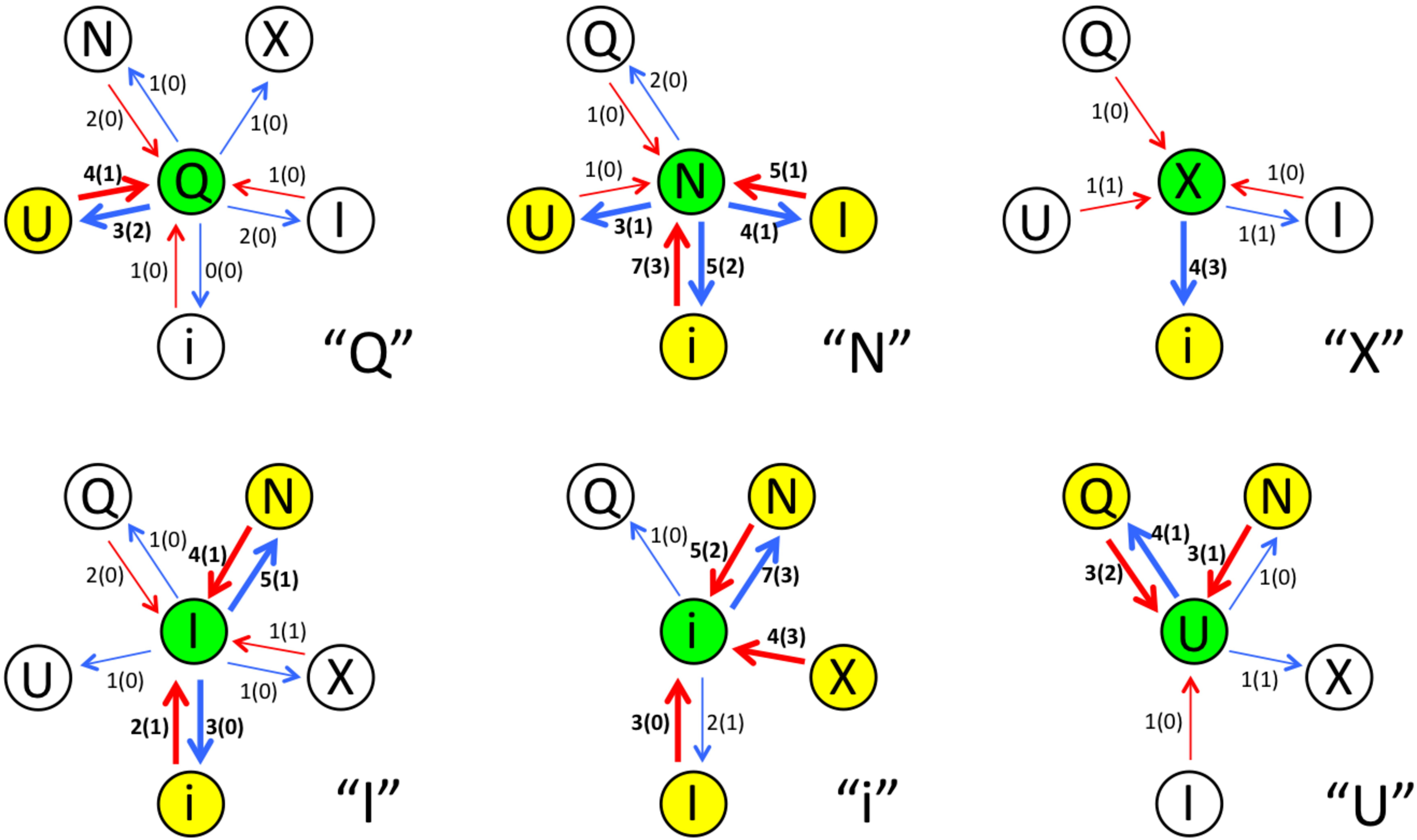

Orbit 3 - 12/12/2016
k18
1
Q: Quiet
0
MR
2
Orbit 6 - 05/26/2017
k0k
U: Unsettled
Orbit 4 - 02/01/2017
k39
2
N: Narrow
Orbit 6 - 05/16/2017
k88
4
3
I: strong Injections
Orbit 7 - 07/16/2017
k1g
6
5
i: injections
Orbit 5 - 03/19/2017
k57
8
7
9
X: eXternal perturb.

Figure 4.



PJ03
PJ04
PJ05
PJ06
PJ07
external perturbation
injections
narrow-unsettled
quiet
X
I
i
N
U
Q
Family Index
DOY of 2017

Figure 5.



Q: Quiet, U: Unsettled, N: Narrow,

i: moderate injections, I: strong Injections, X: eXternal perturbation