Icarus 268 (2016) 145–155

Contents lists available at ScienceDirect

Icarus

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

Stability within Jupiter's polar auroral 'Swirl region' over moderate timescales

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ARTICLE INFO

Article history:
Received 29 May 2015
Revised 26 November 2015
Accepted 22 December 2015
Available online 5 January 2016

Keywords:
Aurorae
Jupiter, atmosphere
Infrared observations
Ionospheres

ABSTRACT

Jupiter's Swirl region, poleward of the main auroral emission, has been characterised in previous observations as having highly variable auroral emission, changing dramatically across the region on a two-minute timescale, the typical integration time for UV images. This variability has made comparisons with H_3^+ emission difficult. Here, we show that the Swirl region in H_3^+ images is characterised by relatively stable emission, often with an arc of emission on the boundary between the Swirl and Dark regions. Coadding multiple UV images taken over the approximate lifetime of the H_3^+ molecule in the ionosphere, show similar structures to those observed in the H_3^+ images. Our analysis shows that UV auroral morphology within Jupiter's Swirl region is only highly variable on short timescales of ~100 s, an intrinsic property of the particle precipitation process, but this variability drops away on timescales of 5–15 min. On moderate timescales between 10 and 100 min, the Swirl region is stable, evolving through as yet unknown underlying magnetospheric interactions. This shows that observing the UV aurora over timescales 5–15 min resolves clear auroral structures that will help us understand the magnetospheric origin of these features, and that calculating the variability over different timescales, especially >15 min, provides a new and important new tool in our understanding of Jupiter's polar aurora.

1. Introduction

We have a broad understanding of how most of Jupiter's auroral regions are formed, the magnetospheric origin of the currents that drive these aurora, and the auroral morphology which is produced as a result of these currents (Clarke et al., 2004; Badman et al., 2015; Delamere et al., 2015; Grodent, 2015). However, the source of polar aurorae, in particular emission in the dawn side of this polar region, remains controversial. Ground-based observations have shown that this region is directly associated with the solar wind, with ions in this region held at a zero velocity in the inertial frame (Stallard et al., 2003). However, the two leading theories on how the solar wind controls this region require very different interactions with the surrounding magnetosphere. Cowley et al. (2003) evoke an Earth-like Dungey cycle interaction with the solar wind, while Delamere and Bagenal (2010) explain the interaction through closed field lines connected to viscous processes with the magnetopause boundary.

Past observations of Jupiter's aurora have been made in numerous wavelength bands, but our understanding of Jupiter's auroral morphology comes broadly from ultraviolet and infrared light. Ultraviolet (UV) aurorae are the result of prompt emission from atomic and molecular hydrogen, as in-falling energetic electrons excite these species, so that the observed UV emission provides a measurement of the instantaneous particle precipitation process, both in morphology and with the brightness of the H_2 Lyman and Werner bands being linearly proportional to the precipitation energy flux. In contrast, infrared observations typically measure emission from the H_3^+ molecule, though IR observations have also been used to study the aurora within H_2 quadrupolar emissions at 2.1 μm (Trafton et al., 1988; Raynaud et al., 2004) and hydrocarbon emissions in the mid-infrared (Caldwell et al., 1983; Kim et al., 1985). This H_3^+ is produced by ionising molecular hydrogen in the upper atmosphere then thermalized through collisions with the neutral atmosphere, producing infrared ro-vibrational emission over its ~10 min lifetime.

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http://dx.doi.org/10.1016/j.icarus.2015.12.044
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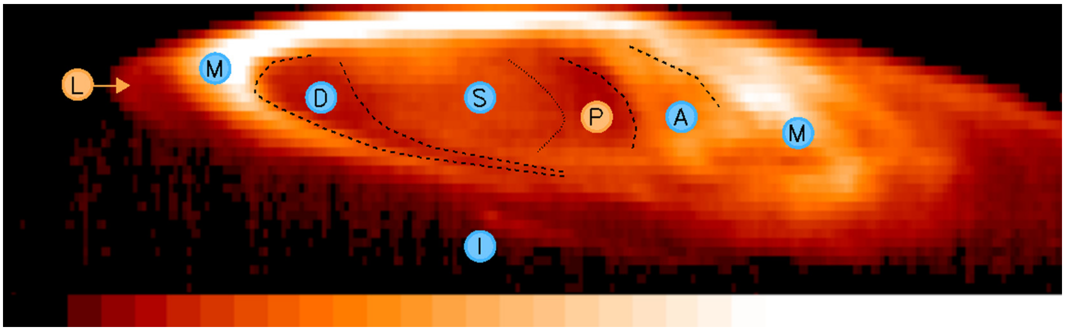

Fig. 1. Jupiter's H_3^+ northern auroral morphology. This image, started at 02:35 on the 31 December 2012 and constructed from a scan of individual 10 s long-slit spectra, was collated over ~15 min, with each vertical pixel representing emission from a single spectrum. It shows the northern auroral emission from the H_3^+ ν_2 Q(1,0$^-$) spectral line at Jupiter, at a CML of 181–193. The major UV auroral features are identified (M: Main emission, D: Dark region, S: Swirl region, A: Active region and I: Io spot and trail; Grodent et al., 2003a,b), along with two regions commonly seen within H_3^+ images (L: dawn Limb brightening, P: Polar darkening). A linearly increasing scale is presented at the bottom, ranging from 0 to 1.52 W m^{-2} μm^{-1} str^{-1}.

Jupiter's main auroral emission co-rotates with the planet, forming an approximately oval morphology aligned around each magnetic pole, offset from the planet's rotational pole (Connerney et al., 1993; Clarke et al., 1996; Grodent et al., 2008). These main aurorae are driven by the breakdown in corotation within the magnetosphere, when the equatorial plasmasheet, loaded with plasma that originated from the volcanic moon Io, drives currents into the ionosphere (Cowley and Bunce, 2001).

Additional auroral components away from the main emission were initially investigated using ground-based infrared observations of the H_3^+ aurora. These observations also identified an auroral spot and trail directly associated with Io (Connerney et al., 1993). Other moons have since been shown to have analogous auroral features and the interaction between Jupiter's magnetosphere and its moons that causes these features have been studied in detail in the UV (Clarke et al., 1996, 2002; Bonfond et al., 2008; Hess et al., 2011). Poleward of the main emission, Satoh and Connerney (1999) identified broadly stable H_3^+ auroral structures, with a polar region consisting of a 'Ying-Yang' emission, dark in the dawn and bright in the dusk. However, our understanding of the morphology of this region is now much more detailed, as a result of studies of Jupiter's UV auroral morphology (Grodent, 2015; and references therein).

Fig. 1 shows an image of the H_3^+ aurora taken over a CML range of 181–193 at 02:35 on the 31 December 2012, constructed from a scan of individual 10 s long-slit spectra. The 40″ × 0.2″ slit of the CRIRES instrument, on ESO's Very Large Telescope, was aligned East–West across the auroral region and scanned through the auroral region over a period of ~15 min. The high spectral resolution of the observations (~100,000) results in an auroral image entirely containing only pure H_3^+ emission.

The auroral emission seen in Fig. 1 broadly follows the UV emission described by Grodent et al. (2003a,b). Both the main emission and Io spot and trail are clearly displayed, though small-scale structures are not easy to distinguish in the IR due to the lower spatial resolution. Poleward of the main emission, the 'Active' region fills the dusk side and has been associated with bright variable emission that forms into flares and arc-like structures, observed to exist over entire sequences of images, suggesting relatively stable structures that last for more than an hour, though this region does see a 2–3 min periodicity which may be associated with pulsed dayside reconnection (Bonfond et al., 2011). This region has been shown in past observations to have a H_3^+ brightness between 50% and 75% of the peak auroral brightness (Stallard et al., 2001). The dawn side of the polar region is split into two regions. The 'Dark' region is a crescent shaped region adjacent to the poleward edge of the dawnside main auroral emission. In the UV, this region is almost devoid of auroral emission, the order of only a few tens of kR above the background level. Past IR ground-based observations of this region have proven difficult, as it is narrow, and turbulence in the Earth's atmosphere usually blends this region with the surrounding main oval and Swirl regions. In Fig. 1, where the observing conditions are particularly clear, this region is clearly visible, and has an emission ~25% of the peak auroral brightness. Poleward of this, the 'Swirl' region, in UV emission, is a region of faint patchy emission features that occasionally form swirls. Emission in this region appears to be transitory, with emission features changing from image to image, suggesting the features occur with a cadence of ~100 s (Grodent et al., 2003a,b). Past observations have suggested the presence of arc-like features in this region, both following the main auroral emission (Pallier and Prangé, 2001) and producing trans-polar arcs (Nichols et al., 2009a,b), but such observations have remained controversial due to the essentially transient nature of the emission in this region. Past H_3^+ observations have shown that this region appears much less variable in the infrared, producing a general brightening of ~50% the peak auroral brightness (Stallard et al., 2001).

Despite differences in production, the broad distribution of the H_3^+ and UV aurora have previously been shown to be similar, particularly on the main auroral emission and within the aurora associated with moon interactions, with the major differences most likely the result of changing temperature driving variability in the H_3^+ emission (Clarke et al., 2004; Radioti et al., 2013). The Active region has also been shown to have broadly similar in morphology in both wavelengths (Clarke et al., 2004; Radioti et al., 2013). However, the Swirl region shows significant differences in the instantaneous emission in the two wavelengths. The differences seen are dominated by the high variability seen within the UV Swirl aurora, making any comparison with the more long-lived H_3^+ emission difficult.

In this paper, we will identify the typical H_3^+ emission structure seen within the polar region. We will then look at the UV emission over an extended timescale, removing any short-term variability, so that the emission can be observed under similar conditions as H_3^+ emission and a direct, like-for-like, comparison of morphology can be made.

2. H_3^+ infrared images

Jupiter's H_3^+ aurorae have been observed in detail over an extended period of time, including extensive observations between 1995 and 2000 by J. Connerney and T. Satoh using the NSFCam instrument on the NASA Infrared Telescope Facility (IRTF) (Shure