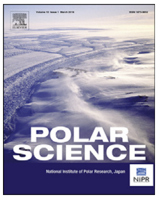
Polar Science xxx (2016) 1–9

Contents lists available at ScienceDirect

Polar Science

journal homepage: http://ees.elsevier.com/polar/



Quasi-periodic rapid motion of pulsating auroras

Yoko Fukuda [a, b, *], Ryuho Kataoka [b, c], Yoshizumi Miyoshi [d], Yuto Katoh [e], Takanori Nishiyama [b], Kazuo Shiokawa [d], Yusuke Ebihara [f], Donald Hampton [g], Naomoto Iwagami [a]

[a] *Department of Earth and Planetary Science, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan*
[b] *National Institute of Polar Research, 10-3 Midori-cho, Tachikawa, Tokyo 190-8518, Japan*
[c] *Department of Polar Science, SOKENDAI (The Graduate University for Advanced Studies), 10-3 Midori-cho, Tachikawa, Tokyo 190-8518, Japan*
[d] *Institute for Space-Earth Environmental Research, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan*
[e] *Graduate School of Science, Tohoku University, Aramaki-aza-aoba, Aoba-ku, Sendai, Miyagi 980-8578, Japan*
[f] *Research Institute for Sustainable Humanosphere, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan*
[g] *Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK 99775, USA*

ARTICLE INFO

Article history:
Received 29 October 2015
Received in revised form
5 February 2016
Accepted 19 March 2016
Available online xxx

Keywords:
Pulsating aurora
Wave-particle interactions
High-speed imaging

ABSTRACT

We report rapid motion of pulsating auroras associated with so called 3 ± 1 Hz modulations embedded in the main pulsations. During the pulsation ON phase, repetitive expansions are often observed around the edges of pulsating patches. Some events show a few detached expansions traveling away from the main deformed pulsating patch. Approximately 80% of all expansion speeds were found to be less than 70 km s^{-1} at ionospheric altitudes, which is less than the projected Alfvén speed from the magnetospheric equator to the ionosphere. The rapid motions with speeds of tens of km s^{-1} are unlikely to be explained by obliquely propagating chorus elements, which are known to cause the 3 ± 1 Hz modulation, because the perpendicular speed of the oblique chorus waves is higher than the Alfvén speed. We discuss the slow-mode Alfvén wave as a candidate modulation source to generate the rapid motions. A few non-repetitive expansion events with a speed of more than 150 km s^{-1} also appear at the onset of the ON phase. These non-repetitive expanding motions are characterized by a long displacement compared to the repetitive expanding motions. The differences in the expansion speeds indicate different formation mechanisms of the patch motions.

1. Introduction

A pulsating aurora is a phenomenon defined by the repetition of irregular ON–OFF switching of auroral intensity. The typical repetition period is a few seconds to 20 s (Yamamoto, 1988). The pulsating aurora is typically observed during the recovery phase of substorms in both auroral and subauroral zones over a wide range of magnetic local times (e.g., Cresswell, 1972; Royrvik and Davis, 1977). A quasi-periodic intensity modulation of 3 ± 1 Hz is often observed during the ON phase (e.g., Nishiyama et al., 2014; Sandahl et al., 1980; Sato et al., 2004). From sounding rockets and satellite observations, flux modulations of precipitating electrons with energies of a few to tens of keV were shown to be present at 3 ± 1 Hz (e.g., Miyoshi et al., 2010, 2015; Nishiyama et al., 2011; Sandahl et al., 1980; Sato et al., 2004).

Two source regions for the pulsating aurora have been considered. The first is located far from the earth, around the magnetic equator. Nishimura et al. (2010) indicated a one-to-one correspondence between chorus waves and auroral intensity modulation from a conjunction event of THEMIS satellites located at the magnetic equator and ground auroral imagers. Miyoshi et al. (2010) proposed a new model for the time-of-flight effect of the precipitating electrons by considering the propagation of chorus waves. Miyoshi et al. (2010) and Nishiyama et al. (2011) conducted time-of-flight analyses assuming wave–particle interactions of electrons with propagating chorus waves from the equator and showed that the region is covered up to approximately 15° of MLAT off the equatorial plane. Another possible source region is located much closer to the earth. Sato et al. (2004) showed that the aurora of Syowa–Iceland pair observations were not conjugate in shape and

---

* Corresponding author. Department of Earth and Planetary Science, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan.
E-mail address: yoko.f@eps.s.u-tokyo.ac.jp (Y. Fukuda).

http://dx.doi.org/10.1016/j.polar.2016.03.005
1873-9652/© 2016 Elsevier B.V. and NIPR. All rights reserved.

Please cite this article in press as: Fukuda, Y., et al., Quasi-periodic rapid motion of pulsating auroras, Polar Science (2016), http://dx.doi.org/10.1016/j.polar.2016.03.005

the FAST satellite detected an anti-correlation between electrons and ions, suggesting that the field-aligned potential drop contributes to the modulation. From the FAST observations, their study indicated that the source region was ~2–6 R_E above the FAST satellite.

Miyoshi et al. (2015) elucidated the origin of internal modulations, including the 3 ± 1 Hz of the pulsating aurora by means of a comparative study of the Reimei satellite observations and a computer simulation. They concluded that the main modulations, with periods of a few seconds, are caused by lower-band chorus bursts and the 3 Hz modulations are caused by a repetition of rising tone chorus elements embedded in the chorus bursts. Katoh (2014) showed using a simulation study that the propagation of chorus elements from the magnetic equator is dependent on the background density distribution. In cases of density enhancement or decrease to form a wave duct, chorus elements can propagate well along the magnetic field; in cases without such a duct, they obliquely propagate and gradually depart from the initial magnetic field.

It is well known that horizontal patches move with speeds in the order of km s^{-1} at ionospheric altitudes by E × B drift (Nakamura and Oguti, 1987). In addition, complicated spatial and temporal motions of pulsating patches have been observed and classified into several types according to their shapes, sizes, and propagating features (e.g., Oguti, 1978; Yamamoto and Oguti, 1982). The fastest motions that have been reported are fast auroral waves (Boyd et al., 1972; Cresswell, 1968; Cresswell and Belon, 1966; Scourfield and Parsons, 1971) and superfast auroral waves (Hough et al., 1992). Fast auroral waves are east–west aligned in an arc-like form and travel equatorward at a speed of up to 300 km s^{-1} over a distance exceeding 250 km. Their repetition rate is typically 1 Hz. Superfast auroral waves also propagate equatorward over a distance exceeding 1400 km with a typical speed of 700 km s^{-1} and a maximum speed of 1200 km s^{-1}. Although the generation

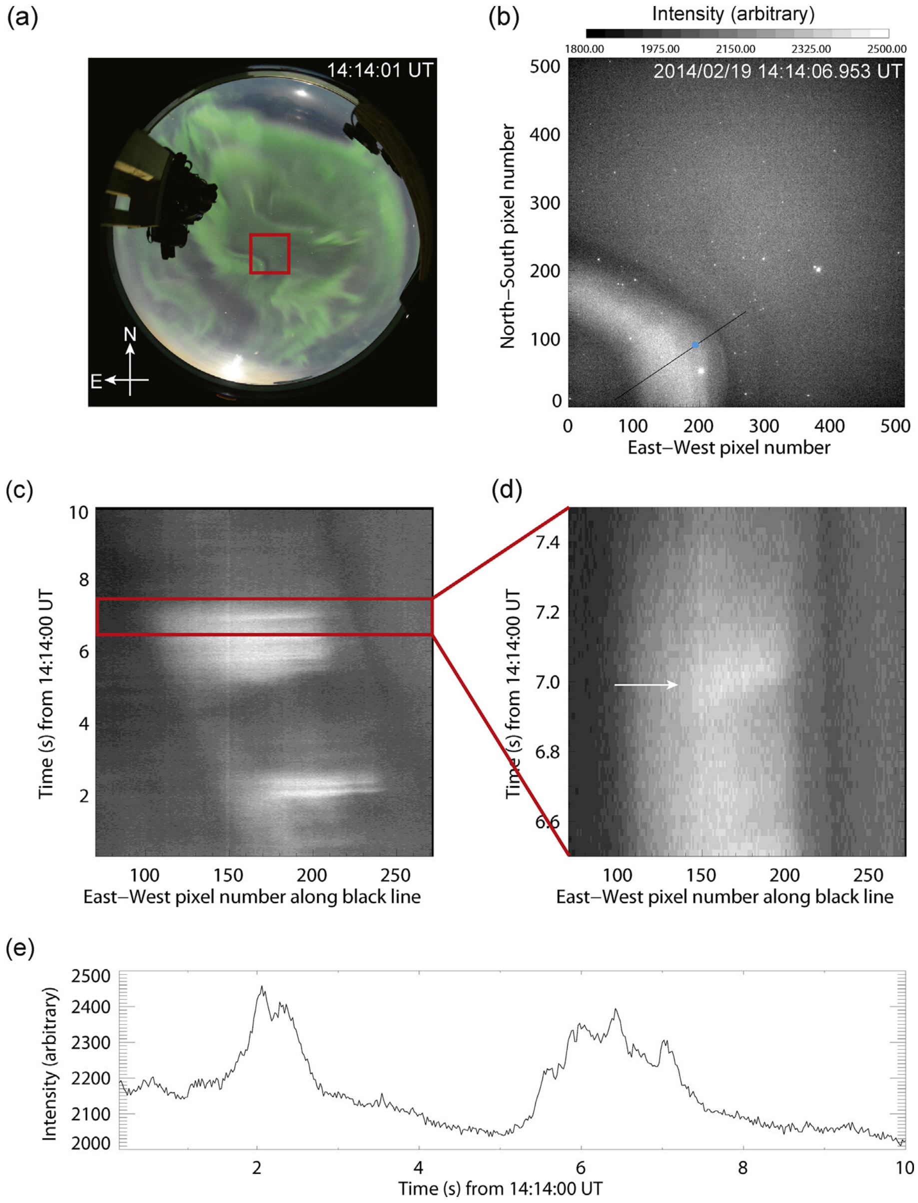


Fig. 1. (a) All-sky image captured at 14:14:01 UT on 19 February 2014. Top is north, and right is west. The red square is the field-of-view of the sCMOS camera. (b) Example of repetitive expansions at the edge of a pulsating patch. Intensity is shown by gray scale in arbitrary unit. (c) Keogram aligned at the black line shown in Fig. 1b for 10 s. (d) Extended keogram between 14:14:06.5 and 14:14:07.5 UT. (e) Averaged auroral intensity of the 5 × 5 pixels region centered at x = 195 and y = 91.

Please cite this article in press as: Fukuda, Y., et al., Quasi-periodic rapid motion of pulsating auroras, Polar Science (2016), http://dx.doi.org/10.1016/j.polar.2016.03.005