Statistical study of the response of Jovian EUV aurora of the solar wind from Hisaki observations

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In order to reveal the solar wind response of Jovian ultraviolet (UV) auroral activity, we made a statistical analysis of Jovian UV aurora obtained from long term Hisaki observation.

The UV emission from hydrogen molecule is excited by collision with high energy electron. The main oval is one of the components of Jovian UV aurora where the auroral particle precipitations are caused by the rotationally driven field-aligned current system. It is theoretically expected that angular velocity of magnetospheric plasma increases when the Jovian magnetosphere is compressed by enhanced solar wind pressure, which decreases the field-aligned current. Regarding this scenario, increase of the solar wind dynamic pressure is expected to be anti-correlated with the intensity of Jovian UV aurora. A previous observation such as that by International Ultraviolet Explorer (IUE) or Hubble Space Telescope (HST) showed the time variability of Jovian UV aurora, while their data still limited in continuity over solar wind variation with good time resolution. On the other hand, Hisaki satellite is an earth-orbiting spectroscope launched in 2013 which has been continuously monitoring the total power of Jovian UV aurora. Therefore, the Hisaki data sets are effective for investigating the solar wind response of Jovian UV aurora.

The purpose of this study is to investigate the solar wind response of Jovian UV aurora observed by Hisaki EXCEED. We used the auroral total power obtained from Dec. 2013 to Feb. 2014 and from Dec. 2014 to Feb. 2015. We compare the auroral total power over 900-1480Å and solar wind dynamic pressure which is extrapolated at Jupiter using a one-dimensional magnetohydrodynamic (MHD) model.

Superposed epoch analysis indicated that the auroral total power increases with the enhancement of the solar wind dynamic pressure. We also found a correlation between the auroral total power and the duration of the rarefaction region of the solar wind before the enhancement of the dynamic pressure. The similar trend could also be found in the thermal current, i.e., incoming electron flux increased with the duration of rarefaction region.

One possible scenario is that mass loading from Io increases the electron density in the Jovian middle magnetosphere and it also increases seed electron of the thermal current whose energy is several keV. The solar wind compression causes adiabatic acceleration of thermal current and then the auroral total power increases. However, it is still unclear how the angular velocity distribution and brightness distribution vary during the solar wind compression.

Symposium on Planetary Science 2016

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Solar wind response of Jovian aurora

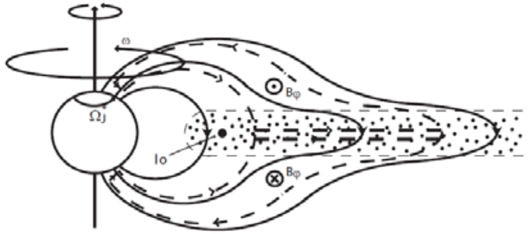
Jovian auroral emission results from magnetosphere-ionosphere coupling current system

- Io supplies massive plasma to the magnetosphere
- Angular velocity decreases and corotation breakdown occurs around 15~40Rj
- The strong current system produces main auroral emission.

Cowley and Bunce [2003]

- Angular velocity of magnetospheric plasma increases when the Jovian magnetosphere is compressed by enhanced solar wind pressure, which decreases the field-aligned current.

➔Anti-correlation between intensity of aurora and solar wind pressure



Solar wind response of Jovian aurora

HST obs. [Clarke et al., 2009]

- Two campaigns in 2007 (Feb-Mar, May-Jun)
- The correlation between EUV aurora and solar wind dynamic pressure is less strong. Total auroral power increases near the arrival of solar wind shocks.

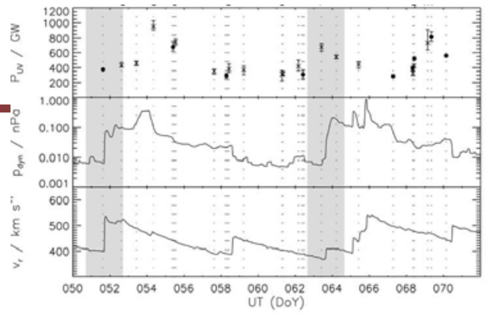


Figure Total auroral power from Jupiter's north (crosses) and south (filled circles) polar regions obtained from HST observations

IRTF obs. [Baron et al., 1996]

- Total intensity and the solar wind pressure have correlation

➔Not consistent with theoretical expectation

However, the data set lacks of continuity and it is necessary to use continuous data set to reveal solar wind response

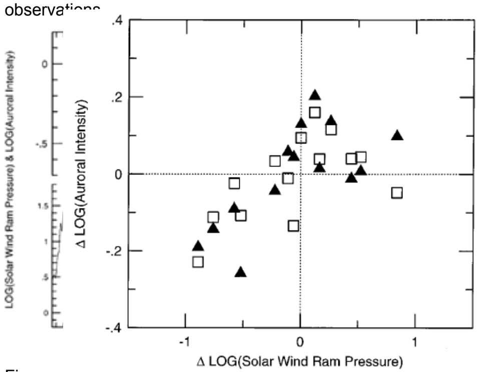


Figure. Left: Time variation of Jovian infrared aurora and solar wind dynamic pressure.

HISAKI observations of Jovian aurora

We could find clear solar wind response of EUV aurora. However, EUV aurora does not always respond to the solar wind

➔It seems that the solar wind shock with <u>long rarefaction region</u> causes large enhancement of EUV aurora.

- Io supplies plasma to the Jovian magnetosphere.
  - <u>long rarefaction region → more plasma supplied from Io?</u>
- Mass loading process also controls the solar wind response of aurora?

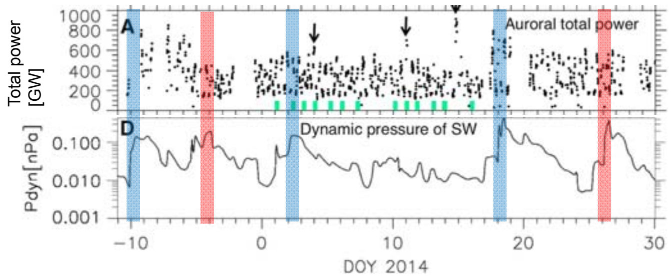


Figure. Time variation of Jovian EUV aurora obtained from HISAKI observations. We can find clear solar wind response of EUV aurora (Blue hatched), but some times aurora do not respond to the solar wind (Red hatched) infrared aurora and solar wind dynamic pressure.

Purpose

- Cowley model expects that increase of the solar wind dynamic pressure is anti-correlated with the intensity of the EUV aurora.
- However, observation showed that Jovian aurora increase with solar wind dynamic pressure [e.g. Baron et al., 1996; Nichols et al., 2009].
- Recent HISAKI observations showed that sometimes aurora does not respond to the enhancement of the solar wind dynamic pressure.

➔<u>Investigate solar wind response on Jovian EUV aurora from continuous HISAKI data set.</u>

<u>Purpose of this study</u>

- Reveal a statistical feature of Jovian EUV aurora to the solar wind properties. (duration of rarefaction region affects Jovian EUV aurora??)

Data analysis

Data set

- Dec. in 2013 – Feb. in 2014
- Dec. in 2014 – Feb. in 2015 (before volcanic eruption from Io affect Jovian EUV aruora)
- (Feb. in 2015 – May. In 2015, after volcanic eruption from Io affect Jovian EUV aurora)

EUV data analysis

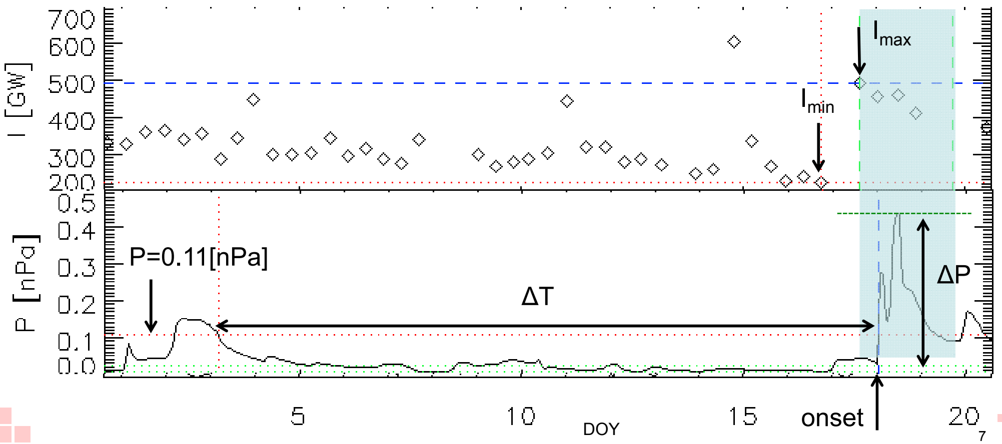
- Level 2 EUV spectrum data → Total power of Jovian northern aurora (L3)
  - Wavelength range : 900-1480 Å, Integration time:10min
- Correct longitudinal dependence
  - Plot each data along CML → calculate median every 6 degrees.
  - Fit cos function
- Exclude the longitude when aurora is difficult to see from the earth, (CML<100, CML>250), and calculate longitudinally averaged EUV aurora.

\+

- Solar wind: 1D MHD model [Tao et al., 2005]

Definition of each parameter

- Duration of rarefaction region (ΔT) : the period of P<0.11[nPa].
- Variation of solar wind dynamic pressure (ΔP) : maximum during the period of P>0.11 ÷ mean during the rarefaction region
- EUV variation ΔI = (maximum intensity during the period of P>0.11 +/- 20~40h) ー (minimum intensity during ΔT)



Summary of HISAKI observation (2014)

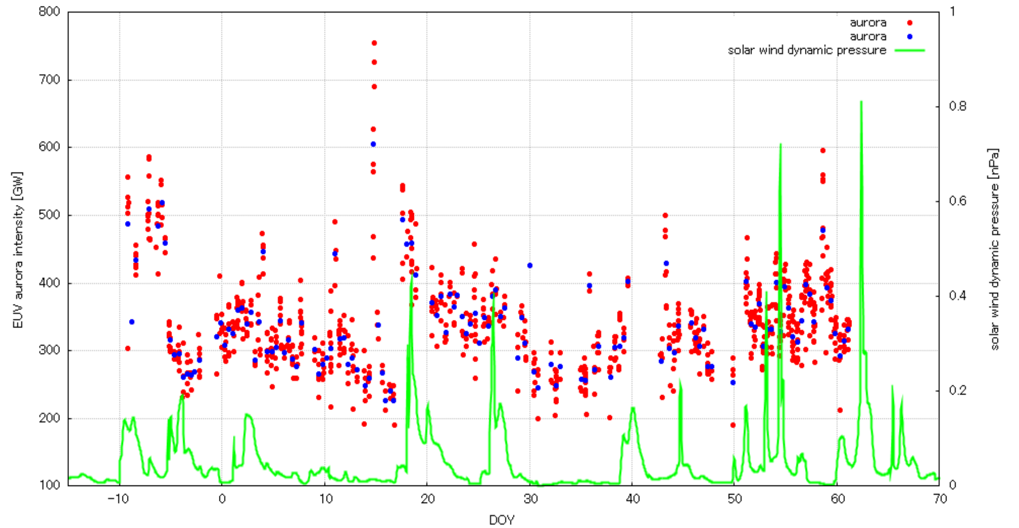


Figure Red : Total intensity of Jovian EUV aurora from 900 to 1480 Å. Blue : one Jovian rotation average of EUV intensity. Green : A and solar wind dynamic pressure which is extrapolated at Jupiter using a one dimensional magnetohydrodynamic (MHD) model from Tao et al., [2005].

Summary of HISAKI observation (before volcanic eruption affect EUV aurora)

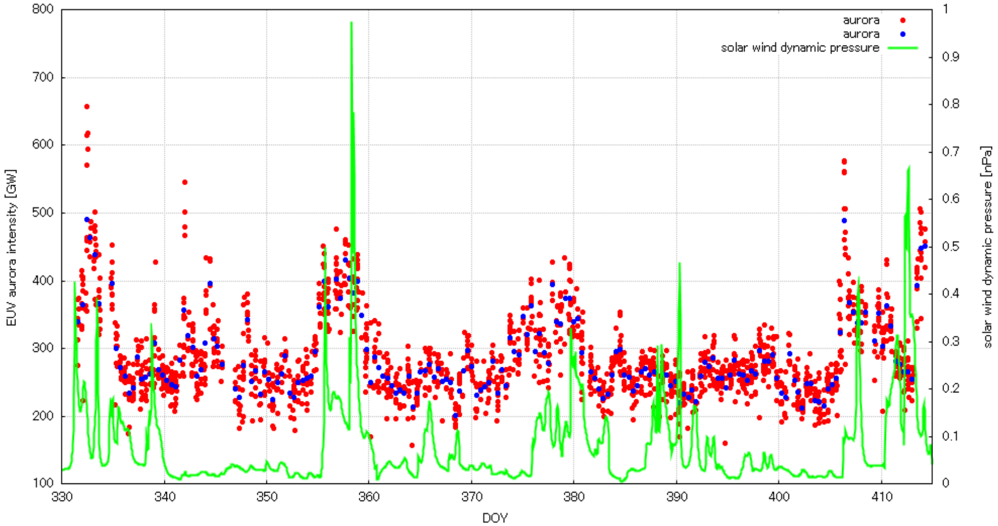


Figure Red：Total intensity of Jovian EUV aurora from 900 to 1480Å. Blue：one Jovian rotation average of EUV intensity. Green： A and solar wind dynamic pressure which is extrapolated at Jupiter using a one dimensional magnetohydrodynamic (MHD) model from Tao et al., [2005].

Summary of HISAKI observation (after volcanic eruption)

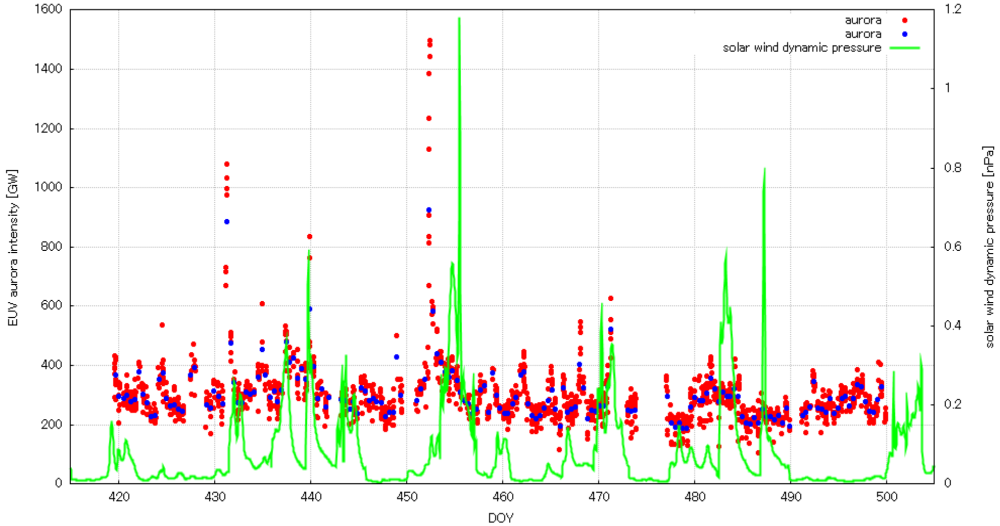


Figure Red：Total intensity of Jovian EUV aurora from 900 to 1480Å. Blue：one Jovian rotation average of EUV intensity. Green： A and solar wind dynamic pressure which is extrapolated at Jupiter using a one dimensional magnetohydrodynamic (MHD) model from Tao et al., [2005].

Superposed profile

- Cowley found that after an impulsive compression the main oval will dim because of the increased angular velocity of the equatorial plasma.

  ➔We made superposed epoch analysis for the event of ΔT > 5 days.

  The data are aligned to the onset of dynamic pressure enhancement.

- Aurora does not dim during solar wind compression.

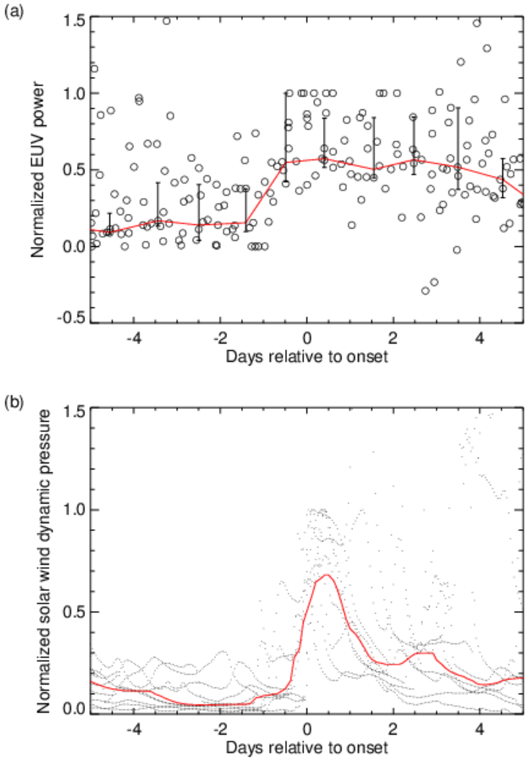


Figure (Top) superposed profile of EUV aurora. Red line indicates median profile for one-day window. Errorbars indicate Interquartile range. (Bottom) superposed profile of the solar wind dynamic pressure. Red line indicates median profile.

Correlation analysis

ΔT－ΔI

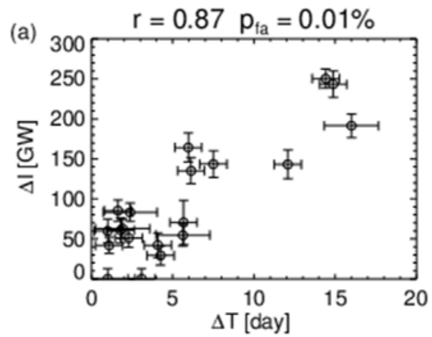
- Correlation coefficient (R) = 0.87
- False alarm probability: <1%

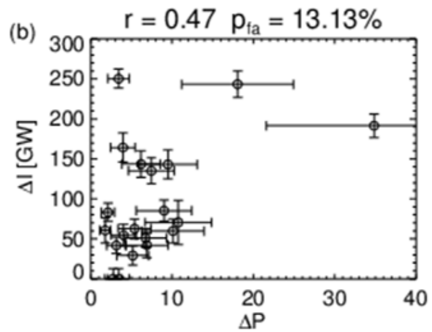
  →ΔT-ΔI have correlation

ΔP－ΔI

- Correlation coefficient = 0.47
- False alarm probability: 13.13%

  →ΔP-ΔI do not have correlation





- EUV aurora depends on the duration of rarefaction region. (➔some process related to the mass loading??)
- EUV aurora does not depend on the pressure variation.

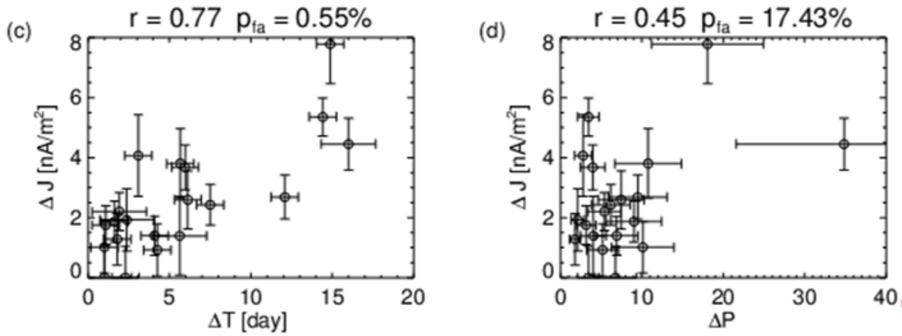
Thermal current

- The thermal current density is the field-aligned current carried by the source magnetospheric electrons without a field-aligned acceleration.
- Tao et al., [2015] estimated thermal current density ($J_{//0}$) from EUV spectrum.

$$j_{//0} = eN_0 \left(\frac{k_B T_0}{2\pi m_e} \right)^{1/2}$$

- We made the same procedure to calculate correlation between variation of thermal current density (ΔJ), ΔT, and ΔP.

➔ΔJ also has correlation with ΔT, but does not have correlation with ΔP.



Effect of volcanic activity on Jovian aurora

ΔTΔI relationship before and after the volcanic event

- If the mass loading process controls the solar wind response of aurora, ΔT-ΔI relation changes by mass loading rate.

➔we made same analysis after the volcanic event.

- Aurora becomes brighter with shorter ΔT.

➔support our scenario

- However, these events include both externally driven (i.e., solar wind) and internally driven enhancement of the EUV aurora. We should check carefully for each event.

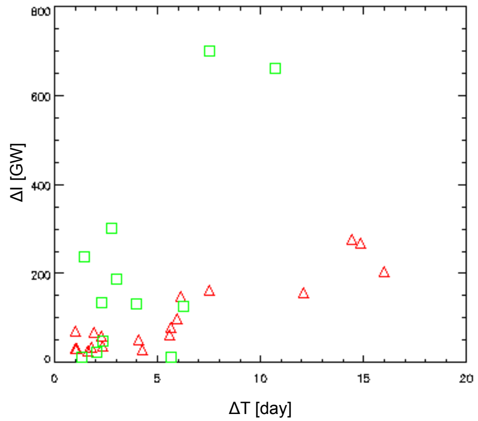
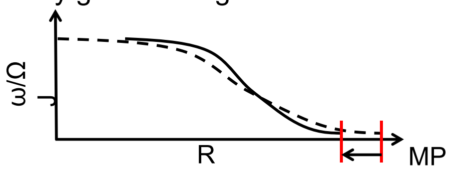


Figure ΔT-ΔI relationship before the volcanic eruption (Red) and after the volcanic eruption (Green).

Hypothesis

A) Mass loading increases the electron density in the Jovian middle magnetosphere and it might increase thermal current. Auroral power enhancements are associated with increases of thermal current in the middle magnetosphere.

B) The more plasma supplied from Io, the heavier Jovian magnetosphere becomes. Under this condition, the solar wind compression might not affect inside magnetosphere, and angular velocity gradient is generated in the middle magnetosphere.

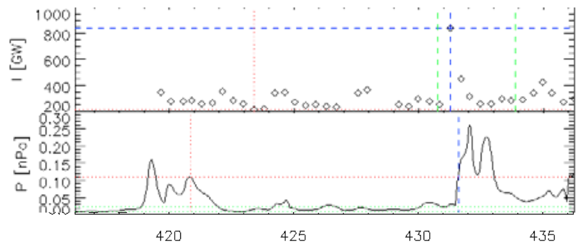


C) The solar wind compression induces reconnection and particle injection at middle magnetosphere, thermal current increases and aurora brightens and expands to the lower latitude.

However, we cannot identify one or a combination of these scenarios for auroral time variation.

Future works

- EUV variations obtained from HISAKI observation are explained by combination of several mechanisms.



➔internally driven or solar wind event??

- HISAKI does not observe morphological variation.
- Variation of angular velocity distribution cannot derive from EUV observation. (Super-rotation or sub-corotation)

Future works

- Morphological variations during the solar wind event (➔main oval and/or polar region and/or low latitude region??)
  - Long-term HST (May-June)
  - IRTF/SPEX (from Dec. 2015)

  (emission mechanism of IR and UV is different, but it gives us a clue to understand which region increases during solar wind event.)

- During solar wind compression magnetospheric plasma becomes superrotation or subcorotation ➔ Ion wind velocity
  - Superrotation → accelerate ionospheric plasma
  - Sub-corotation → decelerate ionospheric plasma

  Continuous HISAKI observation as well as infrared spectroscopic observation in IRTF/CSHELL

Summary

- We found that the correlation between the EUV intensity variation and the solar wind dynamic pressure, and aurora does not dim during compression period.

- We also found that the time duration of rarefaction region of the solar wind has correlation with the intensity variation, which had never been reported.
- Variation in the thermal current has correlation with the duration of the rarefaction region.

  ➔Mass loading process might control Jovian EUV aurora.

- We propose several variation mechanisms, however, we cannot identify one or a combination of these scenarios for auroral time variation.