Symposium on Planetary Science 2013

# Investigation of the solar UV/EUV heating effect on the Jovian radiation belt based on radio/infrared observation

## 太陽紫外線による熱圏大気加熱が木星放射線帯に及ぼす影響 -電波・赤外望遠鏡観測にもとづく考察-

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# Introduction

## Jupiter's Synchrotron Radiation (JSR)

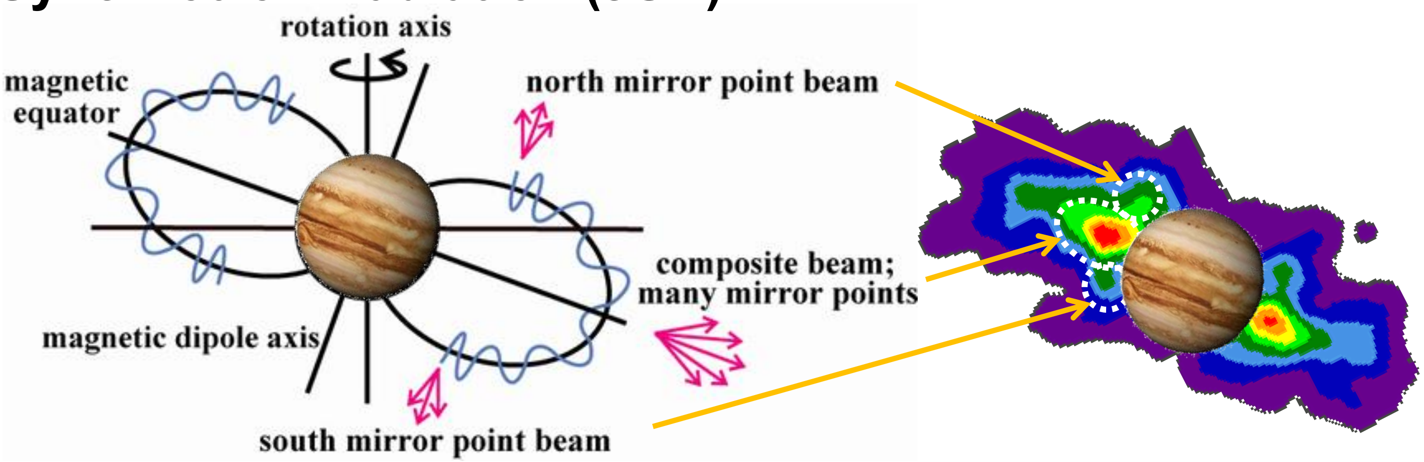



Fig.1. (Left) Schematic figure of Jupiter synchrotron radiation (Carr et al.1983). (Right) Interferometric image of Jupiter's synchrotron radiation from GMRT observation.

- Highly energetic electrons exist in the radiation belt

  few hundreds keV ~ 50 MeV ➔Difficult to observe by spacecraft
- Emitting power and frequency of synchrotron radiation

$$p = 6\times10^{-22} B^2 W^2 \sin^2\alpha \ \ [\mathrm{W}] \qquad f_{\max} = 4.8\times BW^2\sin^2\alpha \ \ [\mathrm{MHz}]$$

➔represent information of relativistic electron in Jupiter's radiation belt

<u>JSR is the most effective prove for remotely sensing of radiation belt from the Earth.</u> <u>We can obtain information on the dynamics of radiation belt.</u>

# Introduction

**Time variation phenomena of JSR**

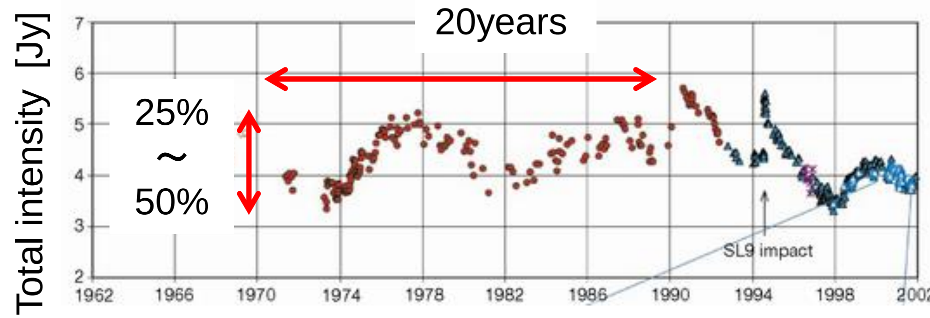
JSR have thought to be stable for a long time

➔due to the intense magnetic field around radiation belt

**Long term variations**

– few years order

– 25~50% variations




**Short term variations**

– After the collision of SL-9, observations of JSR have been intensively made

– few days ~ few months

– 10% variations

Mechanisms of short term variation have not been revealed yet

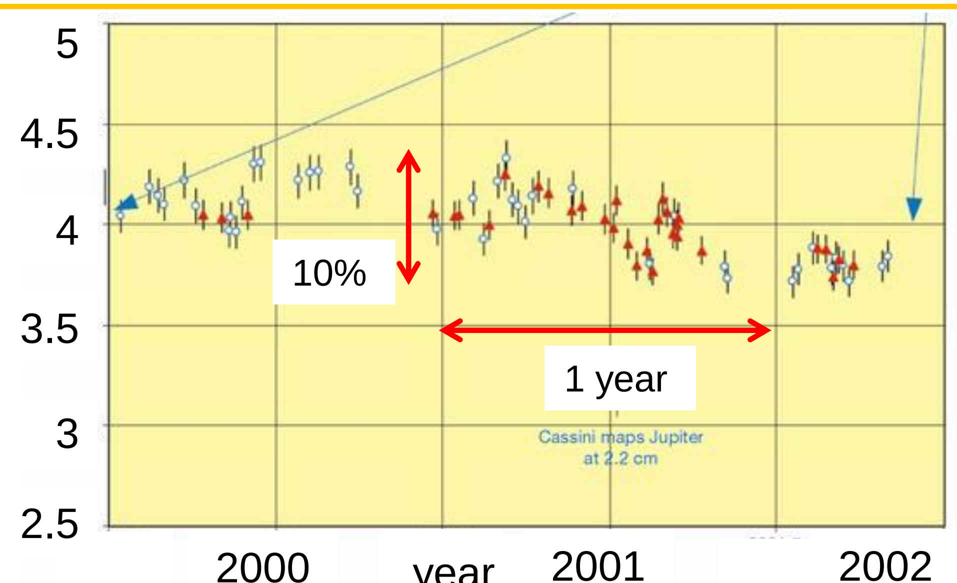



Fig.2. JSR long and short variations (Bolton et al. 2002)

# Introduction

**Expected mechanism of short term variations (Brice & McDonough 1973)**

Solar UV/EUV enhancement

↓

①Temperature of upper atmosphere increase

↓

②Neutral wind perturbation increase

↓

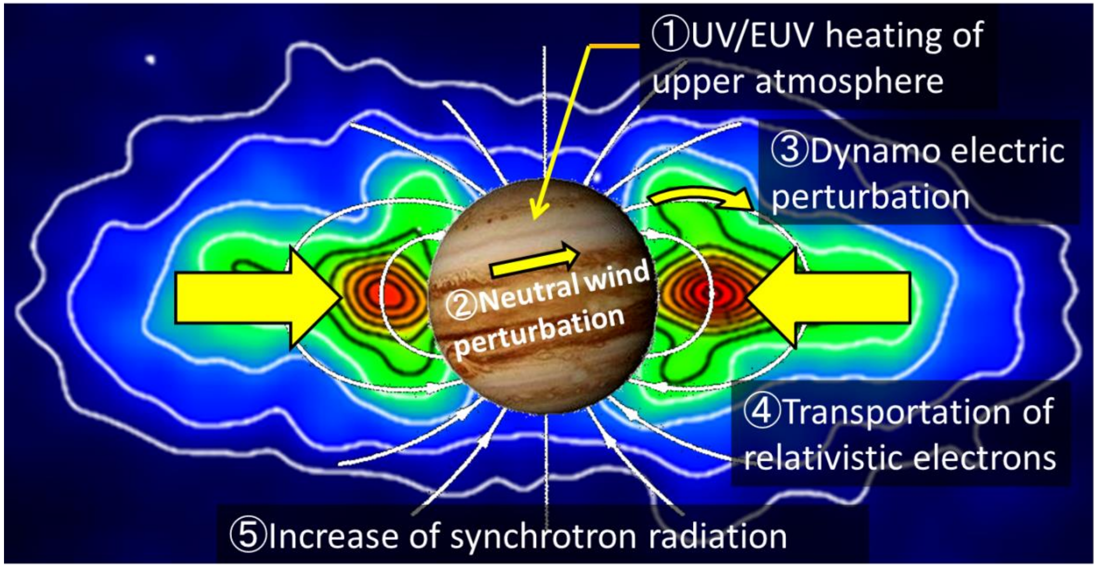
③Dynamo electric field perturbation increase

↓

④Radial diffusion increase globally

↓

⑤Intensity of JSR increase




⑤Equatorial peak move inward

Fig.3. Scenario of the short term variation proposed by Brice & McDonough 1973

# Introduction

## Total flux vs solar UV/EUV

- Observation of JSR at 325MHz is well correlated to the MgII index with lag time 3-5 day

## Brightness distribution vs solar UV/EUV

- The total flux density varied from 5.4 Jy to 6.5 Jy
- Equatorial peak move inward

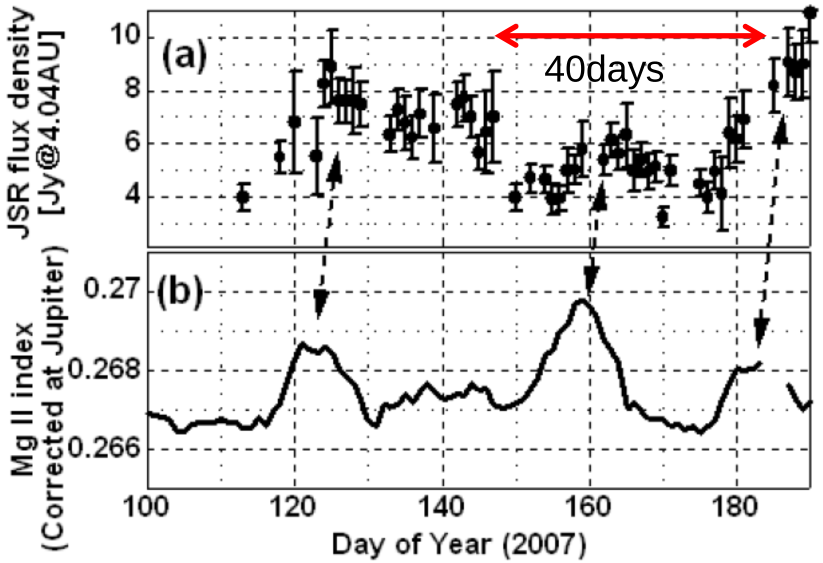
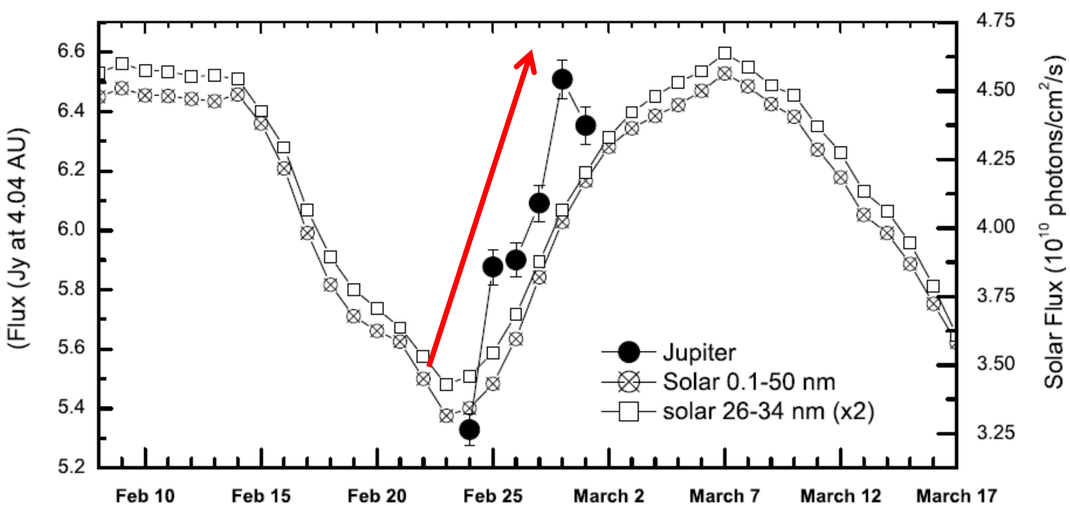



Fig.4. Variations in total flux density of JSR at 325 MHz observed by Iitate Planetary Radio Telescope (IPRT) in 2007.(Tsuchiya et al. 2011)



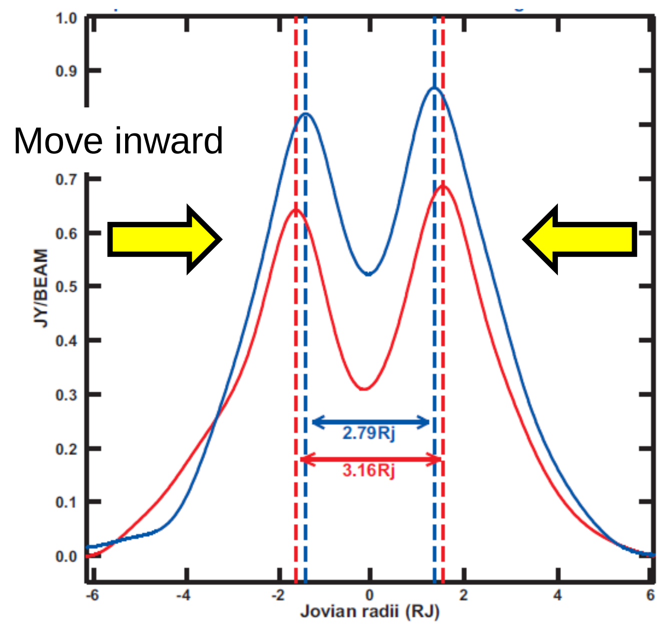
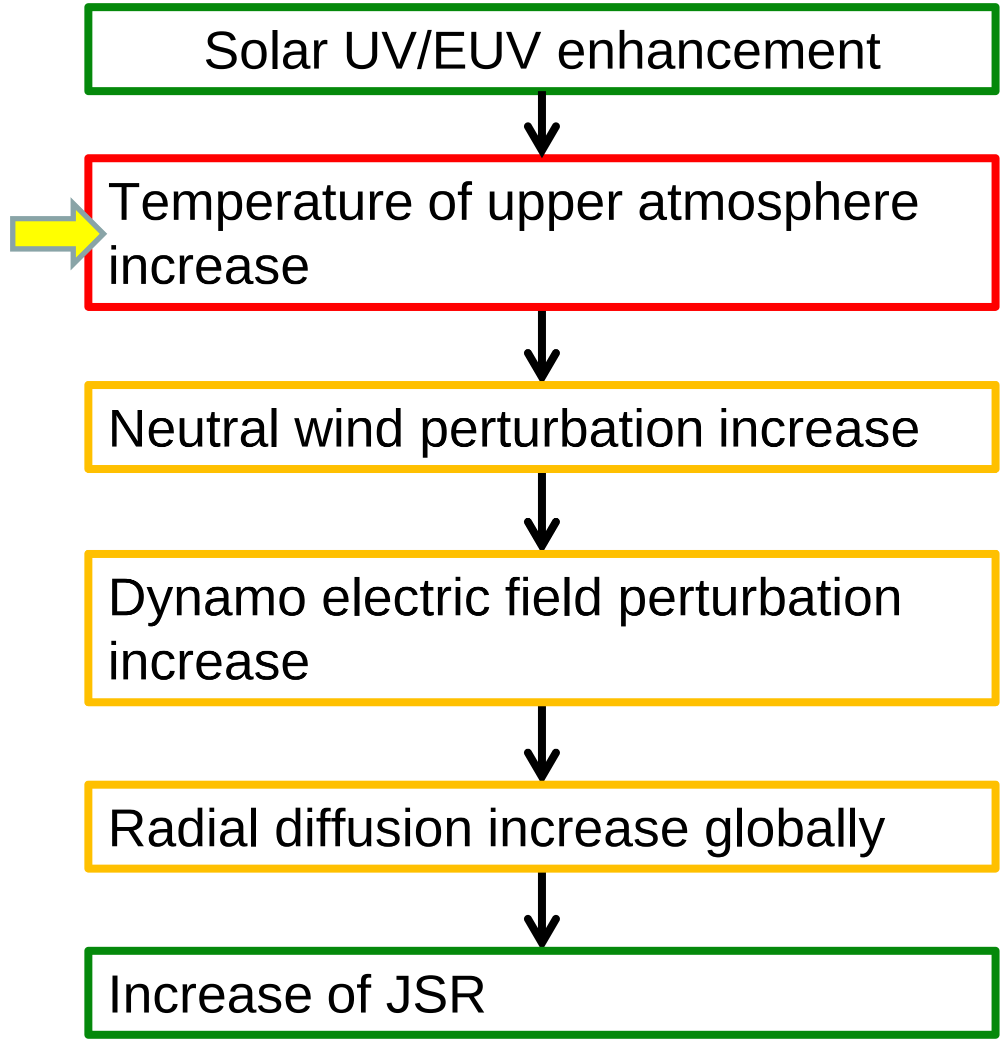




Fig.5. (Left)JSR observed by GMRT in 2003 and its variation was well correlated with solar UV/EUV (Bhardwaj et al. 2009). (Right) Equatorial profiles of 24th Feb and 28th Feb (Imai ,2009).

# Motivation

- Previous observation confirm the relation between solar UV/EUV and total flux of JSR.
- The temperature variations corresponding to the solar UV/EUV variations have never been investigated.
  - $H_3^+$ emission at low latitude is proportional to its temperature

➔We can obtain information on temperature variations of upper atmosphere.



# Purpose of This Study

**Purpose**

Investigate whether solar UV/EUV heating in Jupiter's upper atmosphere can actually causes JSR total flux and brightness distribution.

We made coordinated observations using the GMRT and IRTF.

**RADIO Obs:** GMRT、India (610MHz)

Total flux, spatial distribution

**OPTICAL Obs:** IRTF-CHELL, Hawaii ($H_3^+$ emission)

Emission intensity (use as an index of temperature)

# Observation

**Giant Matrewave Radio Telescope (GMRT)**

- Khodad, India
- 30 of 45m-antennas
- Y-shaped configuration
  (Long arm + central square)
- Frequency:150, <u>235</u>, 325, <u>610</u>, 1060-1420MHz
- Resolution: 5asec – 17amin @610MHz
- FOV: 43amin @610MHz

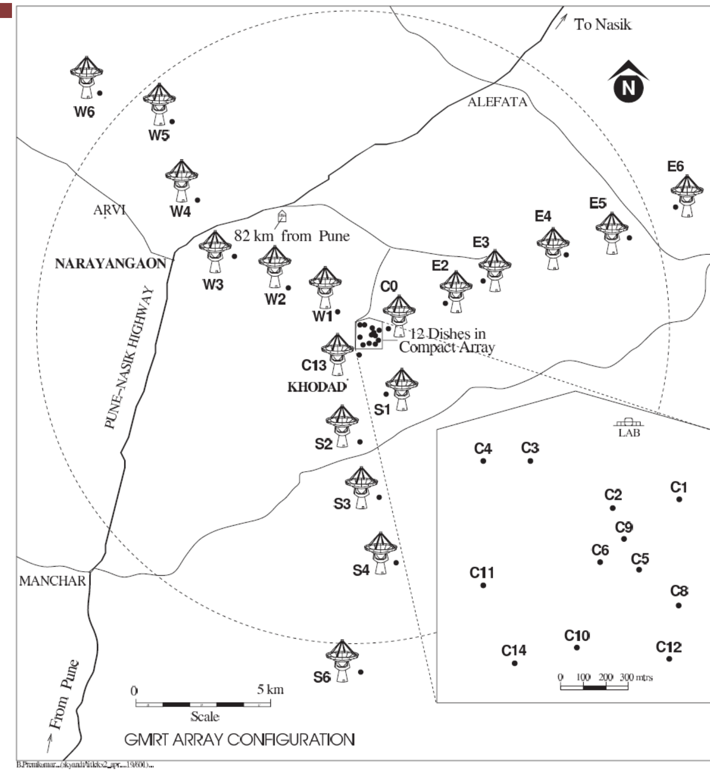
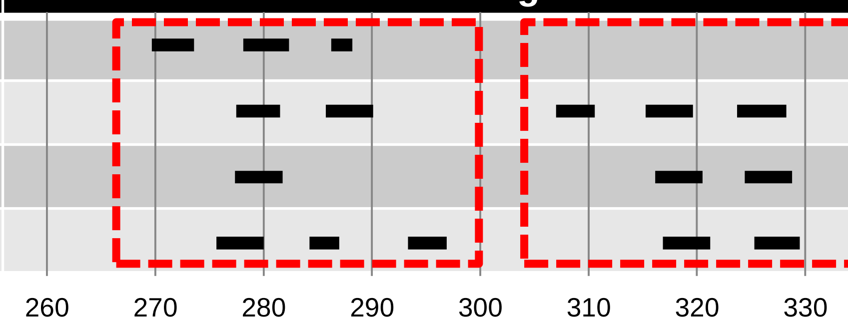



Fig.7. Array configuration of the GMRT

Table.1. Time schedule and CML coverage for each observation day of the GMRT 2011 campaign

| Date | Time(UT) | De | Distance | CML(° ) | CML coverage |
|---|---|---|---|---|---|
| 2011/11/06 | 14:06-15:01 | 3.28 | 3.98 | [270:288] | |
| 2011/11/08 | 15:45-18:07 | 3.27 | 3.99 | [278:328] | |
| 2011/11/12 | 19:17-21:35 | 3.25 | 4.01 | [278:329] | |
| 2011/11/17 | 18:13-20:38 | 3.22 | 4.04 | [276:330] | |



# Observation

**Nasa's InfraRed Telescope Facility**

- Mauna Kea, Hawaii
- 3m telescope

**CSHELL**

High resolution single-order echelle spectrograph

- Slit width: 0.5 asec
- Resolution: $\lambda/\Delta\lambda=43000$

Target

- $H_3^+$ Q(1,0-) 3.953μm
- Equatorial emission intensity
  (Use as a index of temperature)

- 7th Nov Exposure 240 sec
- 13th Nov Exposure 360 sec

Fig.8. IRTF 3m telescope

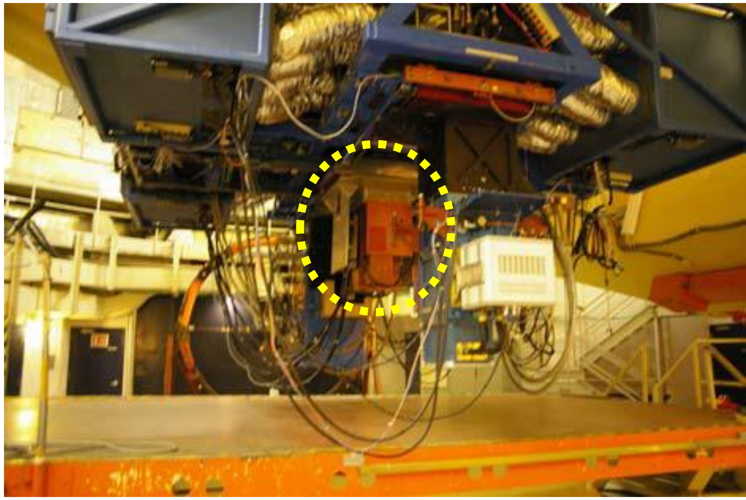


Fig.9. CSHELL spectrometer

# Data Reduction

**Total flux**

①Split each observation into ~30 degrees in Jupiter's rotation

②Make image with resolution of ~1 Rj

③Integrate within emission region and measure integrated flux density

④Subtract thermal emission (500K ~ 0.25Jy, de Pater et al. 2003)

⑤Considering the longitudinal dependence of JSR, weighted average each flux using beaming function (Klein et al. 1989).

$$S = A_0\left[1+\sum_i^3 A_i \sin\{i(\mathrm{CML}+\phi_i)\}\right]$$

S: Flux density at each CML

$A_0$ Averaged flux density

$A_i$ $\Phi_i$ Coefficients as a function of De

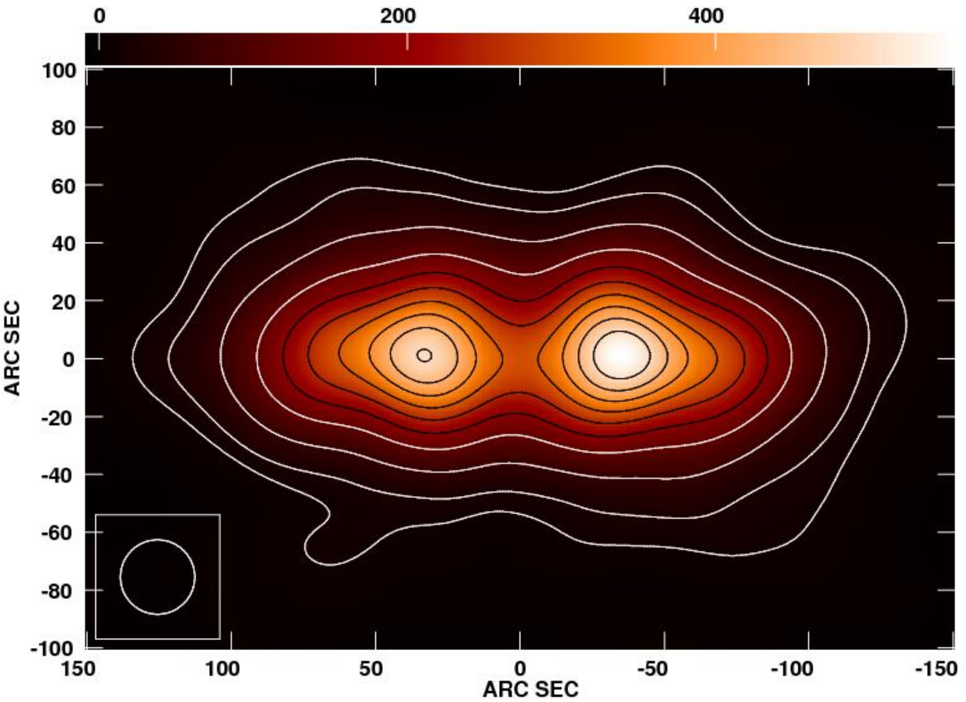



Fig .10. JSR image derived from GMRT observation in 2011. The contour levels are set at 5, 10, 25, 50, 75, 100, 125, 150, 175 and 200σ (σ:back ground rms level)

# Data Reduction

## $H_3^+$ emission intensity

- Sky, dark and flat calibration
  - Subtract sky image
  - Divide by normalized flat image

$$ADU_{obj} = \frac{ADU_{raw} - ADU_{sky}}{(flat - dark)_{norm}}$$

- Flux calibration
  - Sky, dark and flat calibration of standard star
  - Count standard star emission

$$I_{obj} = \frac{\sum_{\lambda} ADU_{obj}}{\sum_{spatial} ADU_{std}} \frac{\delta\lambda}{\Omega} \frac{t_{std}}{t_{obj}} F_{std}$$

δλ: wavelength/pixcel
Ω : solid angle of 1pixcel x slit
Z :airmass
t : integration time
F :standard star flux

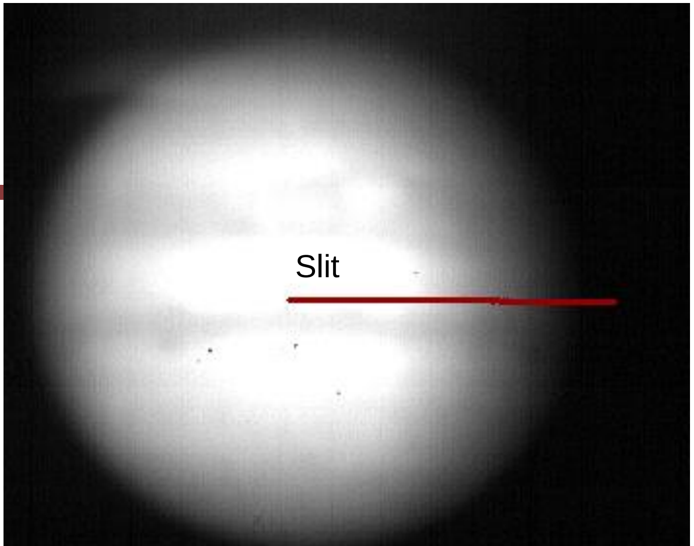



Fig.11. Slit position of IRTF-CSHELL on 11/07.

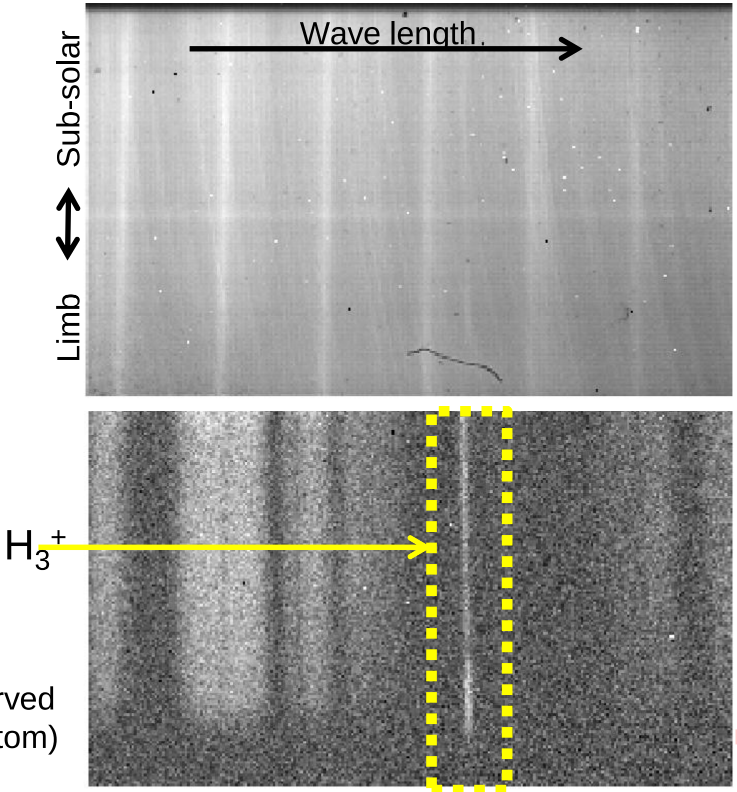



Fig.12. Example of H3+ emission line observed by IRTF-CSHELL (Middle) Raw image, (Bottom) Sky, dark and flat calibrated image

# Result

- **Solar UV/EUV index (SOHO/SEM)**
  - Range : 0.1-50 nm
  - Shifted by -1 day, considering Sun-Jupiter-Earth angle

➔Increase and decrease gradually

- **Total flux density**
  - Max amplitude variation ~5%
  - correlated with solar UV/EUV

➔<u>Caused by increase of radial diffusion??</u>

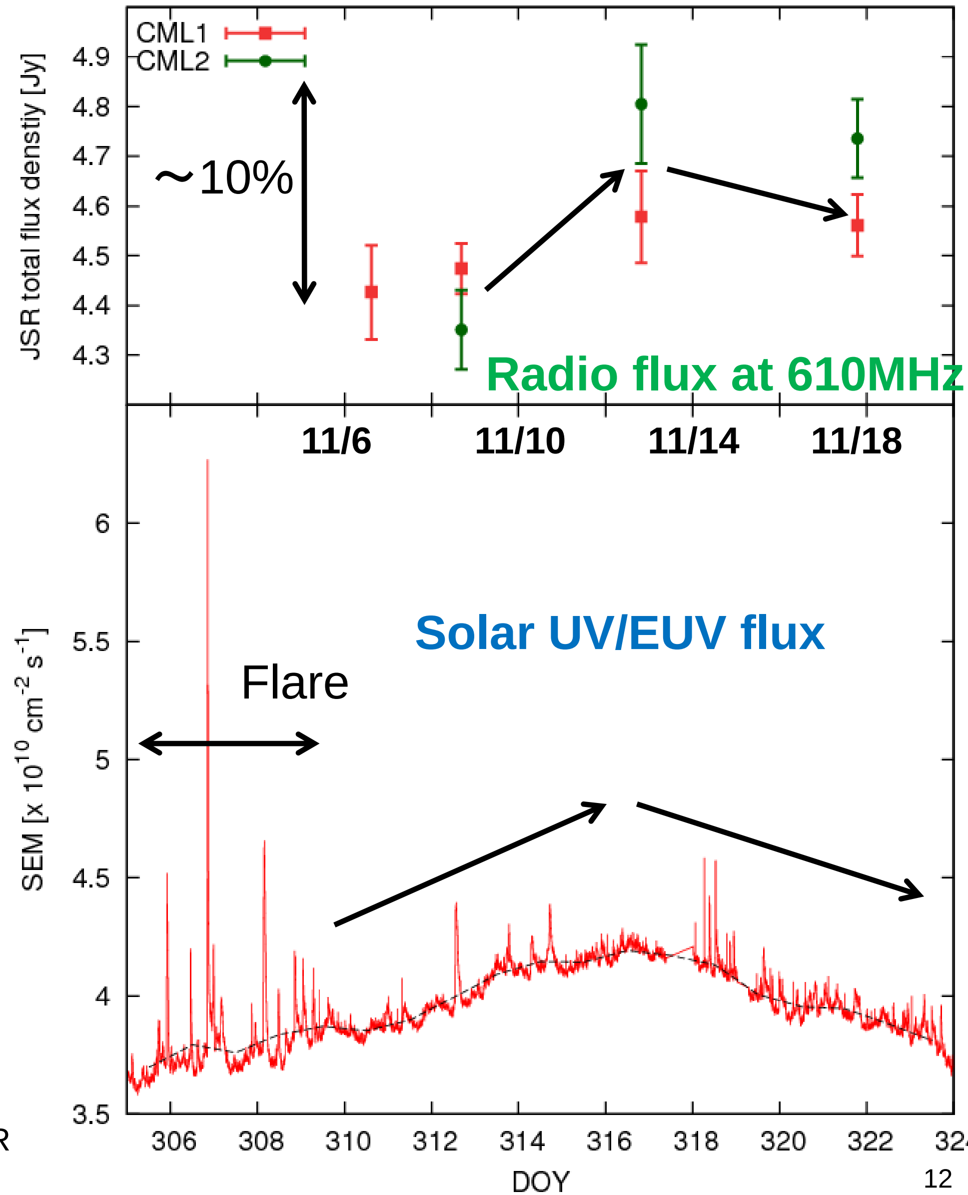



Fig.13. Variations of total flux density of JSR obtained from GMRT observation in 2011

# Result

**$H_3^+$ intensity variation**

- Emission intensity increase from 11/07 to 11/12 by 20-30%

➔ <u>Temperature is expected to increase</u>

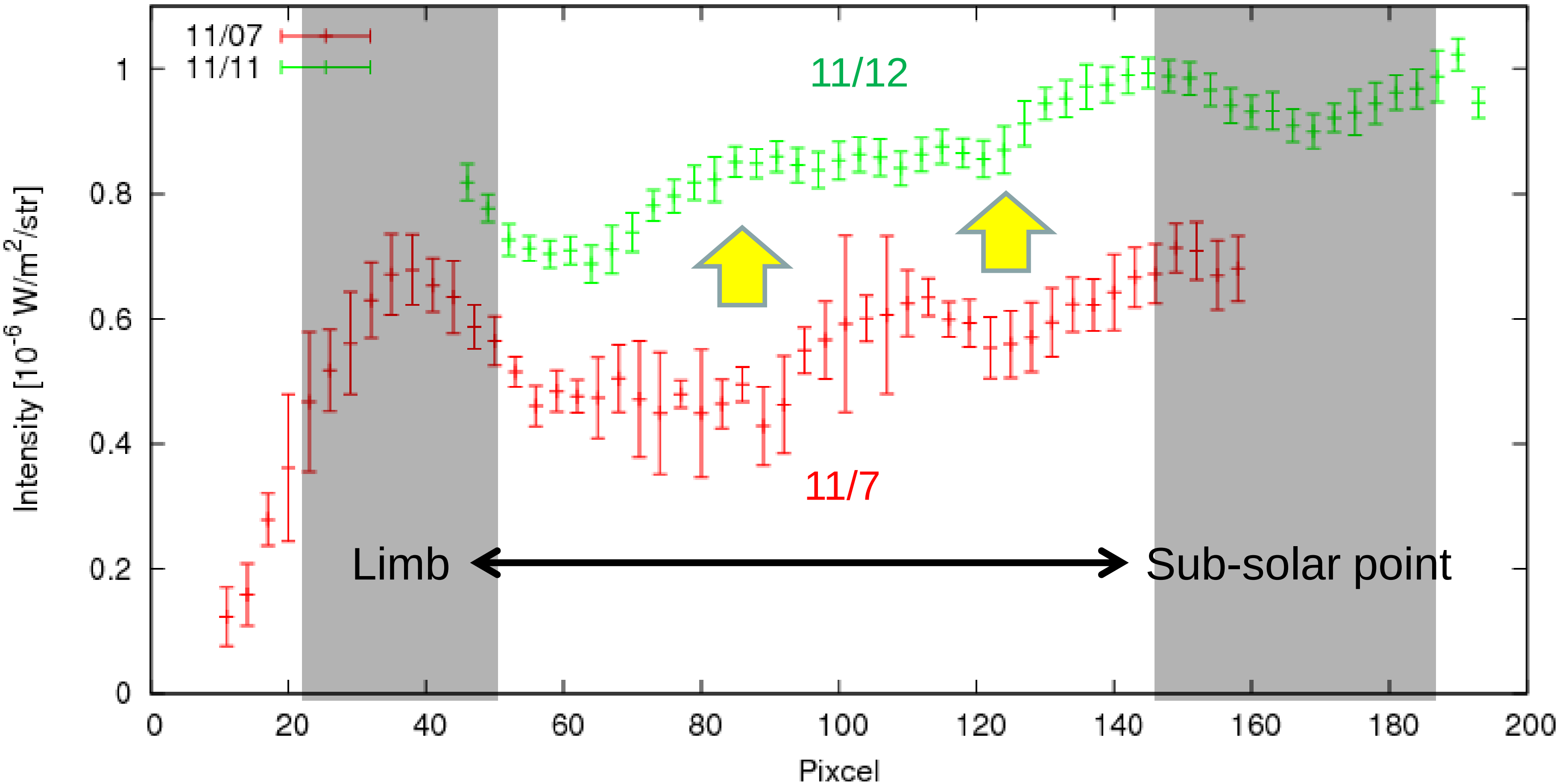



Fig.14. Radial distribution of Jovian H3+ emission at the equator. Data is running-averaged by 20pixcel.

# Discussion

**Slice profile along magnetic equator**

- Peak position moved "outward"

➔ <u>Different from global enhancement of radial diffusion</u>

➔ <u>Non-uniform change of radial diffusion</u>

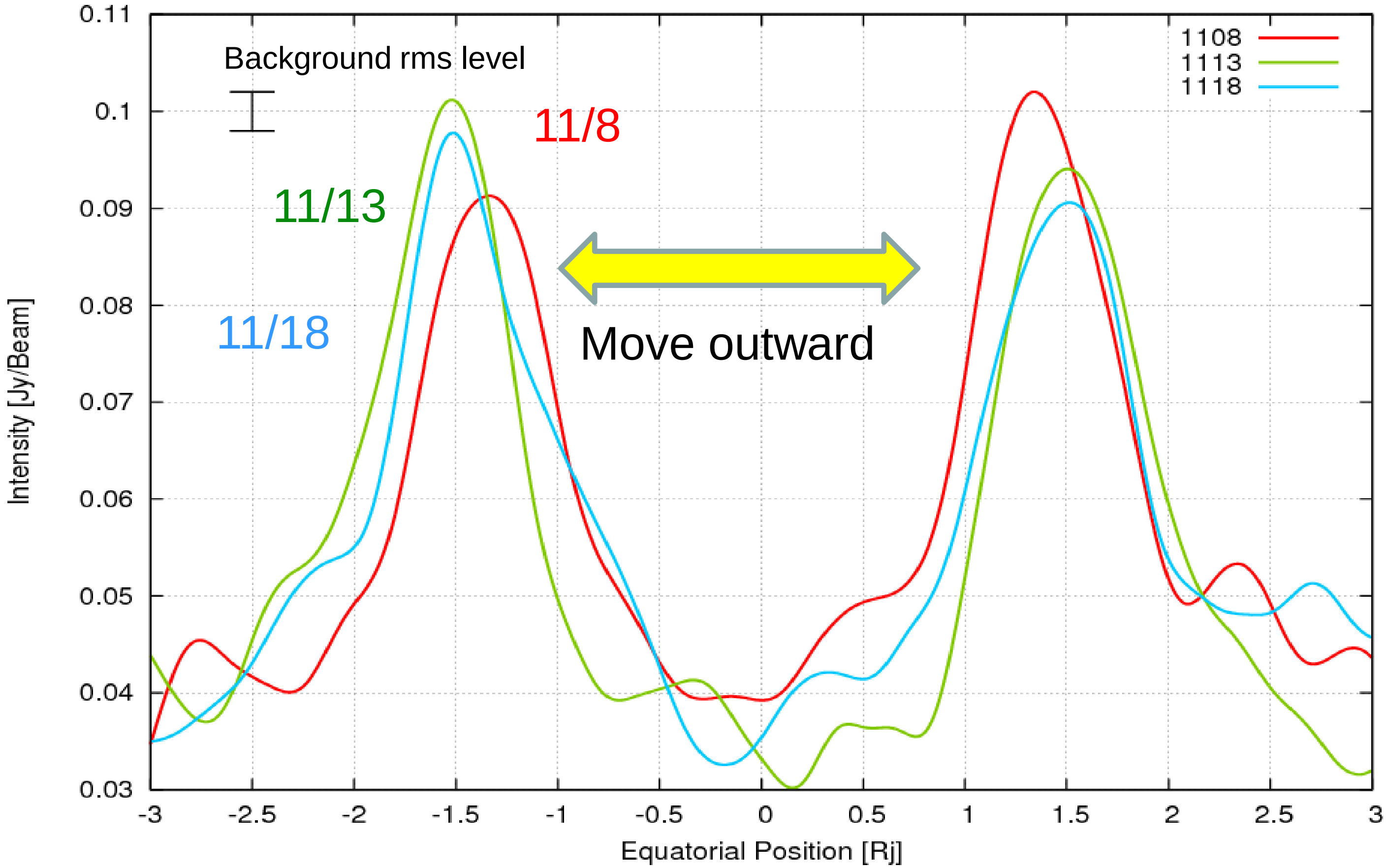



Fig.15. Slice profile along the magnetic equator on 11/8, 11/13 and 11/18

# Discussion

**Non-uniform enhancement of radial diffusion**

➔Explained by a numerical simulation study of the Jovian upper atmosphere (Tao et al. 2010)

– Temperature variations induced by the solar UV/EUV enhancement propagate from the auroral latitude to low latitude region.

– Enhancement of radial diffusion at the outer region

– Shift the equatorial peak position outward.

Radial diffusion increased not globally but locally at the outer region only around L=2-3 during this period.

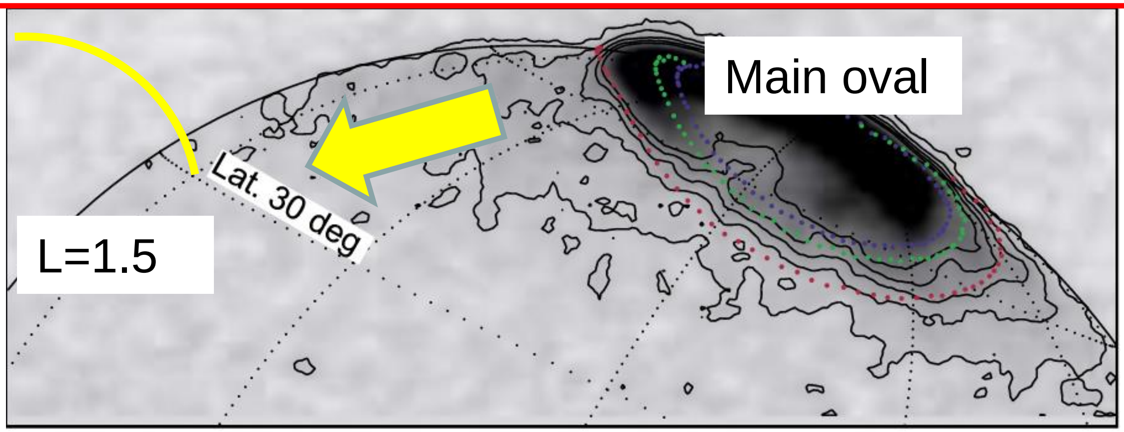



Fig.16. Schematic figure of non-uniform enhancement of radial diffusion

# Summary

In order to evaluate the effect of solar UV/EUV heating on JSR, we have made coordinated observations using GMRT and IRTF.

- Total flux density varied corresponding to the solar UV/EUV flux
- $H_3^+$ emission intensity increased

⇕

- Peak position moved outward

➔Somewhat different from global enhancement of radial diffusion by solar UV/EUV heating.

➔We propose the possibility of non-uniform enhancement of radial diffusion at outer region.

- Future prospect
  - Detail mapping of $H_3^+$ emission and daily base observation
  - Temperature measurement using intensity ratio of $H_3^+$ emission line