Radio and Optical observations of magnetospheres of outer planets

F. Tsuchiya (Tohoku Univ. Japan)

Outline of this talk

1. Brief introduction on the magnetospheres of outer planets and the radio and optical observations with ground based telescopes.

2. Radio emission from Jupiter’s radiation belt

   Synchrotron radiation emitted from relativistic electrons trapped in the dipole magnetic field

3. Optical emission from the Io plasma torus

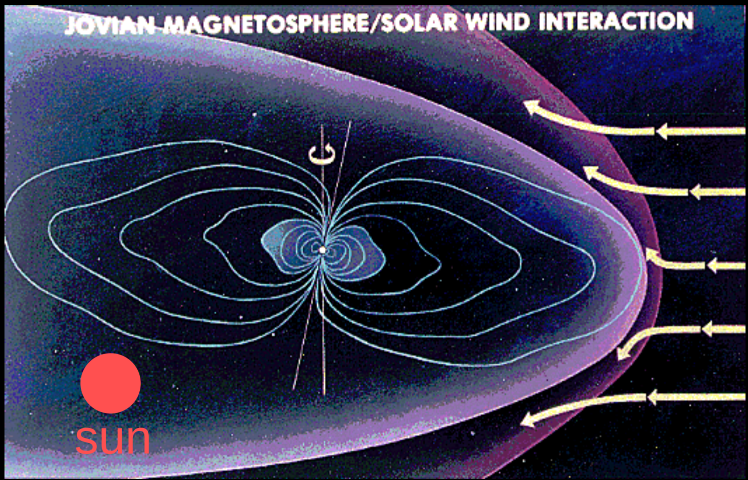
   Forbidden transmission lines in visible range which can be observed by the ground based telescope

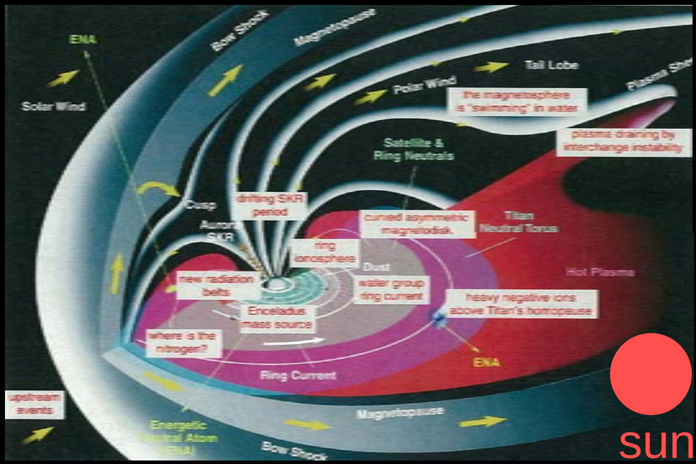
   Allowed transmission lines in EUV range which is planned to observed by the EXCEED/Sprint-A mission

Introduction : magnetospheres of outer planets

- Outer planets (Jupiter & Saturn) have huge magnetospheres due to their strong magnetic fields, fast rotations (10 hours), and internal plasma sources (Io and Enceradus).
- They have different type magnetospheres from the earth.
  - Planetary rotation driven (J,S) vs. The solar wind driven (E)
  - Unique characteristics which are not seen in the terrestrial magnetosphere:

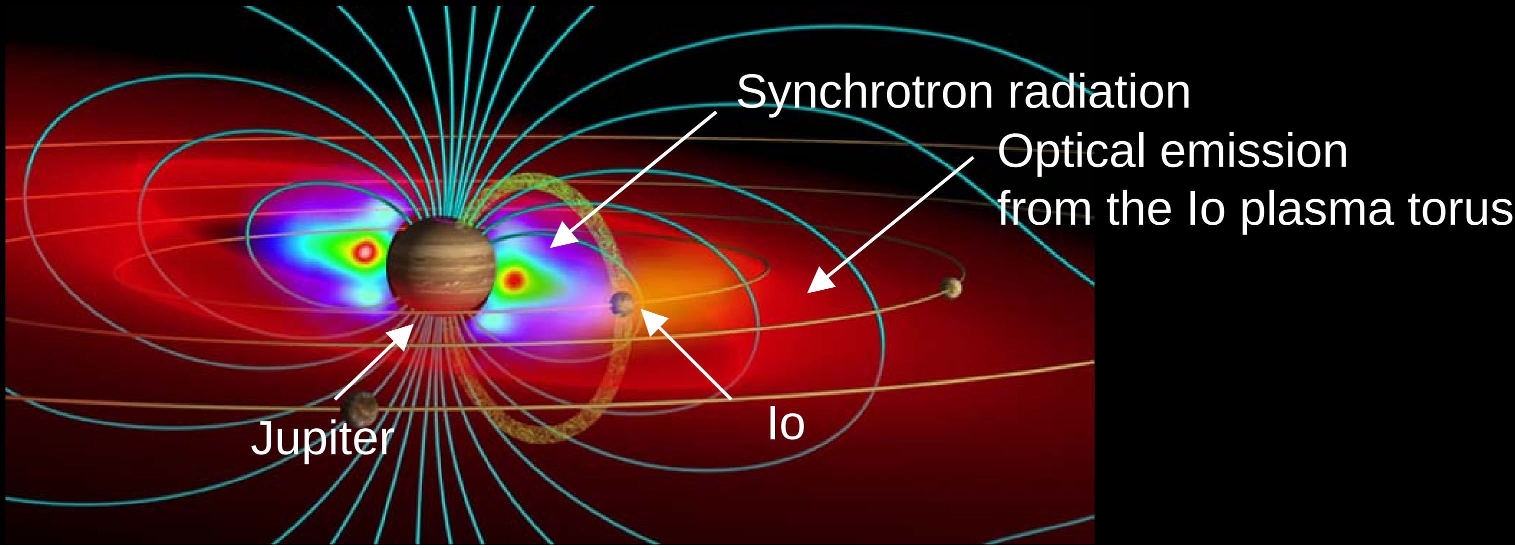
    Interaction with the planetary atmospheres, rings, and moons.





Introduction : Remote sensing from the earth

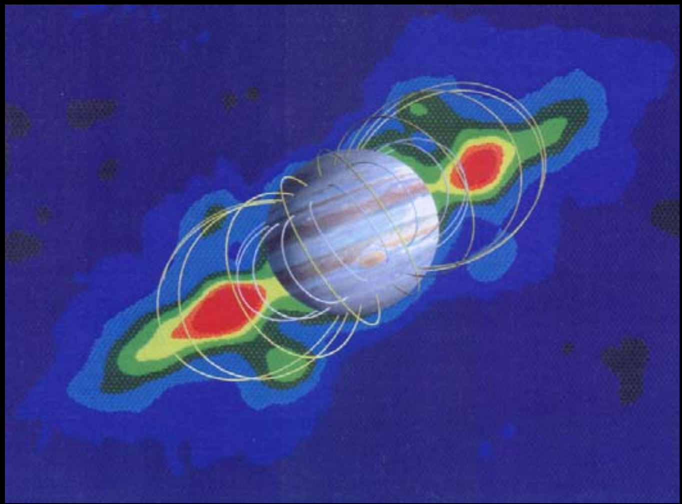
- There are some radio and optical emissions around Jupiter which are strong enough to observe from the earth
- We will focus on two kinds of non-thermal emissions
  - Radio emission from Jupiter's radiation belt
    - Synchrotron radiation emitted from relativistic electrons trapped in the dipole magnetic field
  - Optical emission from plasma and neutral gas in the Io torus
    - Forbidden & allowed transmission lines



Synchrotron radiation from Jupiter's radiation belt

F. Tsuchiya, H. Misawa, A. Morioka, K. Imai,
S. Nomura, T. Watanabe (Tohoku Univ.)
T. Kondo (NICT/Japan, Ajou Univ./Koria)

Observations of Jupiter's radiation belt



Spatial distribution of JSR observed by VLA at 1.4 GHz (Bolton & Thorne 1997)

Radiation belt:

Charged particles with relativistic energy are trapped in the dipole magnetic field.

In Jupiter, due to the strong magnetic field and large amount of trapped electrons, strong synchrotron radiation is emitted:

Jupiter's synchrotron radiation (JSR)

Useful tool to investigate the distribution and dynamic behavior of Jupiter's radiation belt

Radio interferometer: 2D distribution

→ There are only a few large interferometers to obtain clear 2D image

It is difficult to get enough machine time to find time variations

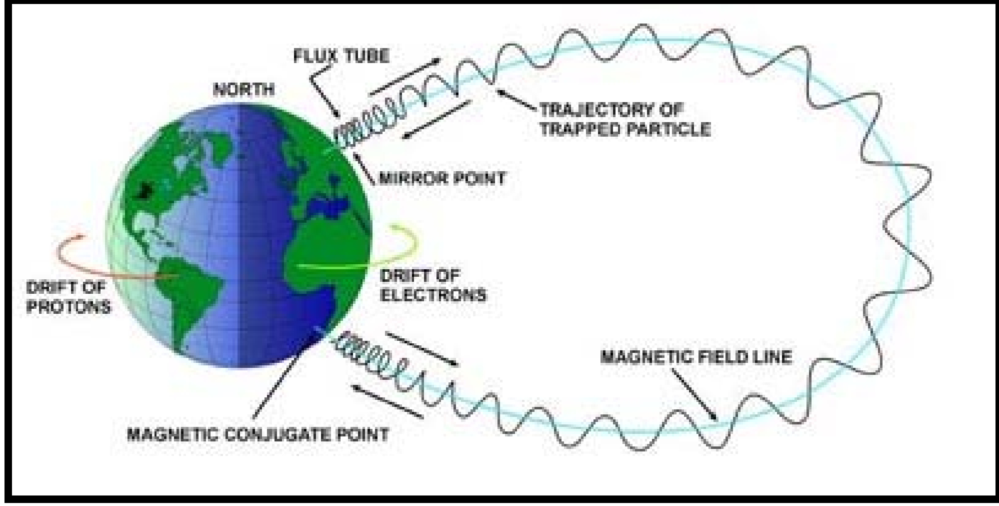
Single dish telescope

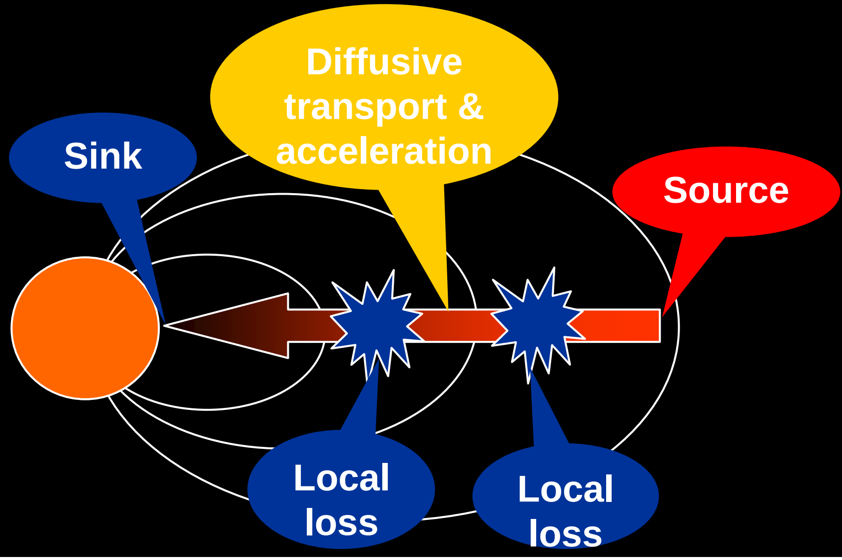
→ Useful tool to investigate the time variation

Radiation belt: Basic property

- The planet with strong magnetic field commonly has the radiation belt
- Charged particle in the planetary dipole magnetic field
  - Trapped on a certain magnetic field line
  - Sometimes de-trapped from the field line due to scattering by electro-magnetic waves, then diffuse inward or outward
  - Because the high-energy electron density increases with increasing radial distance from the planet, net particle flow due to the diffusion becomes inward
  - By diffusing inward, particles gain the energy by the betatron acceleration mechanism and form the relativistic radiation belt around the planets.

The important point is the origin of electro-magnetic wave which causes the diffusion

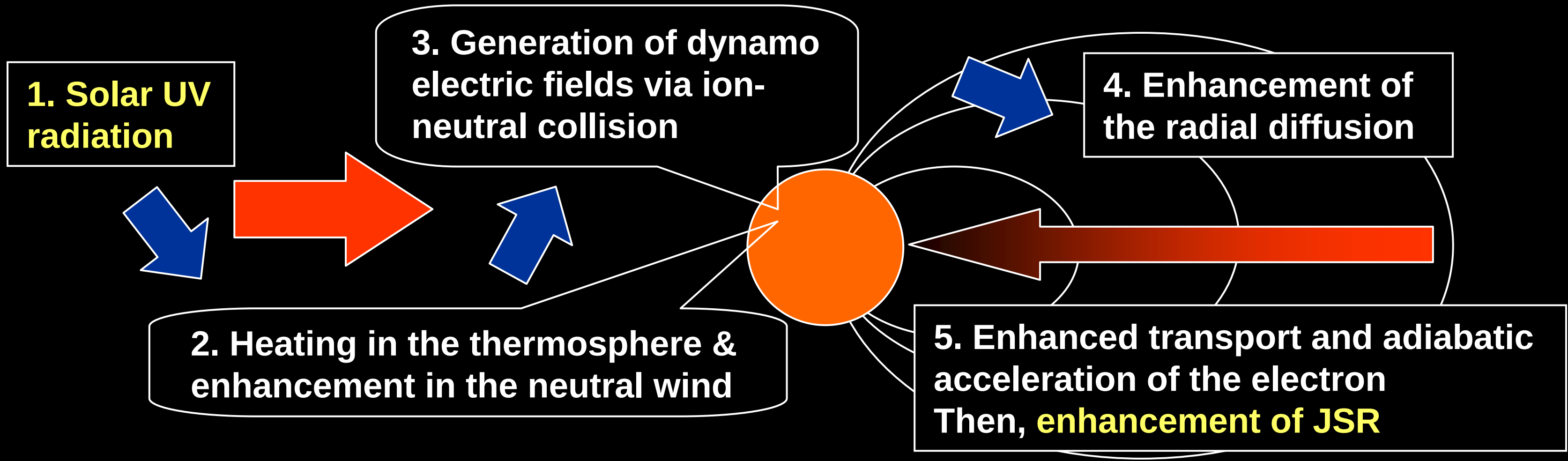




A Theory of radial diffusion in Jupiter's radiation belt

Theoretical prediction Brice and McDnough (1973)

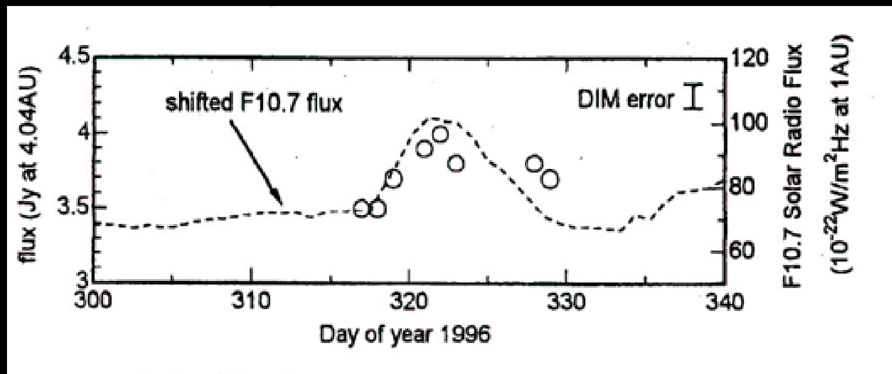
Thermospheric wind & dynamo E fields : A dominant driver of the radial diffusion
Short-term changes in JSR associated with the enhancement of the solar UV



Observational evidence:

Miyoshi et al. (1999)

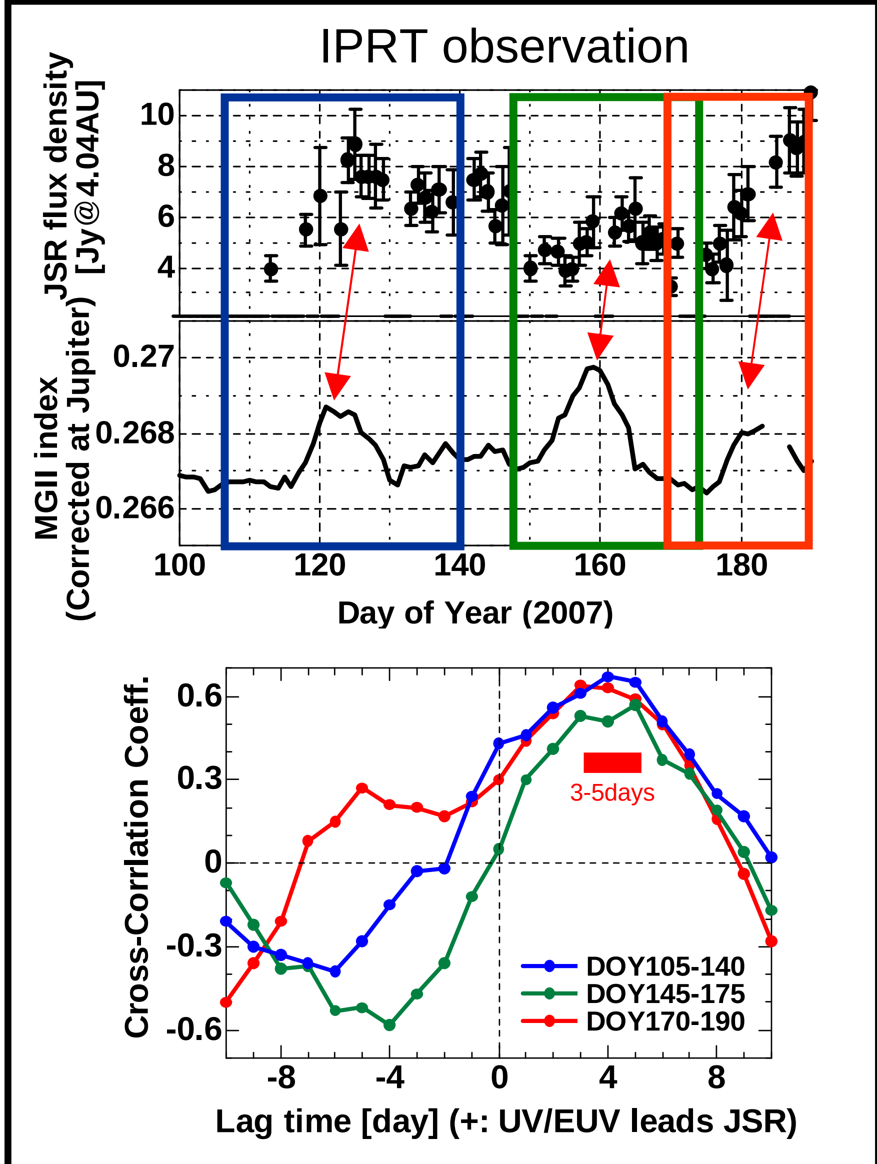
- A short-term change at a high frequency of 2.3GHz shows correlations with F10.7



JSR at 2.3GHz and the F10.7 flux
(Miyoshi et al. 1999)

Only one event has been observed at 2.3GHz
We need regular radio observation of JSR.

Observation of JSR by IPRT



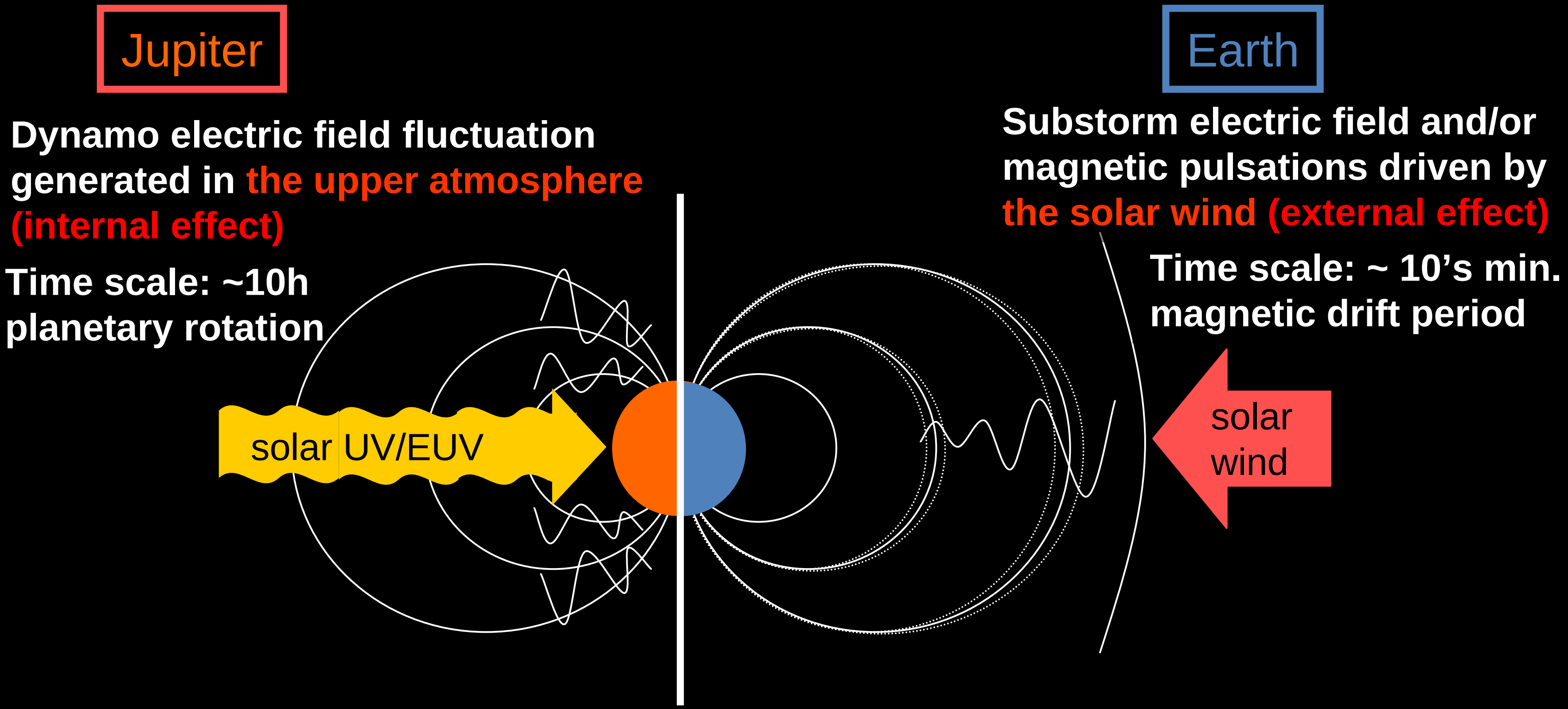
Time variation in JSR is a probe to investigate the time constant of the physical processes which dominate in Jupiter's radiation belt
For this purpose, regular observation of JSR has been made by IITATE Planetary Radio Telescope (IPRT).

<Results from the IPRT observation>
Clear evidence of the short-term variation in JSR & the correlation with the solar UV flux

The solar UV influences the Jupiter's radiation belt through the radial diffusion process.
This result is consistent with the theoretical prediction.

Comparison of the transport process: Jupiter vs. Earth

The radial diffusion is commonly occurred in the planetary radiation belts. But the driver of the diffusion in Jupiter is quite different from the earth.



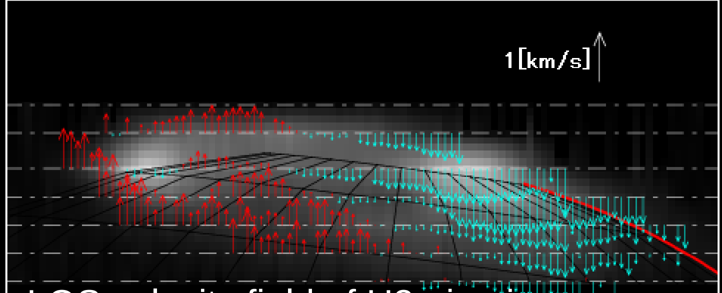
The radiation belt of Jupiter is strongly coupled with the upper atmosphere

Future perspective :

More observation by radio &
Collaboration with the thermosphere and ionosphere studies

The IR observations of ionosphere by IRTF and the development of IR echelle spectrometer has been started in Tohoku Univ.

by Dr. Sakanoi
Mr. Kobuna and Mr. Uno

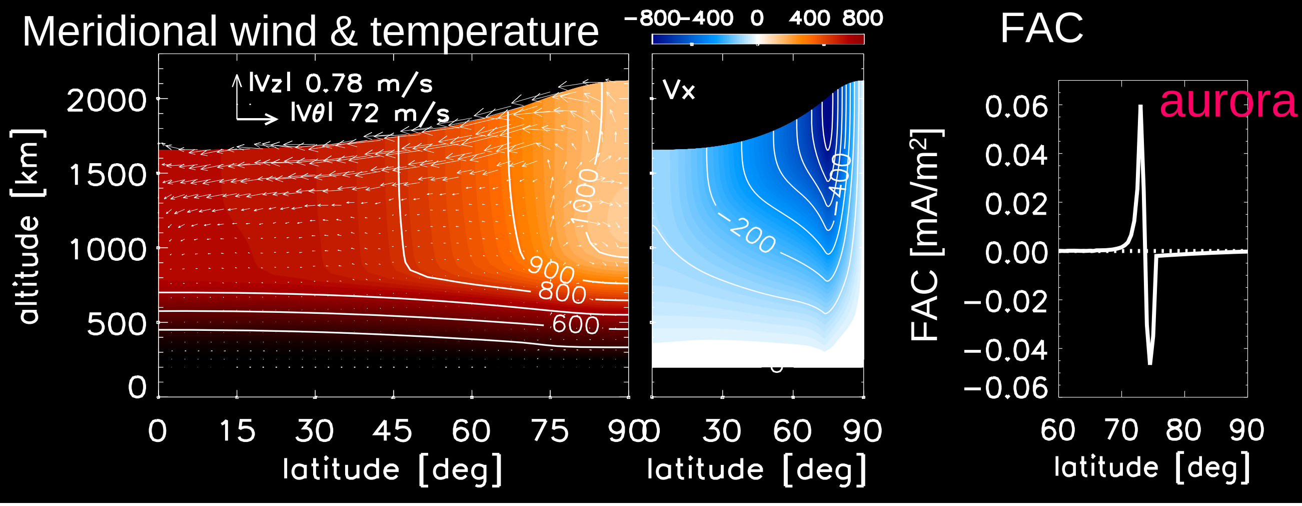


LOS velocity field of H_3^+ ion in the Jupiter's polar region

Simulation Model (Tao et al. 2009)

Development of codes which can calculate thermospheric heating and velocity field

Neutral-ion coupled dynamics contributes to currents system.



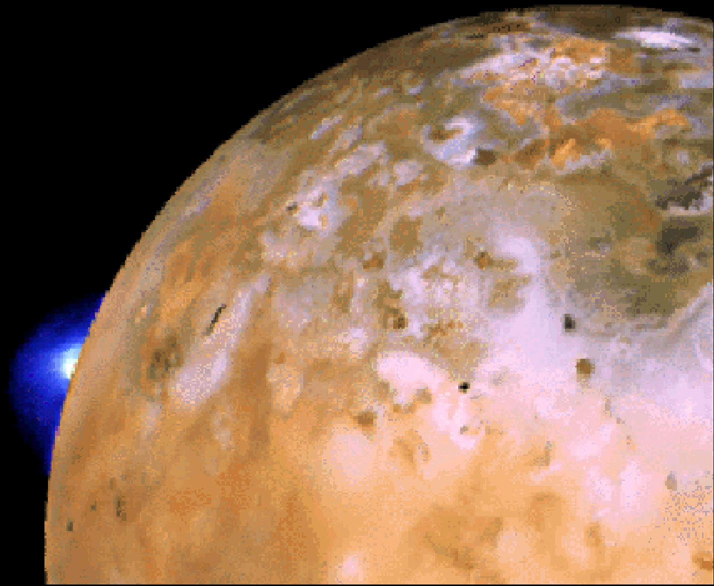
By Dr. Tao

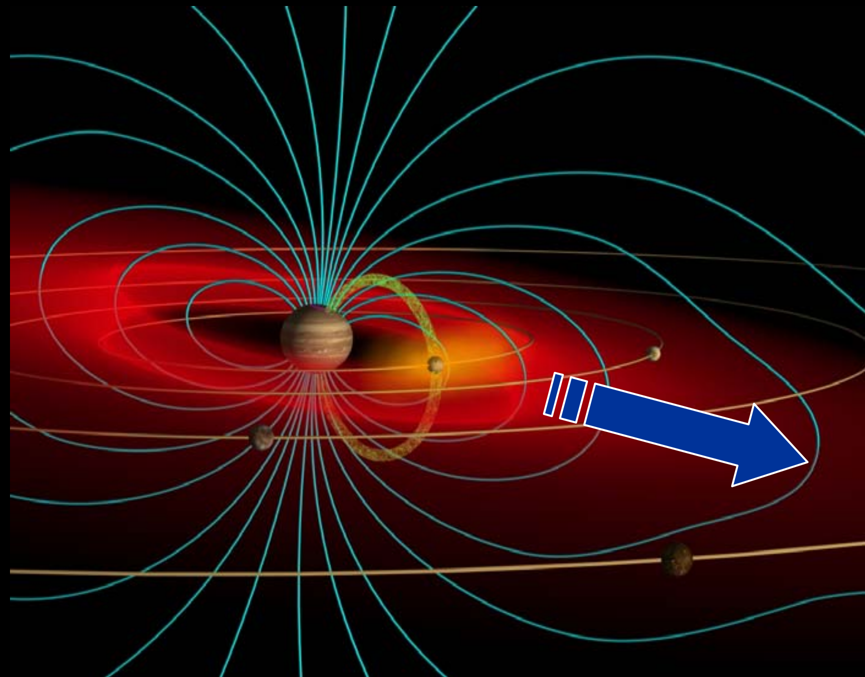
Optical observation of the Io plasma torus

H. Misawa, M. Kagitani, S. Okano (Tohoku Univ.)
H. Nozawa (Kagoshima College Tech.)

Io plasma torus

- The satellite Io has a lot of active volcanoes and releases the neutral gasses around Io.
- Iogenic gases are ionized by the impacts with electrons and ions and form the Io plasma torus.
- The plasma is transported outward and supports the structure of Jupiter's magnetosphere.
- 90% of mass of plasmas in the magnetosphere are originated from Io (~1ton/sec).
- Therefore it is expected that the change in the plasma source affects the property of Jupiter's magnetosphere.



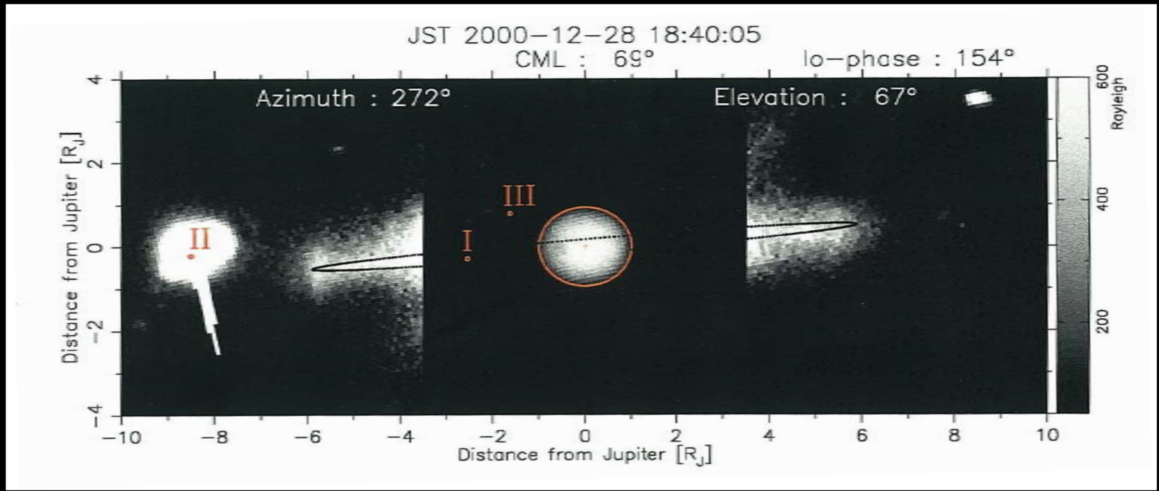


Optical observation of Io plasma torus from ground based telescope

Plasma source property in Jupiter's magnetosphere

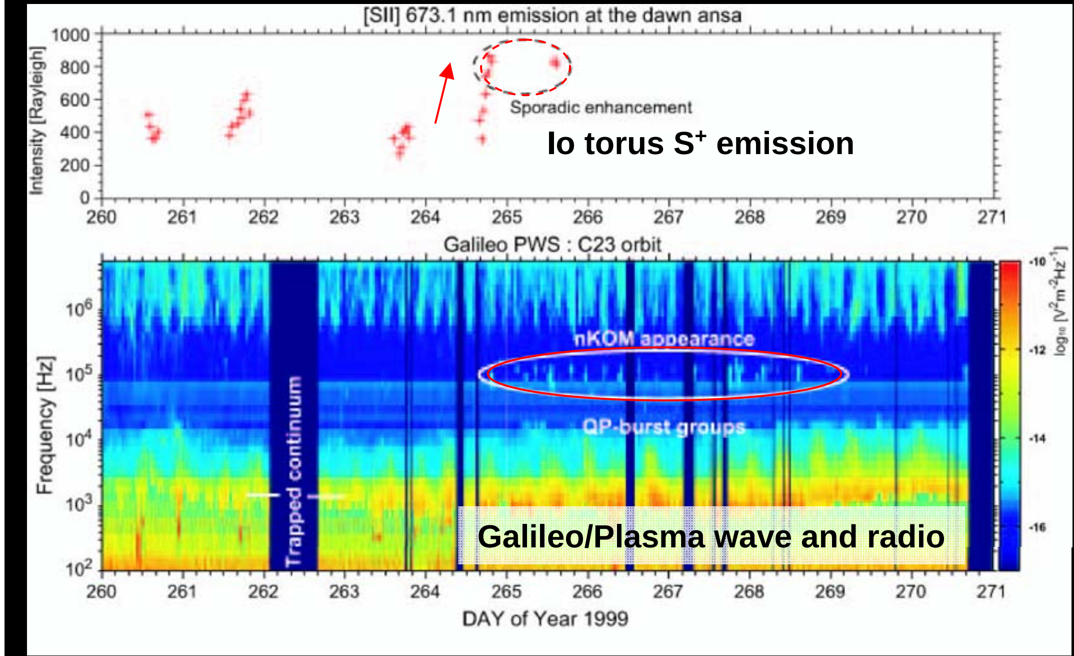
The observation of the Io plasma torus has been started with transportable observation system
35cm telescopes at Alice springs/ Australia (right)

40cm optical telescope at Haleakala/ Hawaii (left) which can be operated remotely from Japan.



Example of 2D image of the Io plasma torus (SII 673.1nm) taken by the transportable telescope

An example of observation results: Unexpected short-time scale event



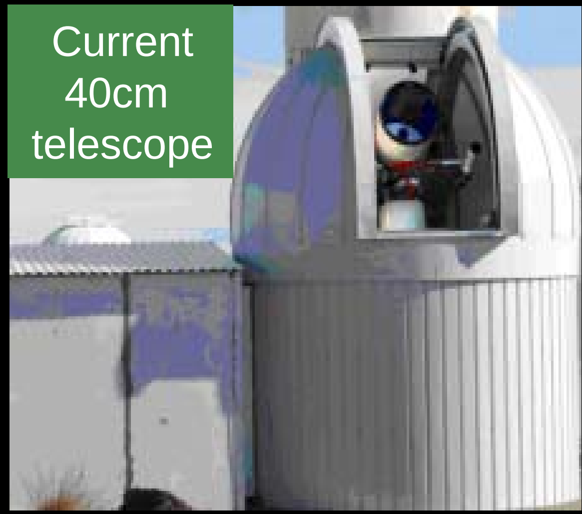
Long term & continuous observation is essential to find a sporadic event.

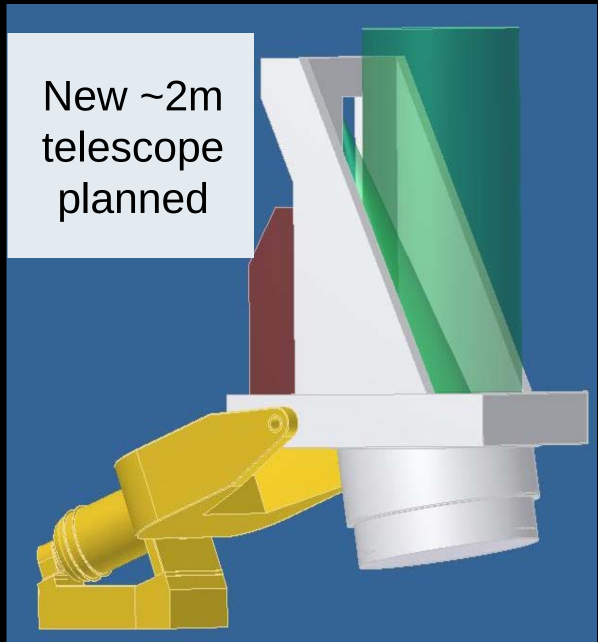
A sudden brightening of S^+ emission and an appearance of nKOM emission simultaneously (Galileo PWS). (Nozawa et al. 2006)

- nKOM is believed to emit from the outer edge of the Io torus and the appearance of nKOM is correlated with the solar wind. (Ulysses observations)
- These observations imply that the solar wind influences the plasma environment deep inside the rotation dominant magnetosphere.
- This phenomena can not be explained by the current understanding on Jupiter's magnetosphere

Future perspective

- Extension of the observations of the Io plasma torus & others
  - Continuous monitoring observation of the Io plasma torus by a optical telescope at Hawaii/Haleakala (Dr. Kagitani & Prof. Okano) & Australia (Dr. Misawa) which can be operated remotely from Japan.
  - Development of new 2.0m telescope in Haleakala (Dr Kagitani & Profs. Okano & Kasaba)
  - Satellite-based observation of the Io plasma torus in EUV by the EXCEED/ Sprint-A mission (first proved mission of the ISAS/JAXA small satellite series, launch : 2012)





Tohoku Univ. Haleakala Observatory with Univ. Hawaii (Maui, Hawaii)

Overview of the EXCEED mission

(EXtreme ultraviolet spectrosCope for ExosphEric Dynamics)

- An earth-orbiting Extreme Ultraviolet (EUV) spectroscopic mission
- The first mission of the ISAS/JAXA Small scientific satellite series (Sprint-A)
- EXCEED measures EUV emissions from tenuous gases and plasmas around the planets
- Observation targets : Mercury, Venus, Mars, Jupiter, and Saturn

Major specifications

- Launching : 2012
- Weight : 330kg
- Size : 1m × 1m × 4m
- Orbit : 950km × 1150km (LEO)
- Inclination: 31 deg
- Mission life : >1 year
- Pointing accuracy : ±1.5 arc-min (improved to be ±5arc-sec by using a FOV guide camera)

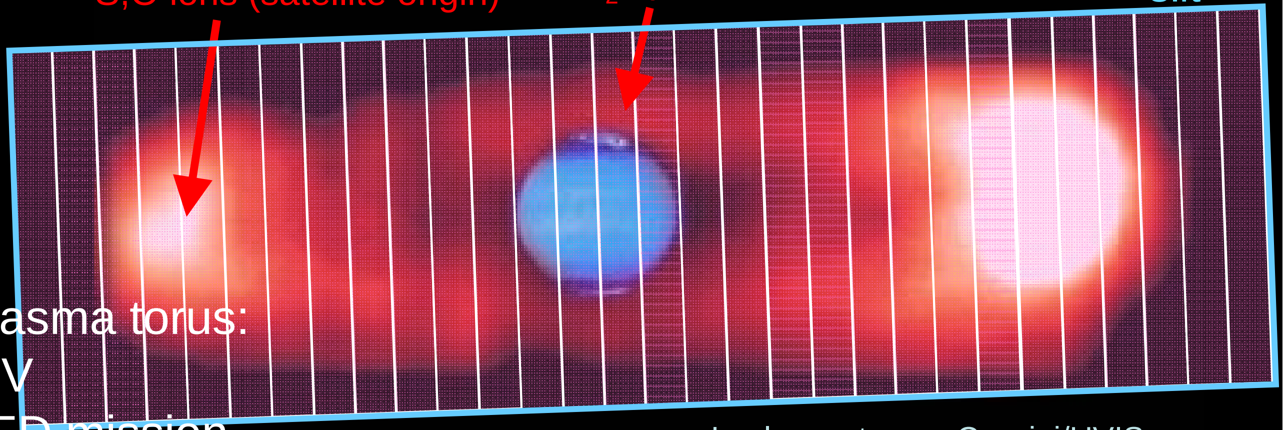
Project scientist:
Dr. Yoshikawa (Univ. of Tokyo) (yoshikawa@eps.s.u-tokyo.ac.jp)

Two main targets of the EXCEED mission

(1) Aurora and gas torus

Jupiter and Saturn

Jupiter's aurora & the Io plasma torus:
many emission lines in EUV
Good target for the EXCEED mission



Io plasma torus : Cassini/UVIS
Jupiter's UV aurora : HST/WFPC2

(2) Simultaneous observation of exosphere, ionosphere, and escaping plasma down the tail

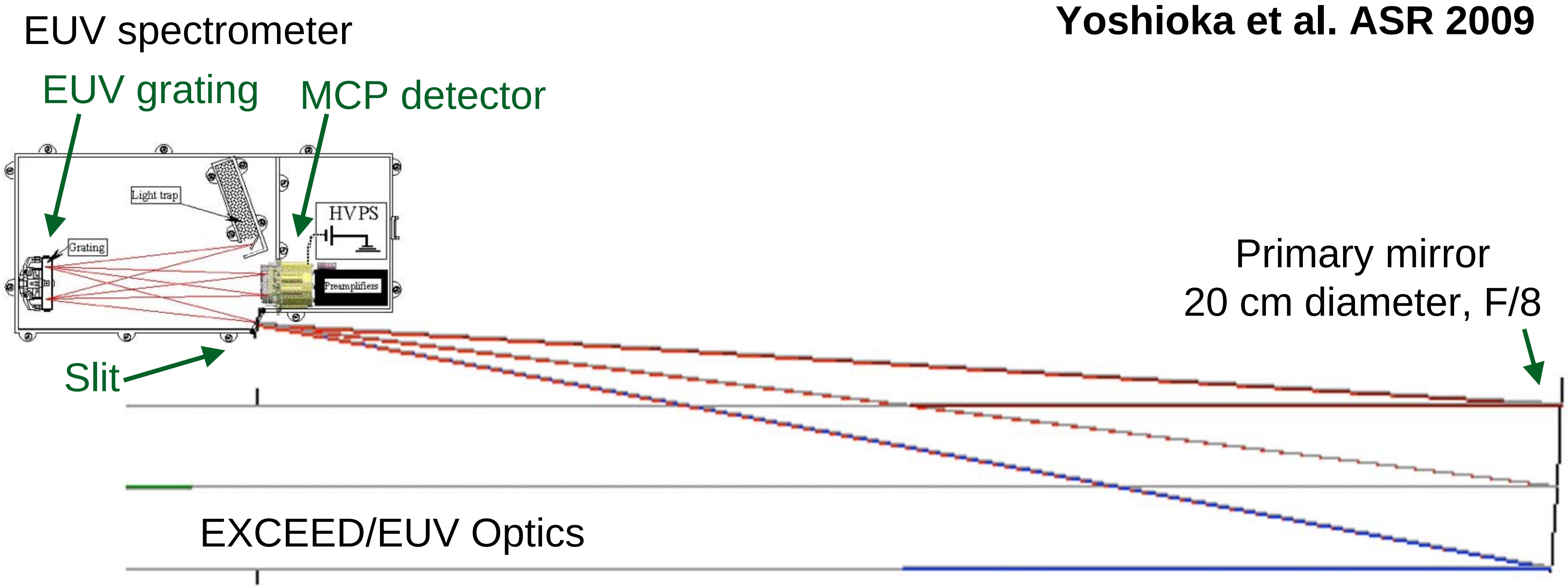
Venus, Mars, and Mercury

The EXCEED optics & spectrometer

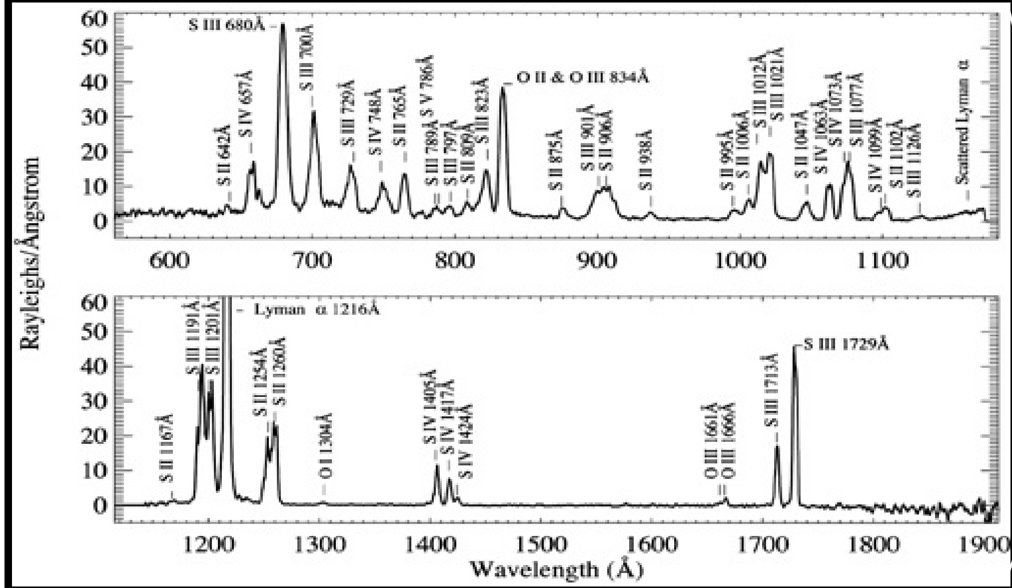
Wavelength range	60 – 145 nm
Slit width (for Jupiter mode)	0.2 mm
Spatial resolution (for Jupiter mode)	25 arc-sec ($1R_J$)
Field of view	400 arc-sec.
Spectral resolution	0.3 – 1.0 nm (FWHM)
Primary mirror	20 cm diameter, F/8

Layout of the optics and spectrometer

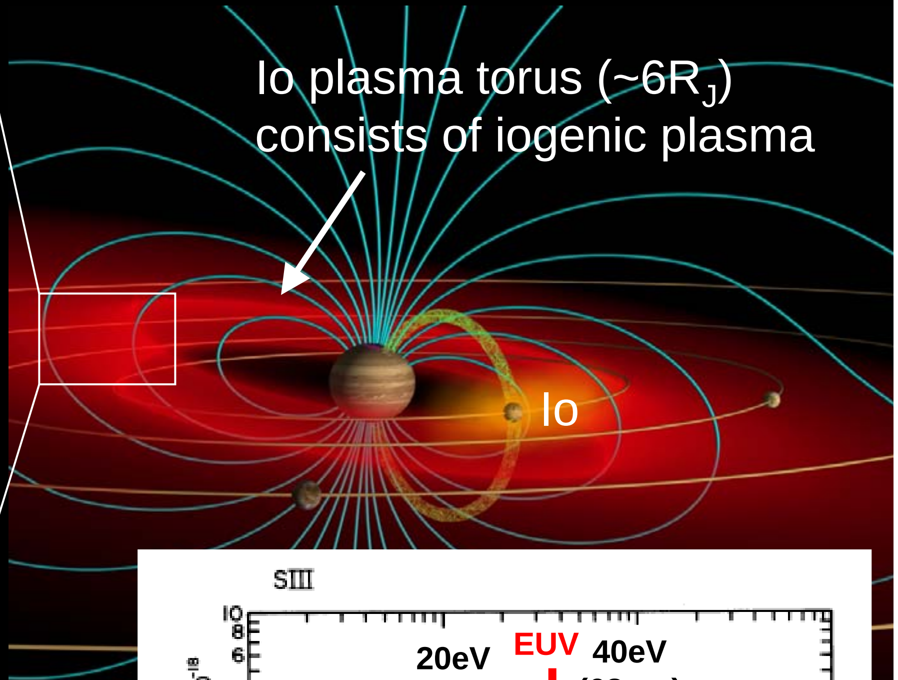
Yoshioka et al. ASR 2009



EUV emission from the Io plasma torus



EUV and FUV spectra of the Io plasma torus observed by Cassini/UVIS (Steffl et al. 2004)



Intensities of S and O ions are sensitive to the electron temperature, particularly to the hot component temperature in EUV.

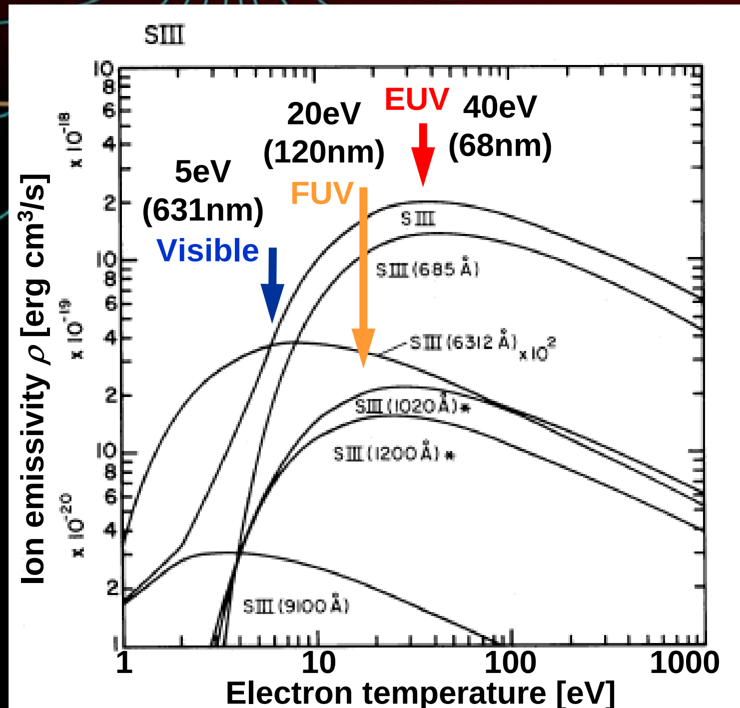
$$I = N_e N_i \rho(N_e, T_e)$$

N_e, N_i : electron and ion densities

T_e : electron temperature

$\rho(N_e, T_e)$: ion emissivity

The wide spectrum observation in EUV provides densities of the major ion species and temperature of the hot electrons.



Emissivity of S^{++} ion (Shemansky 1980)

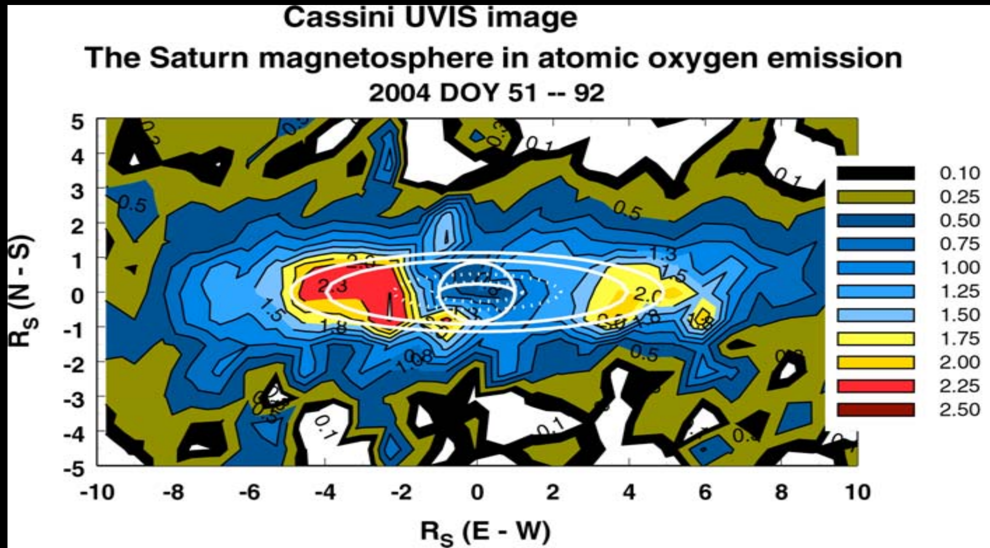
Saturn

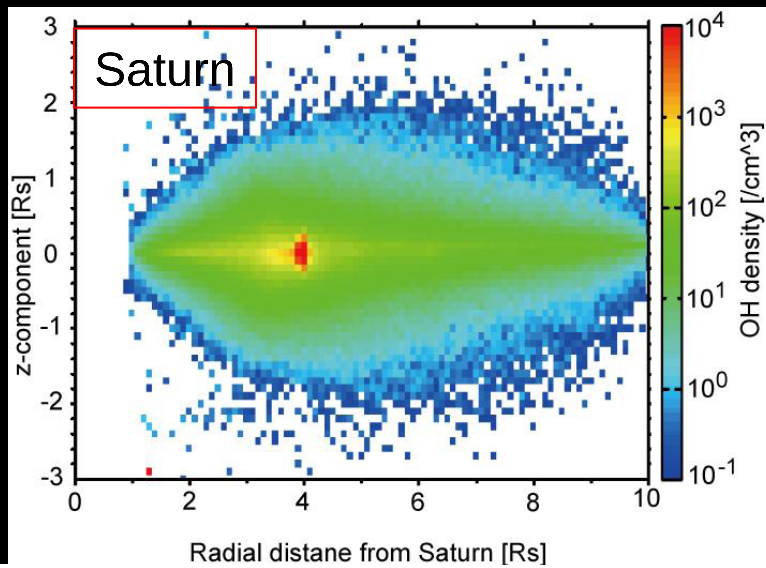
- Saturn's H_2 aurora and the Enceradus neutral gas torus are also observation targets of the EXCEED mission.

Cassini/UVIS observation of the Enceradus (E-ring) torus (Esposito et al. 2005)

- O(I)130.4nm (resonant scattering)

- A few Rayleigh
- Longitudinal asymmetry
- Time variation (~twice)





Neutral density model (By Mr. H. Tadokoro)

Summary

- Radio and optical observations from the earth are useful tools to investigate the magnetospheres of outer planets.
- Radio observation:
  - Transport process in Jupiter's radiation belt is strongly coupled with the upper atmosphere
  - More radio observations will be done by IPRT (& radio interferometers)
- Optical observation:
  - Unexpected short-term change are found in addition to the long term variation
  - Continuous monitoring observation of the Io plasma torus by a optical telescope at Hawaii/Haleakala & Australia which can be operated remotely from Japan.
  - Development of new 2.0m telescope in Haleakala
  - The EXCEED mission will be launched at 2012 and measure the Io & Enceradus tori continuously in EUV wavelength range
  - The IR observations of Jupiter's ionosphere by IRTF and the development of IR echelle spectrometer has been started