Cassini/UVISを用いたイオトーラスのスペクトル診断
及び
SPRINT-A/EXCEEDへの応用

The spectral diagnosis of the Io plasma torus through the data obtained by the Cassini/UVIS, and its application to the SPRINT-A/EXCEED mission

2011/01/06, 宇宙科学シンポジウム@ISAS

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ポスターの流れ

イントロ（1）： 木星磁気圏とイオトーラス　ーターゲットとなる物理ー

イントロ（2）： 極端紫外光を用いた磁気圏の遠隔観測　－手法と原理－

観測： Cassini探査機によるイオトーラスの極端紫外分光観測

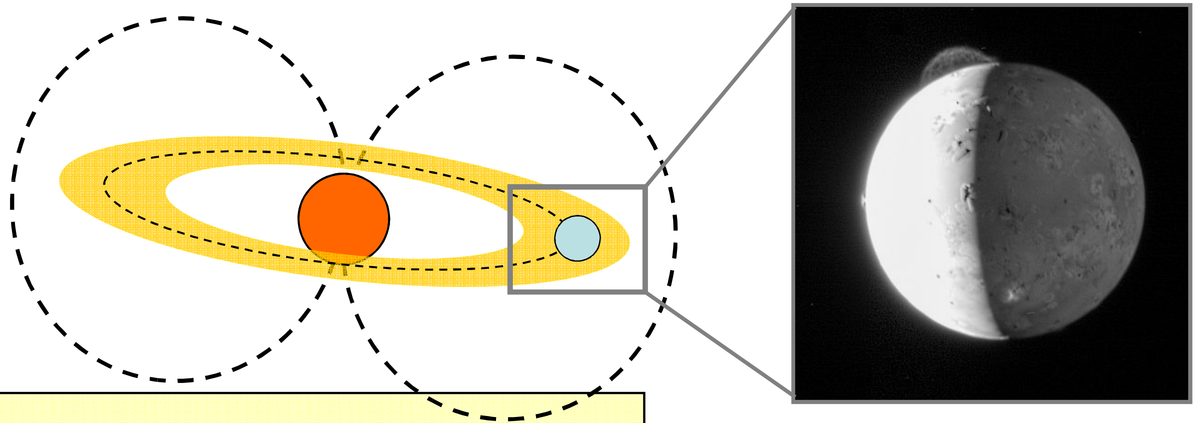
結果・考察： スペクトルフィッティングによるプラズマパラメタの導出

纏め・展望： 2013年打ち上げの地球周回衛星SPRINT-A/EXCEEDについて

Jupiter and Io plasma torus

	Jupiter	Earth
Radius	71500 km	6400 km
Rotation period	9h55min	24 h
Magnetic field intensity	420,000 nT	31,000 nT
Plasma source	Io [1 ton/s]	--
Distance from the Sun	5.1 AU*	1 AU

*** 1 AU = 1.5E+8 km ~ 2000 RJ**



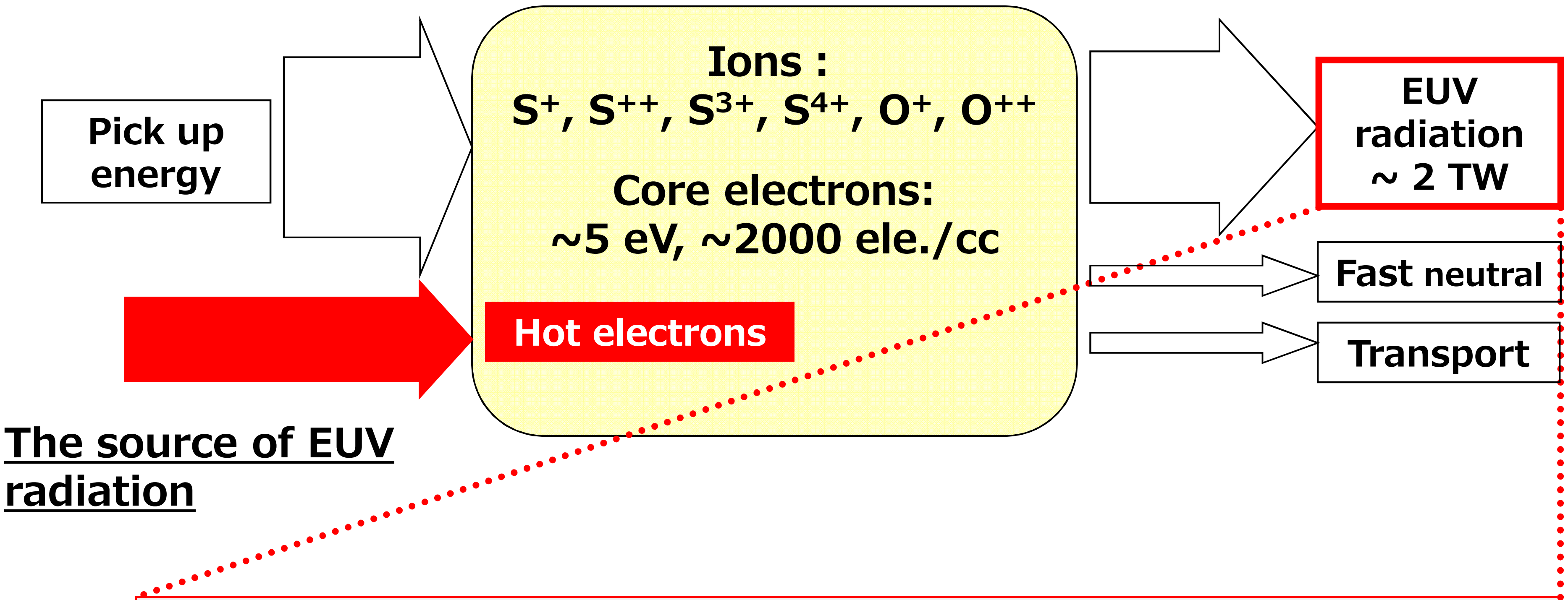
NASA/
NEW HORIZONS (VIS)

☆Io plasma torus☆

The neutrals ejected from the Io's volcanoes are ionized, and form a torus like structure which is located around 5 to 8 times Jupiter radius.

The energy flow around the Io torus

- The ionized ions are picked up by the Jupiter's magnetic field.
- The pickup energy of the ions are ~200 eV
- The inputted energy is emitted (mainly) through the EUV radiation.

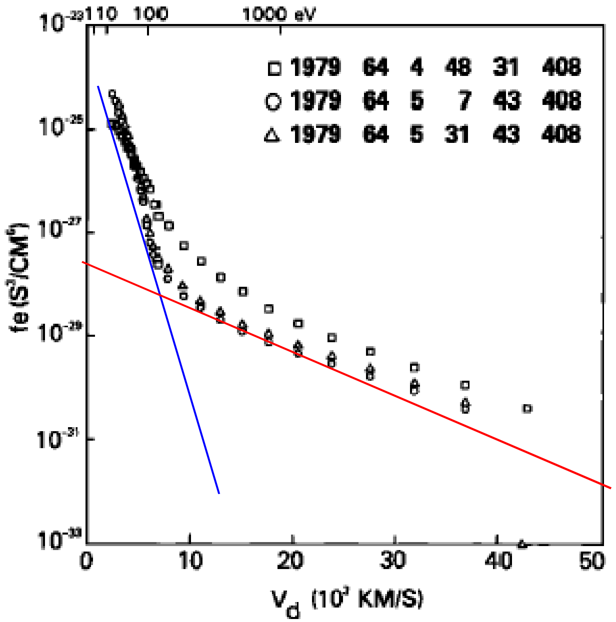


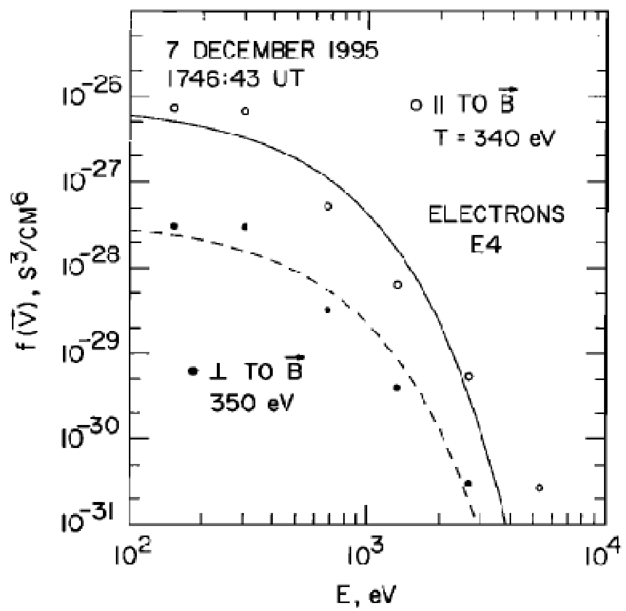
Can we detect those hot electrons through remote sensing ?

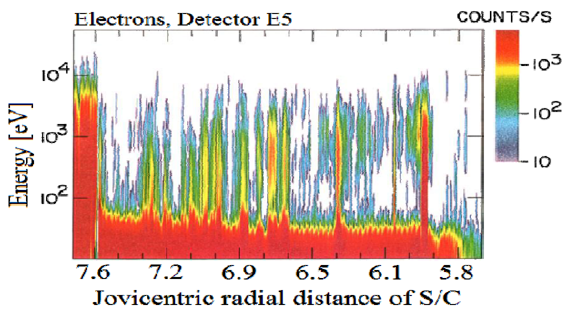
In situ observations of the hot electrons

- Voyager-1 and Galileo spacecrafts detected the hot electron components around the Io torus.
  - Voyager-1: ~500 eV, 2~4%
  - Galileo: ~350 eV, ~<1%

- The impact of the hot electron on the EUV emission is not small. In the other words, the EUV spectrum tells us the condition of the electron around there.





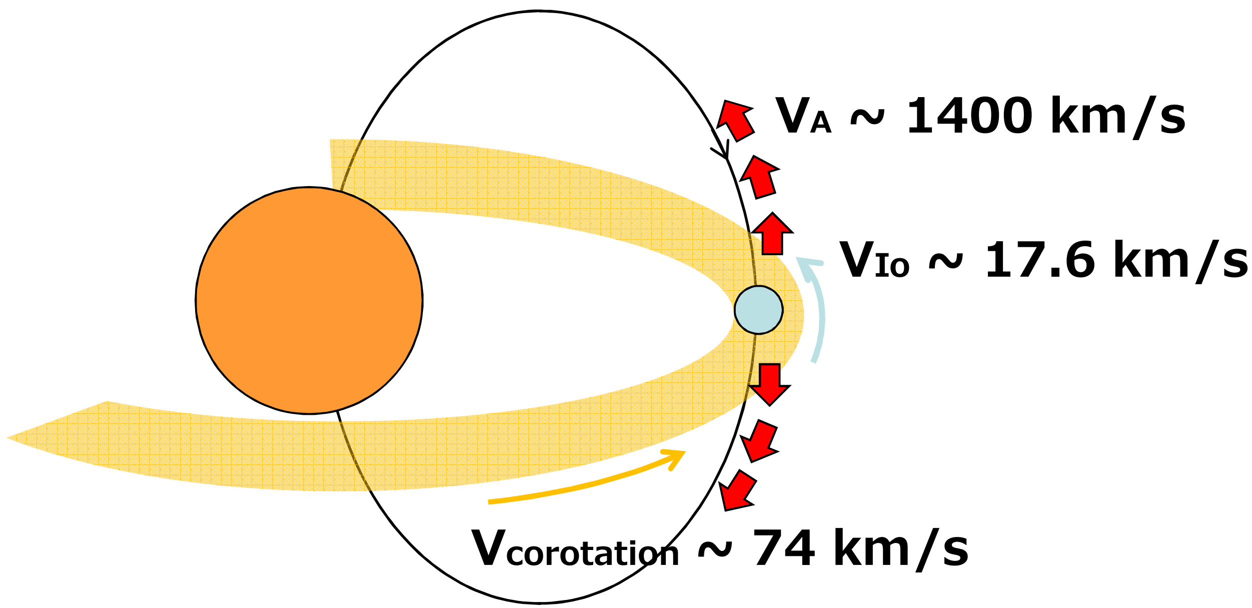


The electron energy spectrum taken by the Voyagr-1 spacecraft (Sitteler and Strobel, 1987)

The electron energy spectrum taken by the Galileo spacecraft (Frank and Paterson 1999)

Where the hot electrons come from?
–Io Flux Tube-

- There is no clear consensus on where these hot electrons get their energy.
- The transfer of energy from ions to electrons via Coulomb collisions is not efficient enough.
- Acceleration by waves is one of the candidate mechanisms (Belcher, 1987; Crary, 1997) . This is so called, **Io flux tube**.

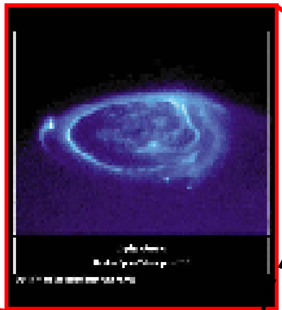


Where the hot electrons come from? -Middle magnetosphere-

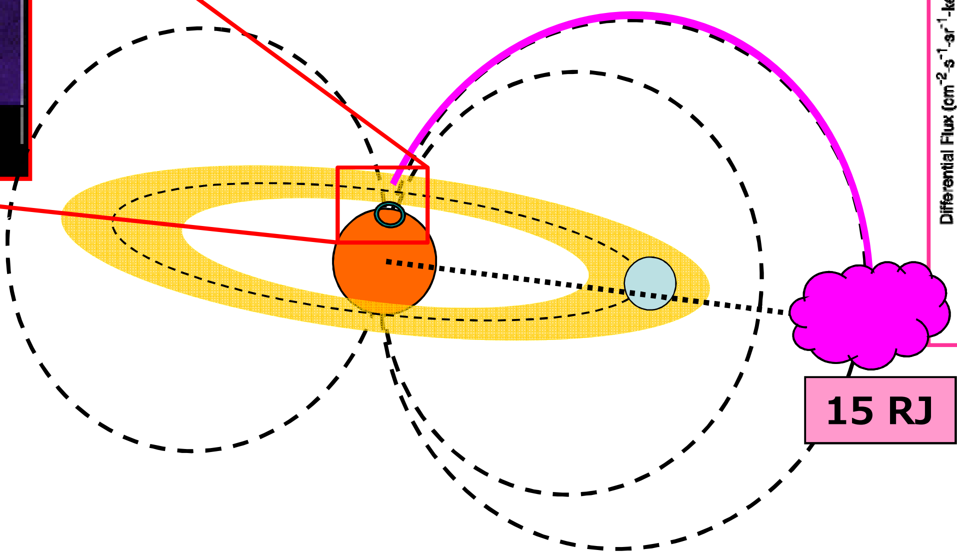
- The injection or interchange between the middle magnetosphere and the Io torus.

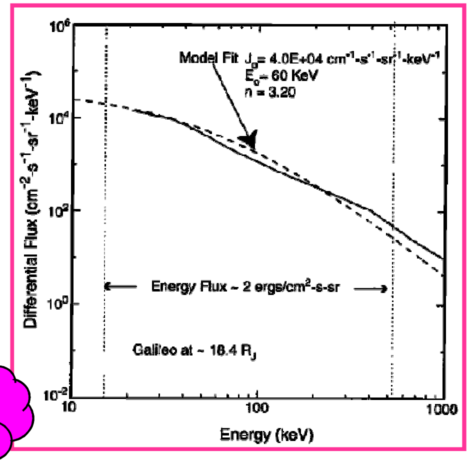
  - The hot electron around the middle magnetosphere (~15 RJ) is closely linked to the Jovian aurora. (Clarke et al. 1998, Bhattacharya and Thorne, 2001)

  - There should be a relationship between the Jovian aurora variability and the Io torus EUV emissions.



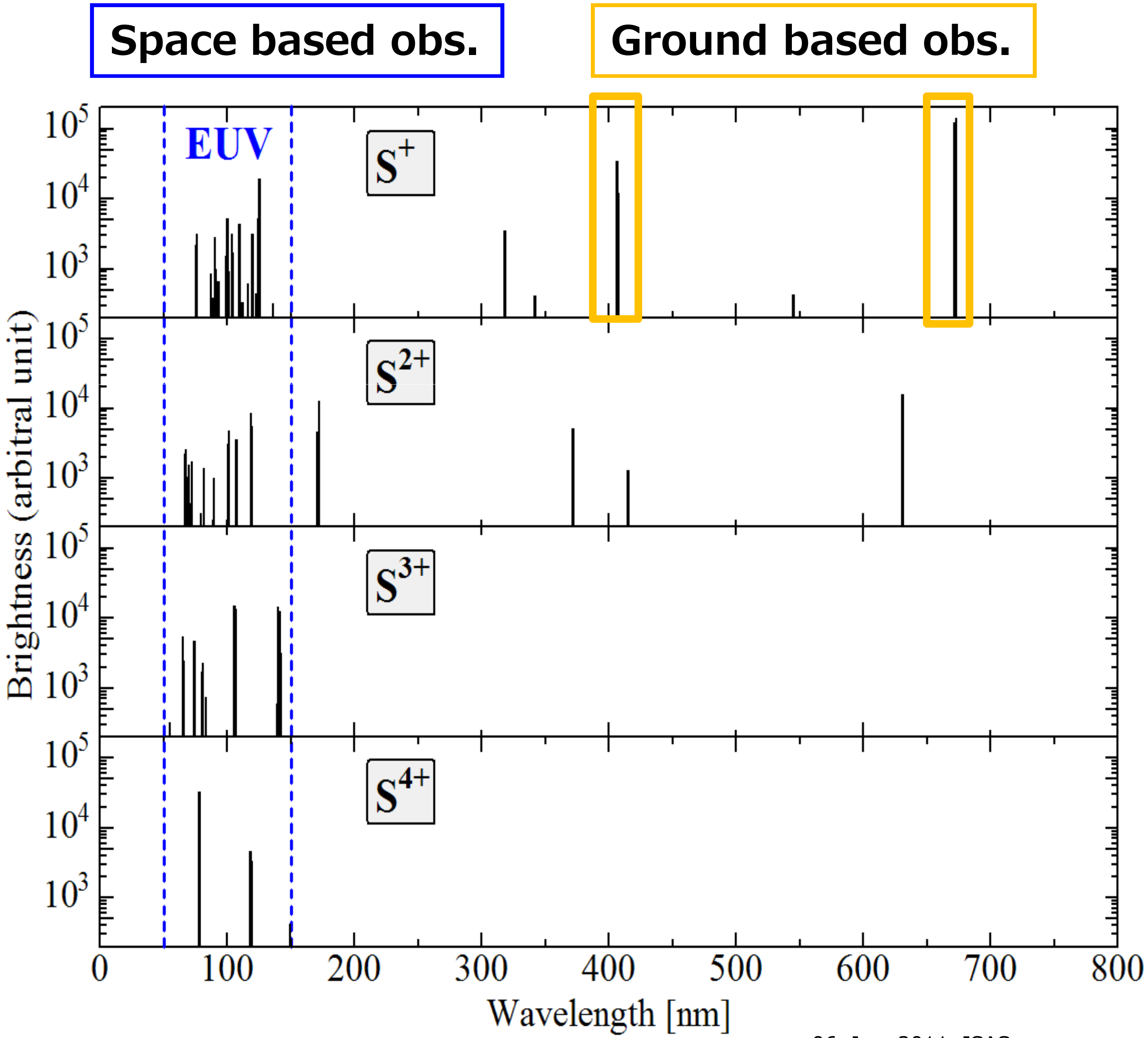
HST UV image from Clarke et al. (1998)





The electron energy spectrum around the middle magnetosphere (Bhattacharya and Thorne, 2001)

The wavelength distribution of the emission lines (Electron impact)



The distribution of the three types of Sulfur ions (+1, +2, +3, and +4).
These emissivities are calculated with same plasma conditions

More than 90% of the lines are in the EUV region.

Emissions from ions caused by electron impact

$$I(\lambda_{ij}) = \frac{1}{4\pi}\int N_j A_{ji} dh \; [\mathrm{photons/cm^2/sr/sec}]$$

$\mathrm{N_j}$: Ion density which is in *Energy − level* "j"

A_{ji} : The emission rate (*A − value*)

$\int dh$: The integration for the line of sight

- The estimation of "$\mathrm{N_J}$"
  - Electron impact coefficient
    - This value depends of the temperature of electrons.
  - A-value
    - The probability of the spontaneous emission from upper energy level to lower one. On ion has various combinations. (e.g. S++ has more than 300 combinations)

  - The database named "CHIANTI" has various information which is taken through laboratory experiments and theorem.

How to estimate the emissivity?

We assume the balance between the various energy levels.

$$(\text{Inflow to the level "i"}) = (\text{Outflow from the level "i"})$$

$$N_i \sum_{j \neq i} \alpha_{ij} = \sum_{j \neq i} N_j \alpha_{ji}$$

$$\alpha_{ii} = -\sum_{j \neq i} \alpha_{ij}$$

Matrix →

$$\begin{pmatrix} \alpha_{11} & \alpha_{21} & \alpha_{31} & \alpha_{41} & \cdot \\ \alpha_{12} & \alpha_{22} & \alpha_{32} & \cdot & \cdot \\ \alpha_{13} & \alpha_{23} & \cdot & \cdot & \\ \alpha_{14} & \cdot & \cdot & & \\ \cdot & \cdot & & & \end{pmatrix} \begin{pmatrix} N_1 \\ N_2 \\ \cdot \\ \cdot \\ \cdot \end{pmatrix} = 0$$

$$\alpha_{ij} = A_{ij} + N_e q_{ij}$$

A-value

q_{ij} : Impact coefficient

$$q_{ij} = \int_0^{\infty} \hat{g}_e(v) \sigma_{ij} dv$$

Thermally averaged cross section

$$\hat{g}_e = 4\pi \left(\frac{m}{2\pi kT} \right)^{3/2} v^2 \exp\left[-\frac{mv^2/2}{kT} \right]$$

Transition to the another level through the electron impact.

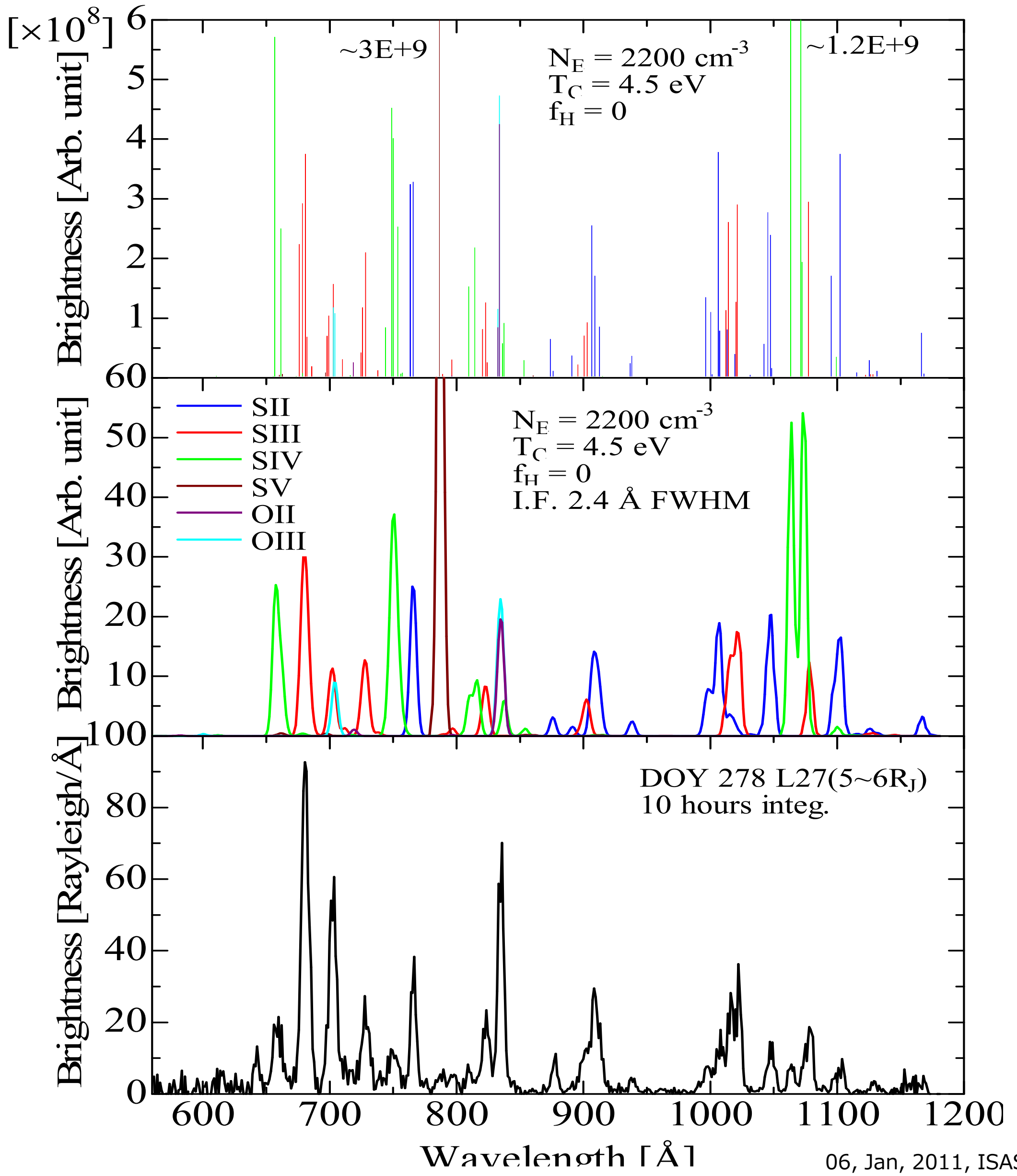
Transition to the lower state through the spontaneous line emission.

The ions in the specific energy level

Transition from the another level through the electron impact.

Transition from the upper level through the line emission.

Making the model spectrums

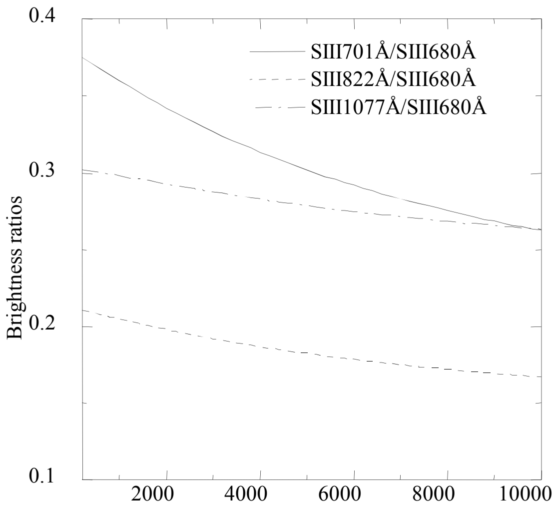


- Calculate the emissivity of the each ion components assuming...
  - Electron temperature
  - Electron density
  - Ion column density
- Make a real spectrum assuming the “instrumental function”.
- Determine the best fit (to the observed spectrum) parameters.
  - The bottom panel shows the spectrum taken by the CASSINI/UVIS instrument during its Jupiter flyby.

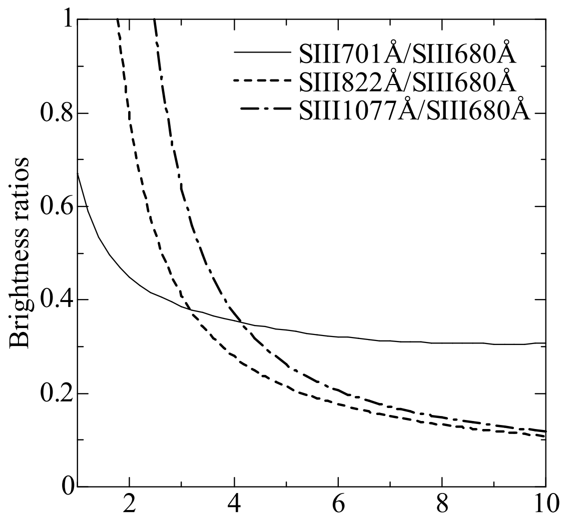
The approach of this study
–Spectral diagnosis-

The brightness of the emission through the electron impact excitation is depends on the temperature of the electrons.

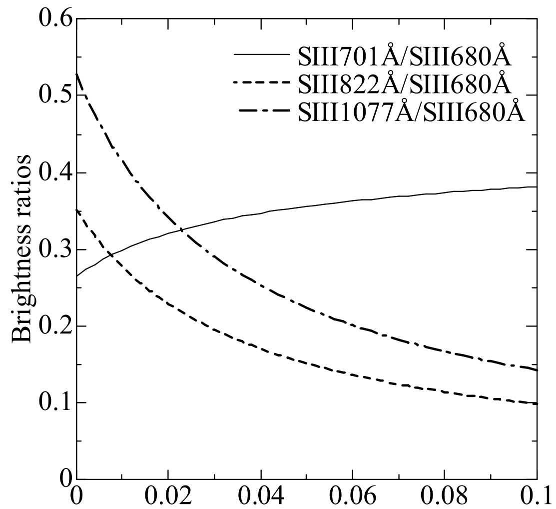
Ex.: The ratios of four emissions from SIII（680, 701, 822, 1077 Å）for various parameters



Electron temperature



Electron Density

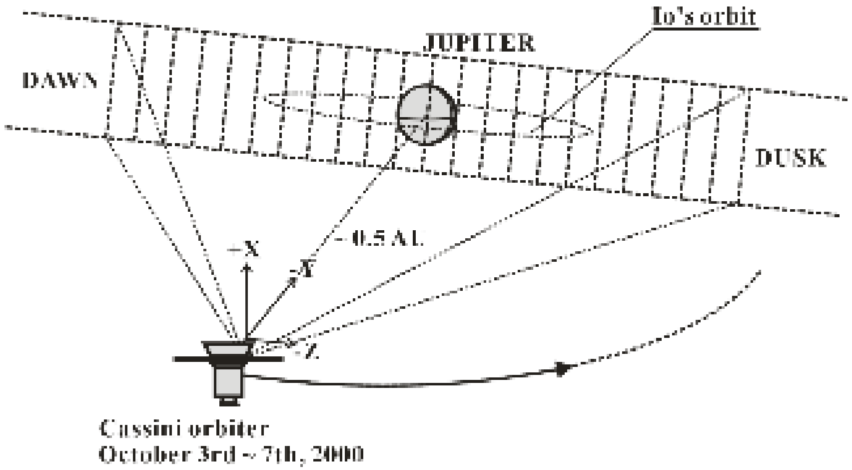


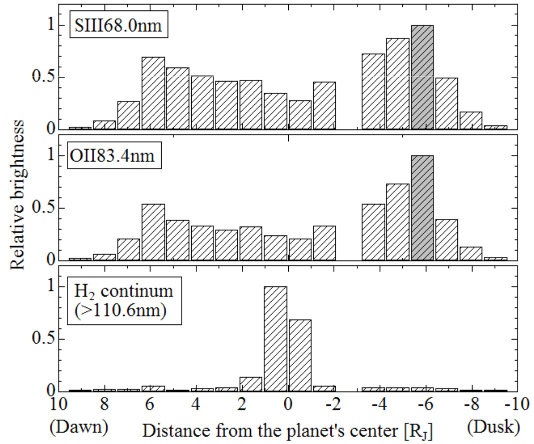
Hot electron fraction

- **Approach**: Remote sensing.
  - It can distinguish the spatial and temporal variations.
- **Method**: The spectral diagnosis.
- **Data**: The UVIS instruments on board the Cassini spacecraft
- **Goal**: Measure the electron temperature or energy spectrum.

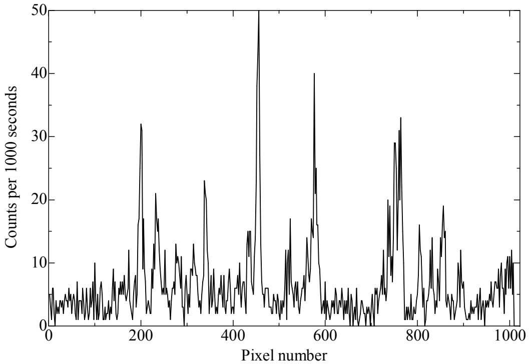
The Io torus observation of Cassini/UVIS

- Cassini
  - Launched in 1997 for Saturn.
  - Jupiter flyby in the end of 2000, from the distance of 0.5 AU.
- UVIS
  - 56.1 ~ 118.1 nm
  - ~0.48 nm FWHM (Spectral resolution)
  - ~0.5 R_J (Spatial resolution)
- Observation
  - 10 hours temporal resolution
  - The brightest area is analyzed in this study.



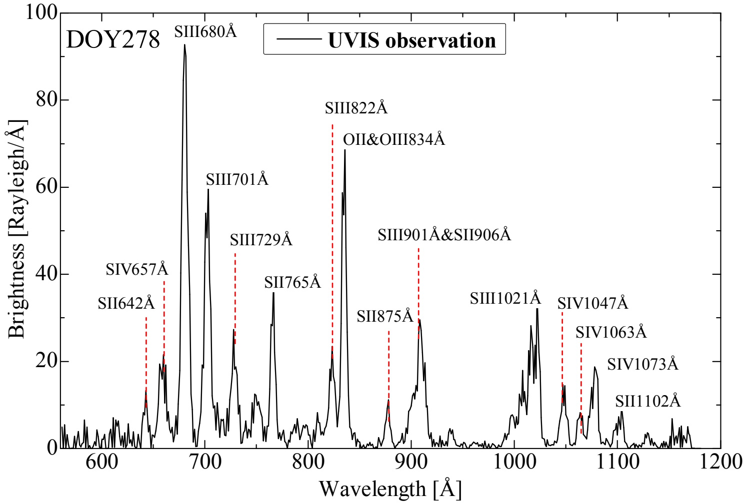


The spatial profile of SII, OII emissions (68.0, 83.4 nm) The auroral emission (110.6 nm) is also shown. The brightest two pixels are analyzed in this study.



The low data for 1000 seconds integration

10 hours averaged spectrum



Data reduction, the parameter settings

Fixed

$[S^+]/[S^{2+}]=0.35$
$[S^{3+}]/[S^{2+}]=0.15$
$[S^{4+}]/[S^{2+}]=0.015$
$[O^+]/[S^{2+}]=1.25$
$[O^{2+}]/[S^{2+}]=0.015$

Hot electron temp. (350 [eV])

Parameters

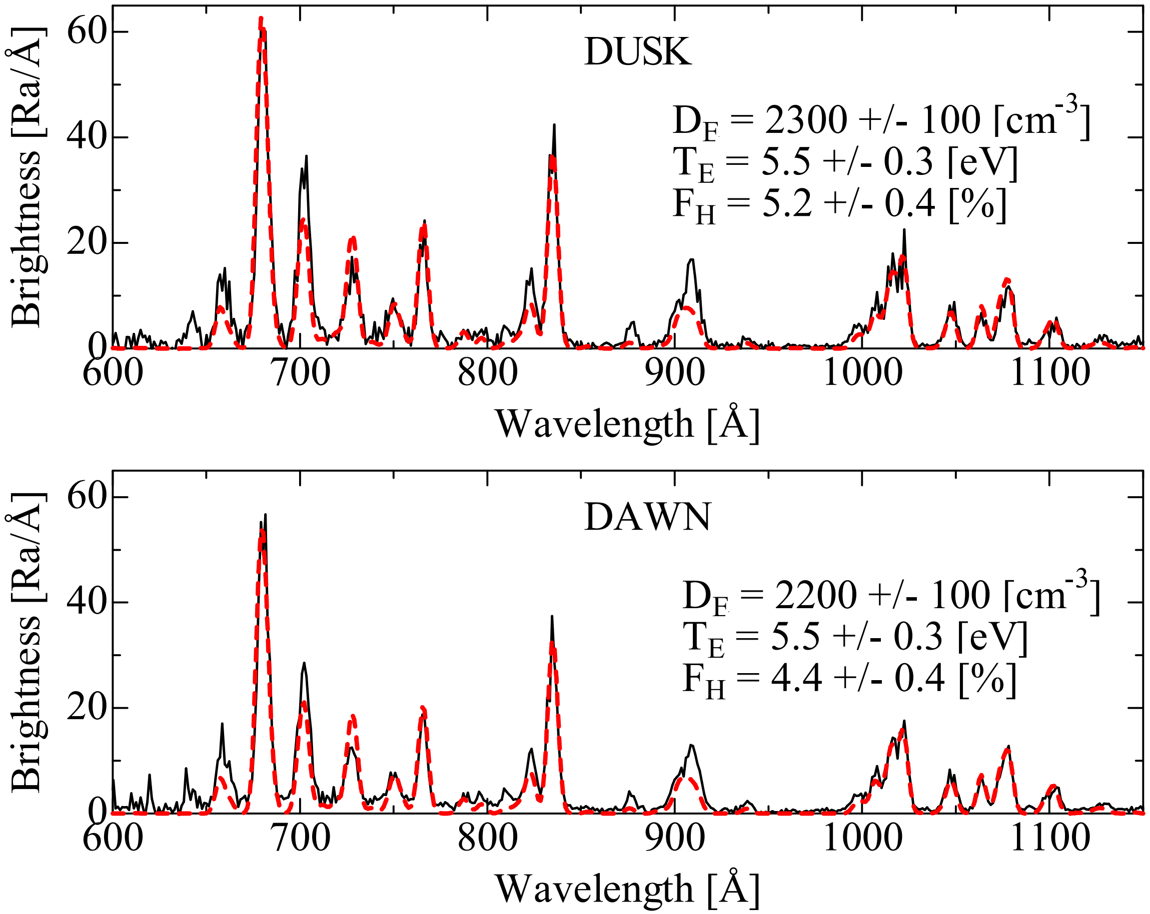
Electron density: N_E [cm^{-3}]

Electron temp.: T_E [eV]

Hot electron fraction: F_H

- Charge neutral condition is assumed.
- The fractions of ions (O^{2+} O^{3+}, S^+, S^{3+} and S^{4+}) are fixed. (after Voyager, Cassini)
- The hot electron temperature is fixed (Frank and Paterson, 1999)
- The line of sight assumption.

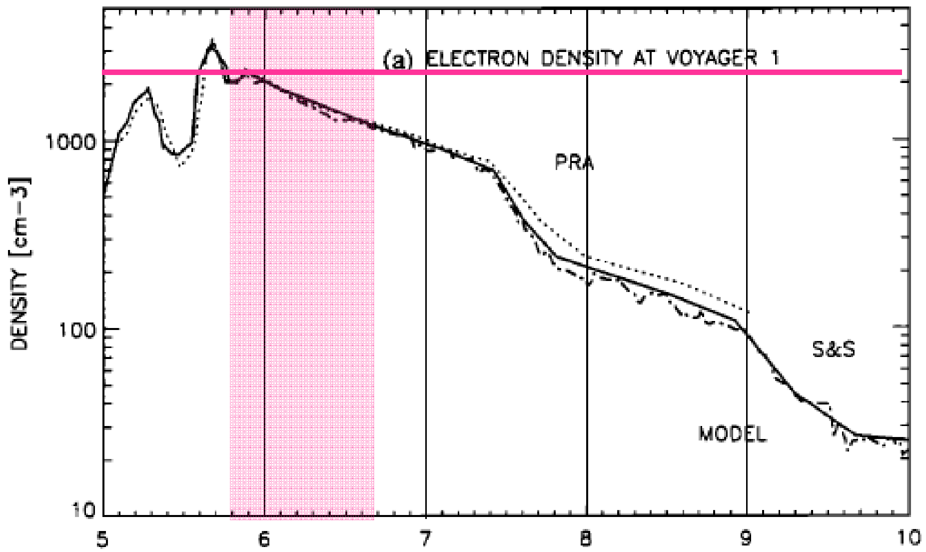
Results of the fitting (Dawn & Dusk)



A fit of the model (red dotted line) to a UVIS spectrum (black line) of the Io torus.

The derived electron density and temperature are close to the results of former *in situ* measurements. (next page)

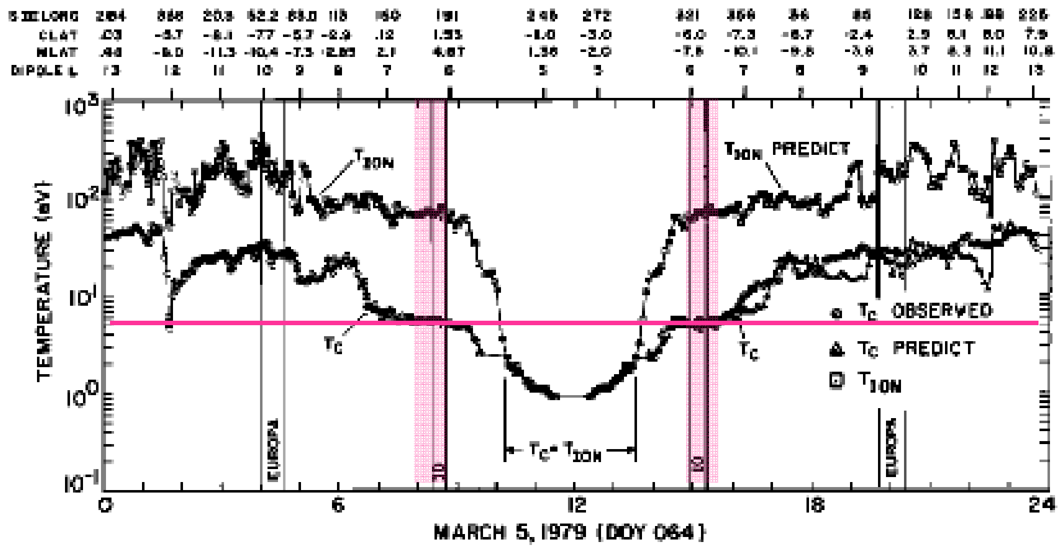
Results of the fitting



The electron temperature profile taken by the Voyager-1 （Sitteler and Strobel, 1987）

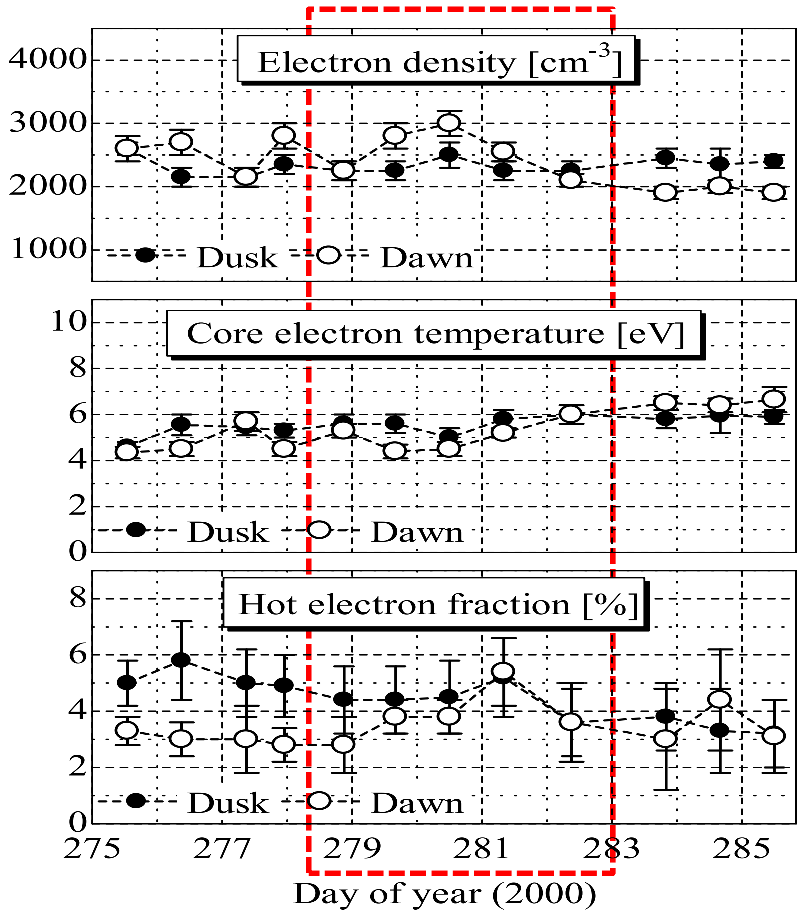
Distance from Jupiter center (RJ)

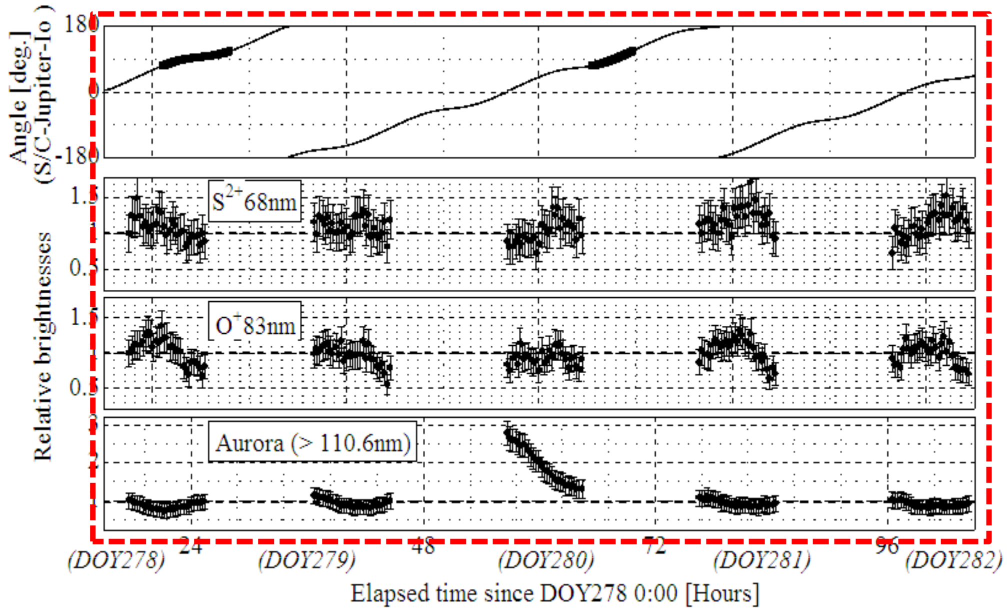
The electron density profile taken by the Voyager-1（Baganel 1994）

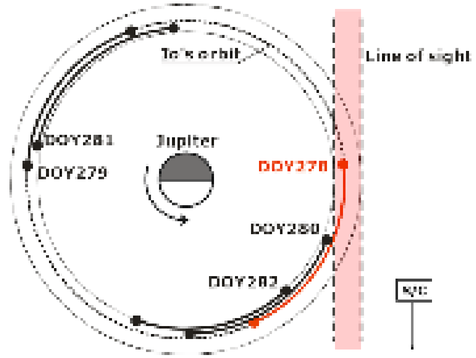


Time series of the derived parameters

Time series of derived parameters.



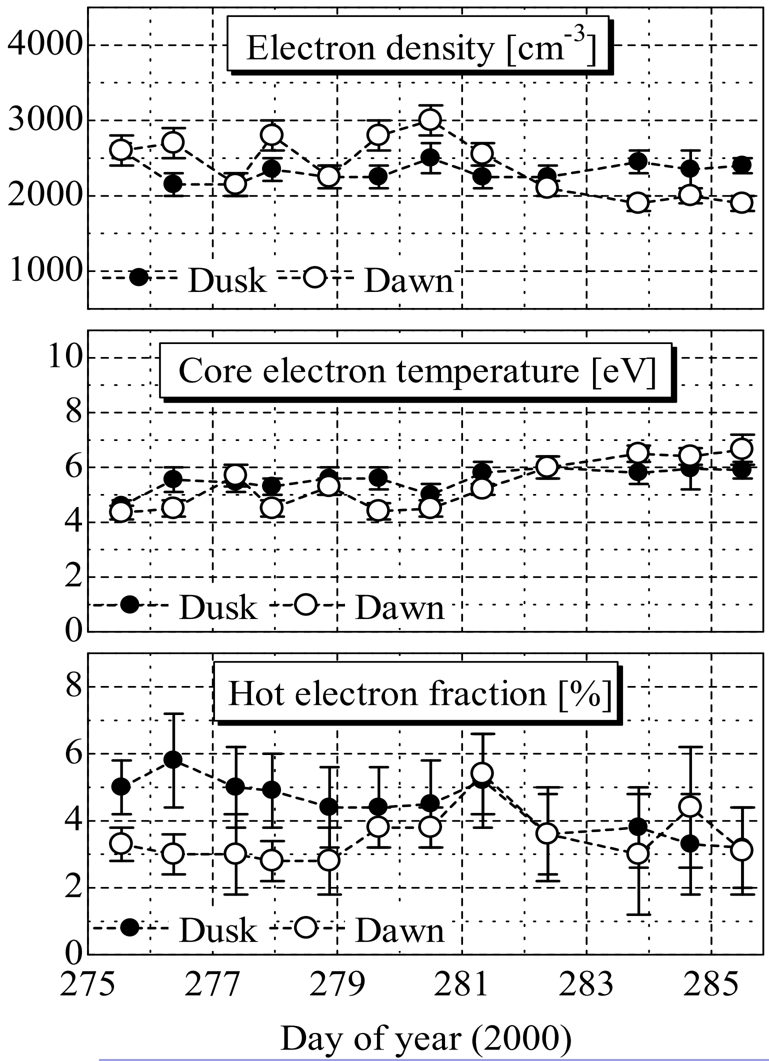




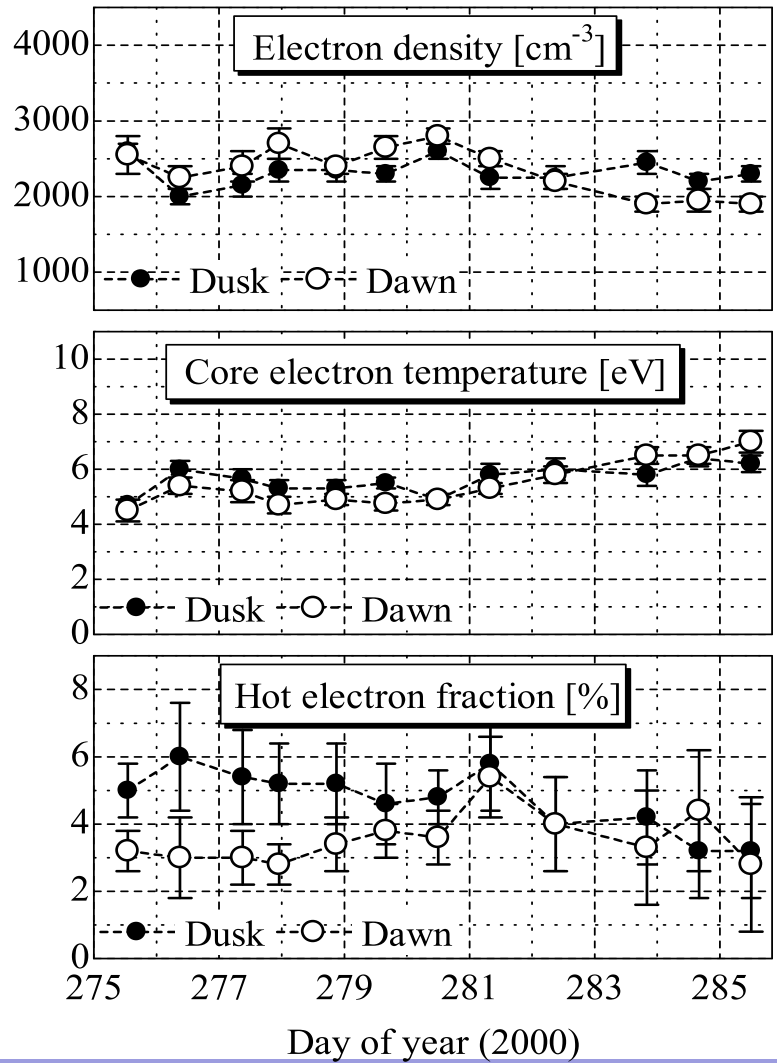
- No relationship between the aurora burst and the torus electrons
- No relationship between the Io phase angle and the torus electrons
- **Faster reaction than 10 hours ?**

Hot component temperature

Th = 350 eV



Th = 550 eV

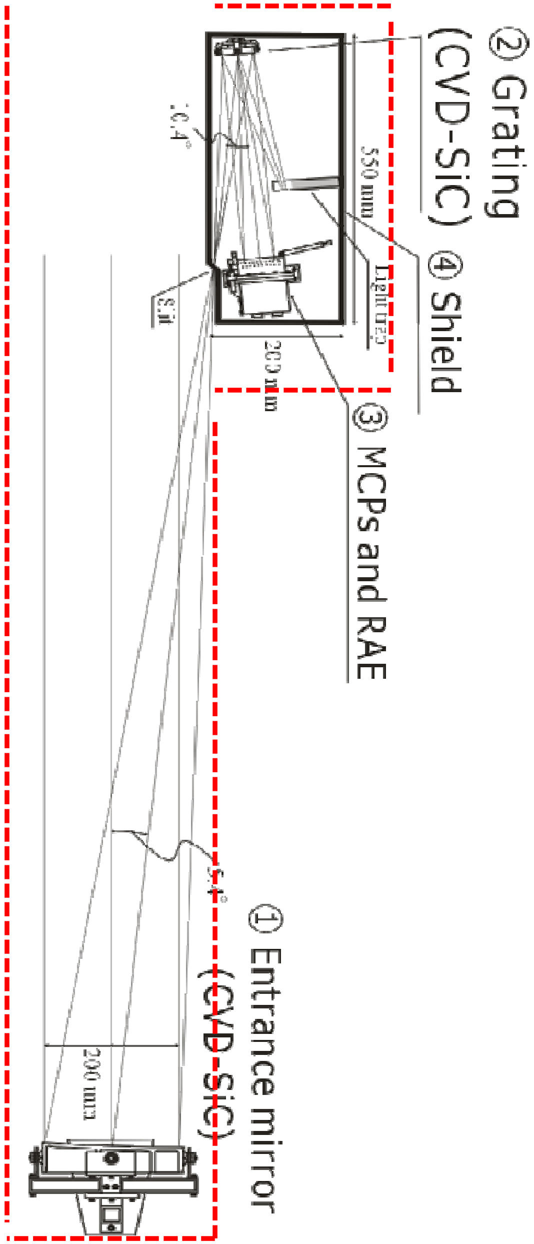


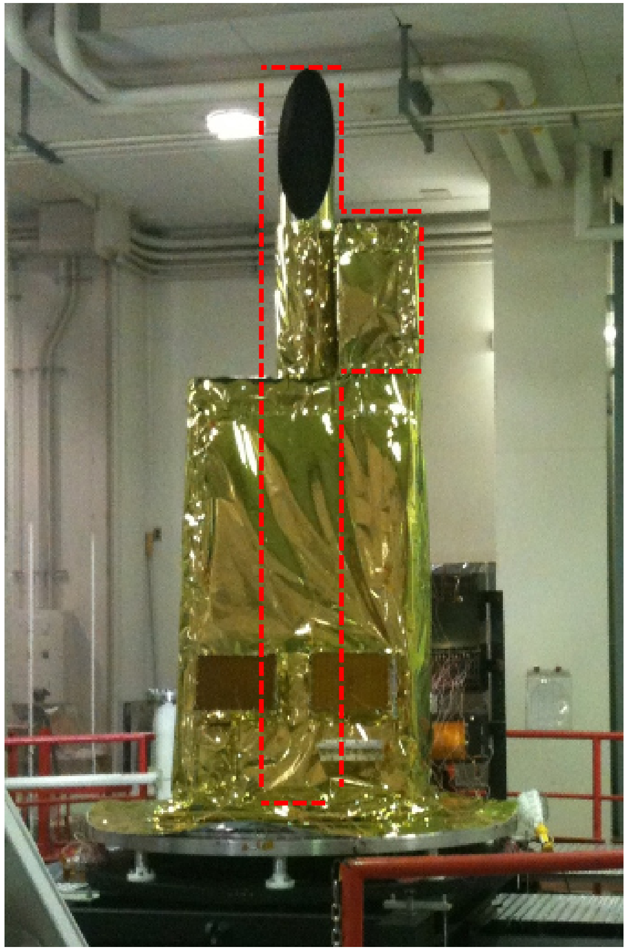
□ The temperature of hot electron can't affect the results.

Summary

- The electron temperature, density, ion compositions are derived through the spectral diagnosis.
- The hot electron component which is 10 times hotter than ambient electrons are detected.
- The coloration of the torus plasma between the Io's phase angle and the aurora variability were not detected.
- There may be a faster response than 10 hours.
  - It takes a few hours for 300 eV electrons to settle into the 5 eV electrons.
- For more detailed discussion, the observation with higher temporal resolution and longer observation period is inevitable.
- If 100 times higher detection efficiency than the Cassini/UVIS can be achieved, the observation from the Earth-orbiting satellite is useful.
- **EXCEED, the Earth orbiting EUV spectro imager** is now under development. The current results of the development shows that it achieved 500 times higher detection efficiency than the Cassini/UVIS!

The Earth-orbiting satellite, EXCEED





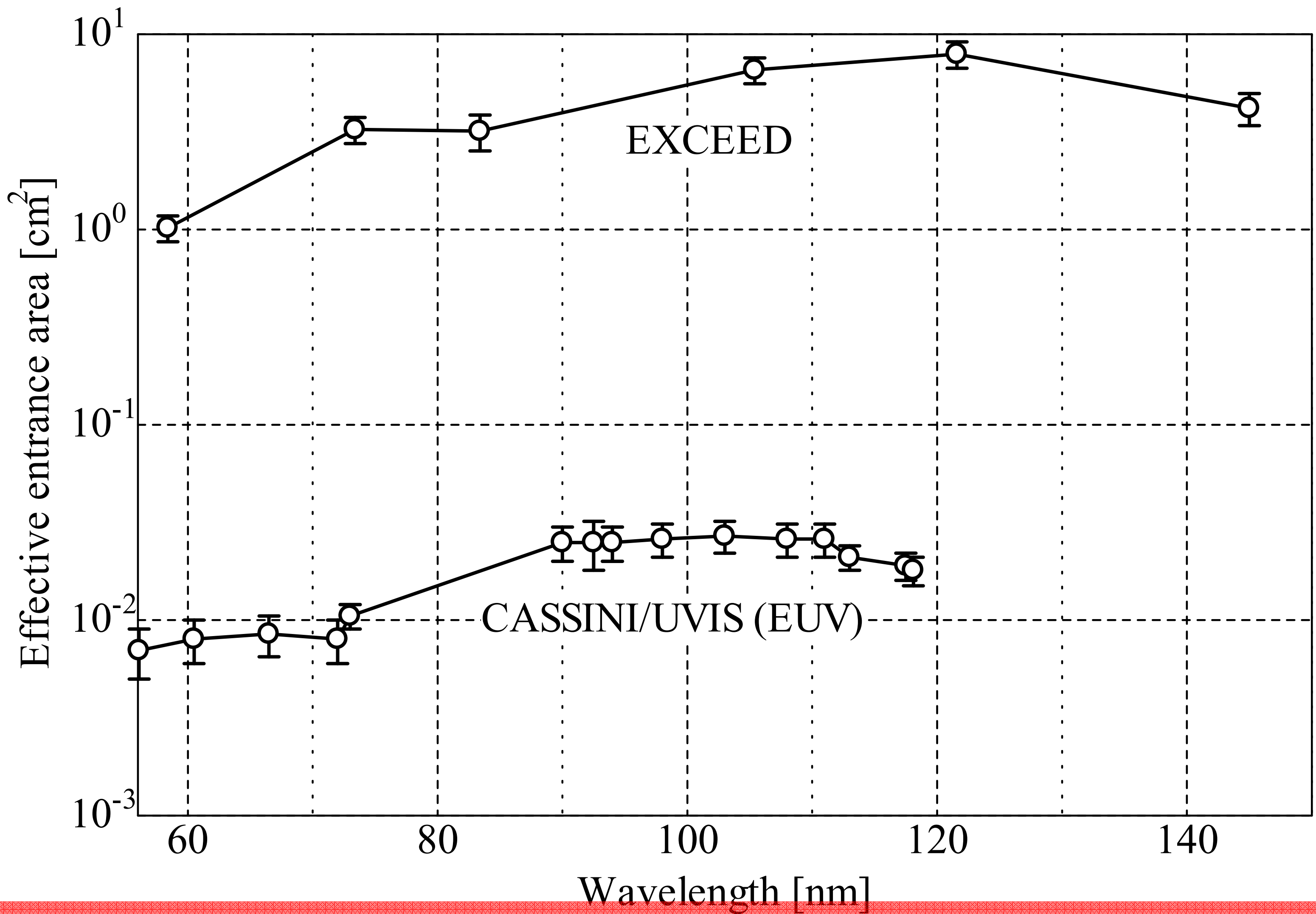
TTM test has been finished!

SPRINT-A/EXCEED will be launched in 2013.

The orbital altitude:
950~1150 km

The orbital period:
106 minutes.

The detection efficiency of EXCEED



10倍の時間分解能が達成できる。