The electron temperature of Io plasma torus deduced from the EUV spectra taken by Hisaki/EXCEED

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The spectral diagnosis

The brightness of a spectral line (B(λ) [Rayleigh]) depends on the ion density and the electron temperature(T_e) and density(n_e).

$$B = 10^{-6} \int A_{ji} f_j(T_\mathrm{e}, n_\mathrm{e}) n_\mathrm{ion}\, dl \ \text{Rayleighs},$$

Aji : the Einstein coefficient for spontaneous emission from state *j* to *i.*

f j : a vector containing the fraction of ions in energy state j.

$Cf = b$ (Balance equation)

$$C[i, j] = A_{ij} + n_\mathrm{e} q_{ij}\ , b = \begin{pmatrix} 1 \\ 0 \\ \vdots \end{pmatrix}$$

The rate coefficient for collisional excitation or deexcitation $q_{ij} = \int_0^\infty \hat{g}_\mathrm{e} v \sigma_{ij}\, dv.$

ge : the electron distribution function

"Spectral diagnosis" method

Fitting the model spectrum to the observed spectrum → The electron temperature(T_e) and density(n_e) can be deduced.

The assumption of the electron distribution function

The spectral diagnosis to the IPT spectra obtained by Cassini

The electron parameters are deduced from the EUV spectra obtained by Cassini on the assumption of the electron distribution function as a Maxwellian and a kappa distribution (by calculating the sum of the Maxwellian distributions). (Steffl et. al., 2004)

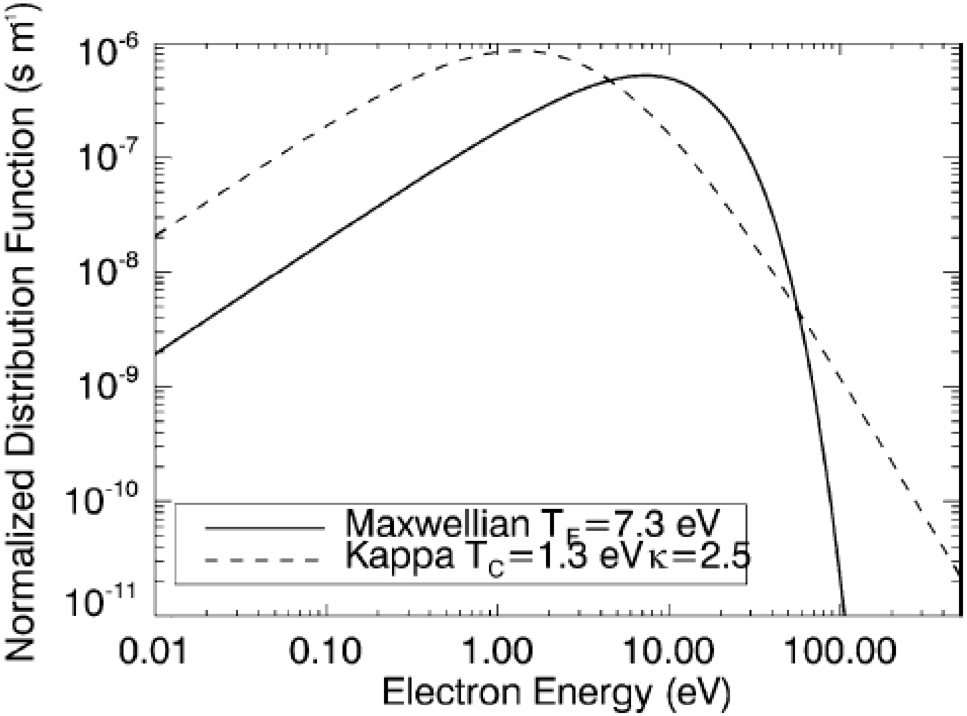


Fig 1. The best-fit distribution functions for a Maxwellian and a kappa distribution at 7.4 RJ.

The spectral diagnosis to the IPT spectra obtained by HISAKI/EXCEED

The electron parameters are deduced from the data obtained by HISAKI/EXCEED on the assumption of the electron distribution function as the sum of 2 Maxwellian distributions. (Yoshioka et. al., 2014)

The inward velocity of hot electrons is estimated from the gradient of the density of hot electrons.

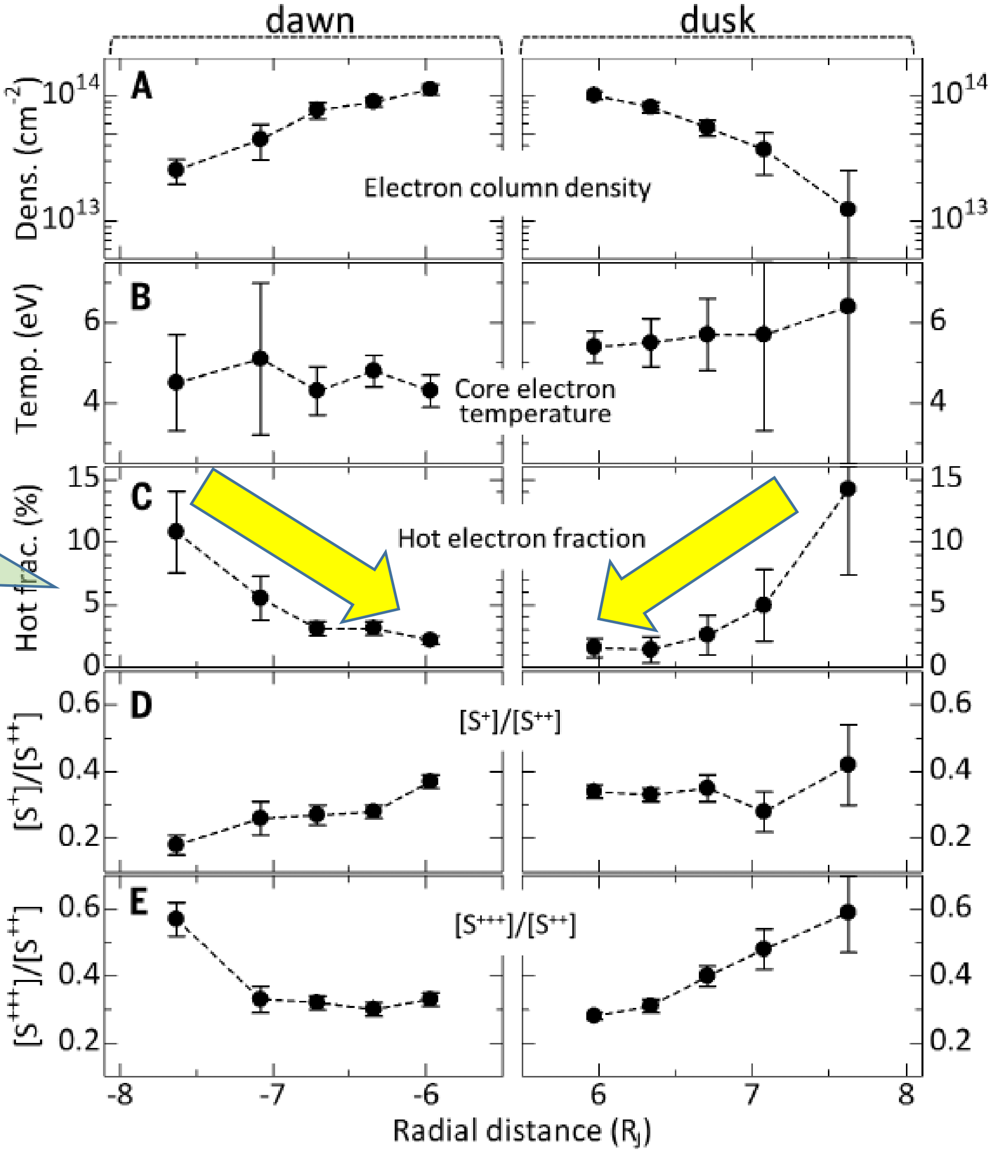
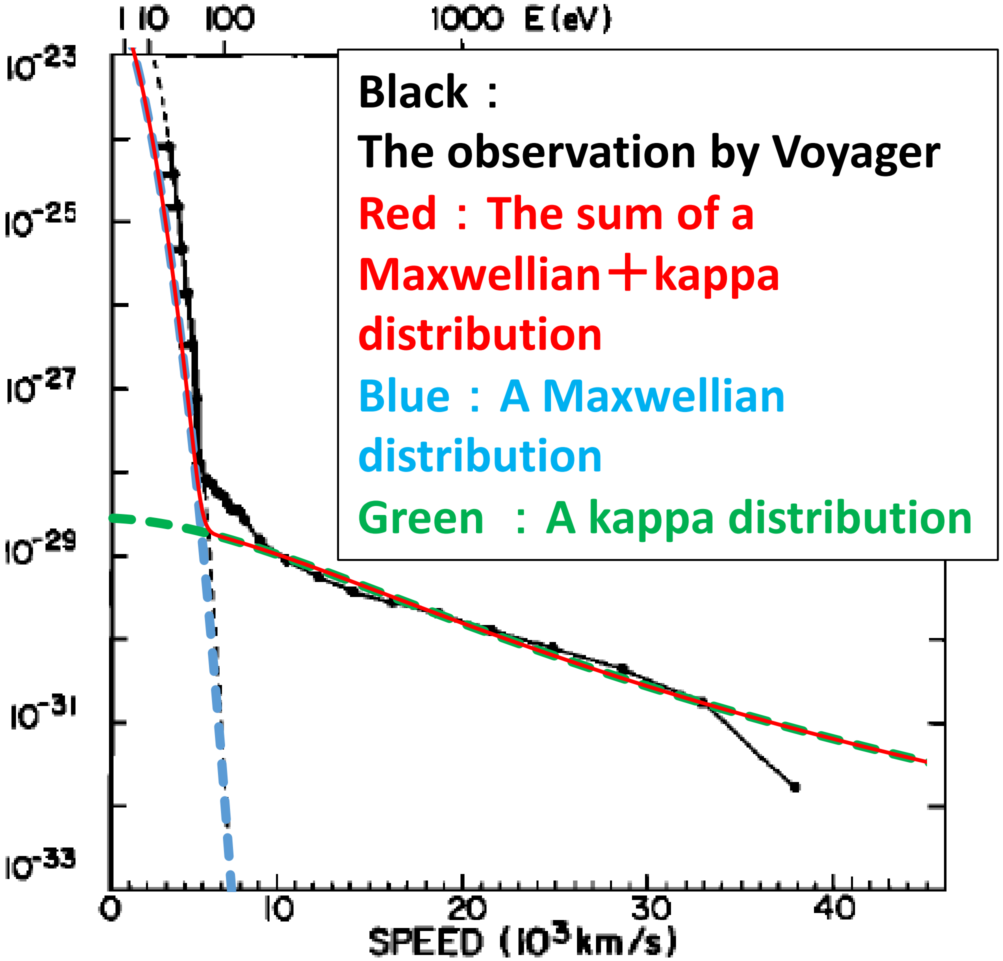


Fig 2. The spectral diagnosis results using the IPT spectrum obtained by HISAKI/EXCEED
The horizontal axis represents the distance from Jupiter. The vertical axis represents (A)the electron column density (B)core electron temperature (C)hot electron fraction (D)(E)the density ratios of sulfur ions（Yoshioka et.al., 2014）.

The electron distribution function in IPT



Black：
The observation by Voyager
Red：The sum of a Maxwellian＋kappa distribution
Blue：A Maxwellian distribution
Green ：A kappa distribution

Fig 4. The black line indicates the electron distribution observed by Voyager/PLS at a distance of 5.5 RJ from Jupiter (Scudder et. al., 1981). The red line indicates the distribution that is the sum of a Maxwellian and kappa distribution fitted to the black line.
The blue and green line indicate a Maxwellian and a kappa distribution respectively used to fit to the black line.

- In-situ plasma measurements made by Voyager(Scudder et. al., 1981) suggest that the electron distribution function in IPT is similar to the sum of a Maxwellian and kappa distribution.

- The data taken by Ulysees suggest that the distribution is expressed by kappa distribution.(Meyer-Vernet et. al., 1995）

Our study

Purpose:

To clarify the proper expression of the electron distribution of IPT and improve spectral diagnosis.

Method:

We assumed 4 electron distributions（Maxwellian, κ distribution, 2-Maxwellians, Maxwell+κ distribution） and compared the results of spectral diagnosis.

The data for identifying the IPT spectral lines

- We use the spectral images obtained by HISAKI/EXCEED using the 10” slit from on Feb. 18, 2015 to Feb. 23, 2015.
- The images that the local time of HISAKI is at night(from p.m. 7 to a.m. 6) are integrated. The effect of geocoronal emissions are minimized.

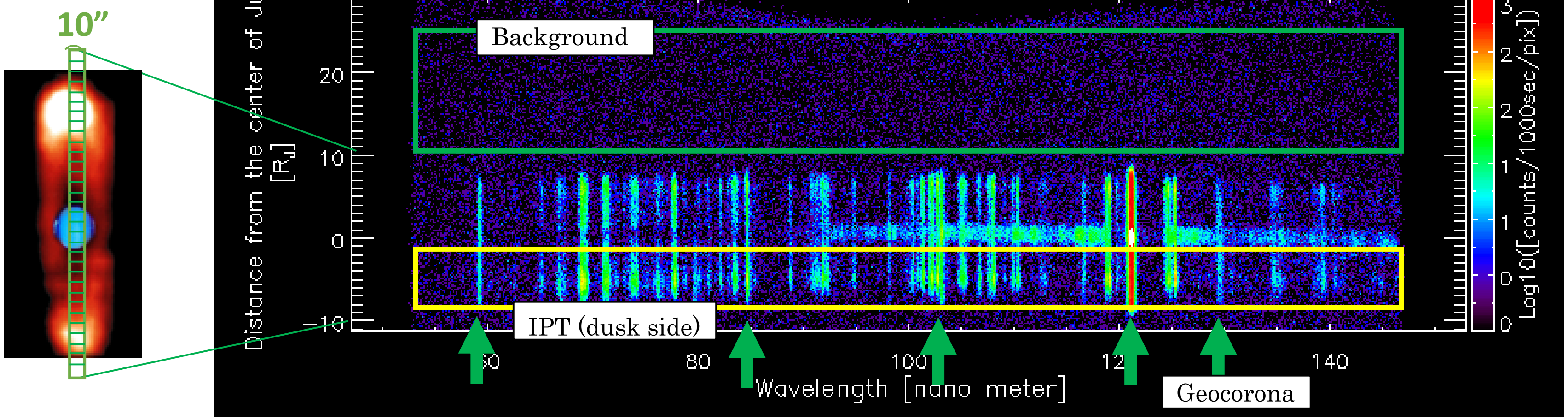
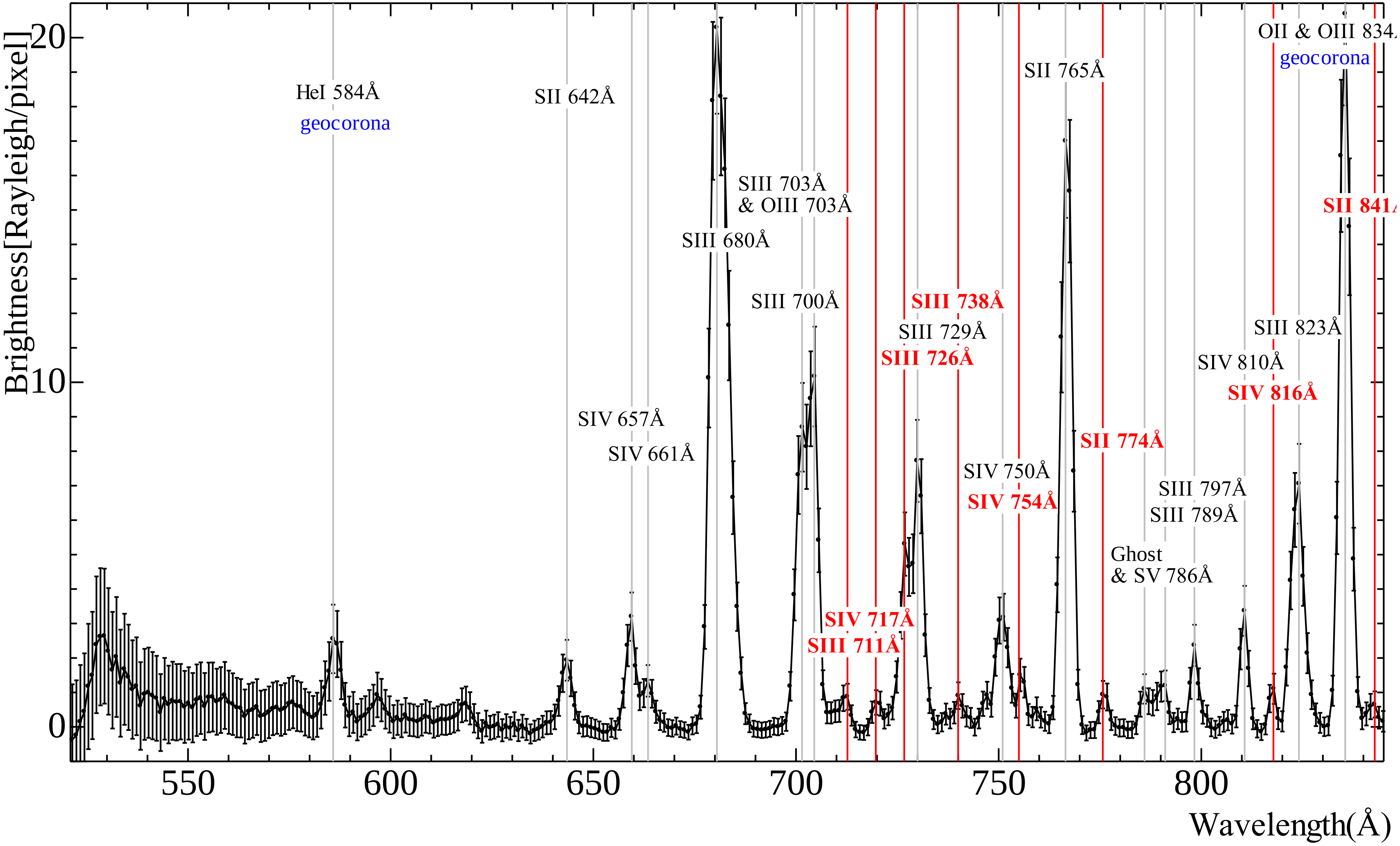


Fig 5. The spectral image obtained by integrating the data obtained by HISAKI/EXCEED using the 10” slit from on Feb. 18, 2015 to Feb. 23, 2015.

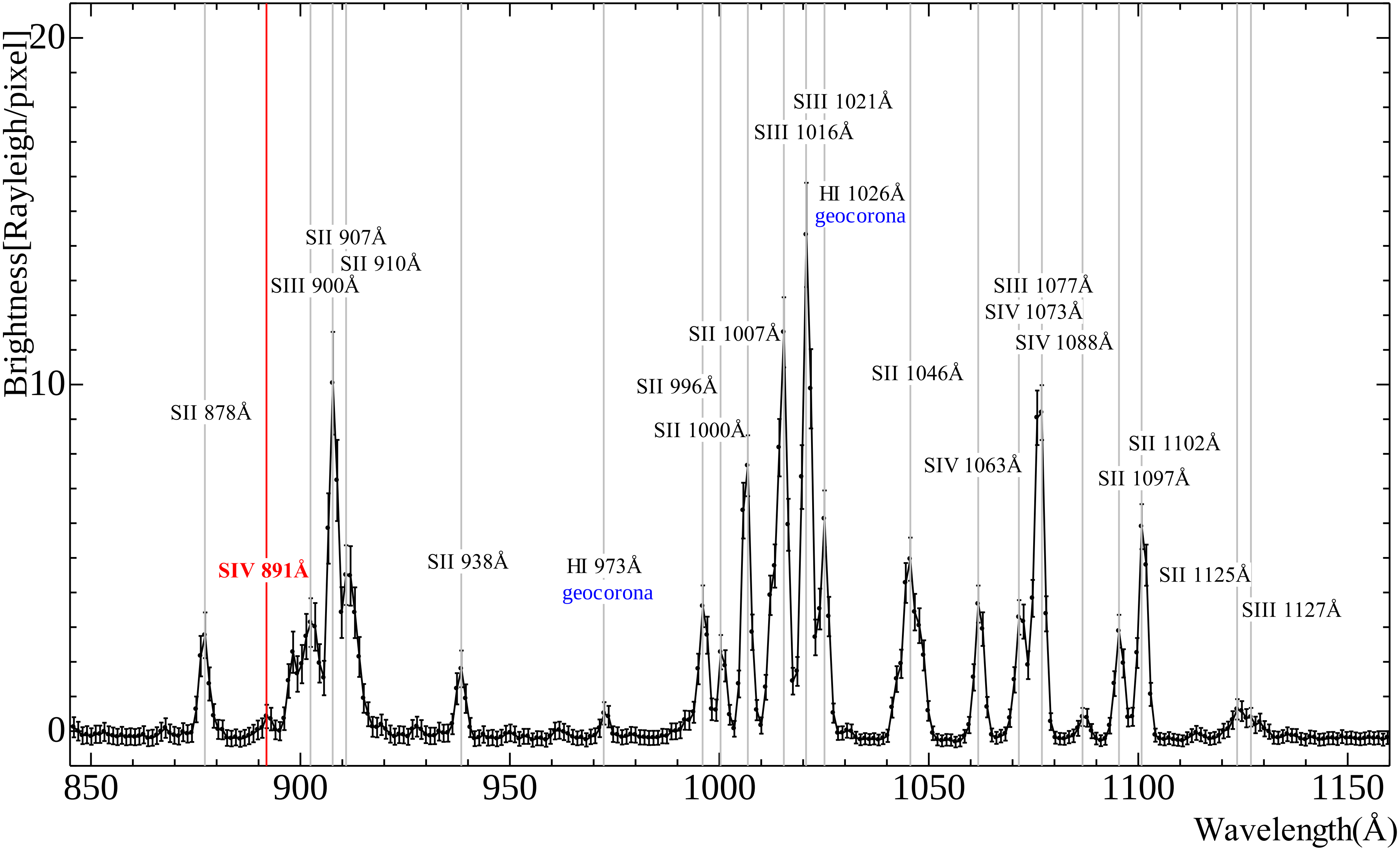
The identification of the IPT spectral lines (1/3)

Red : the newly identified spectral lines



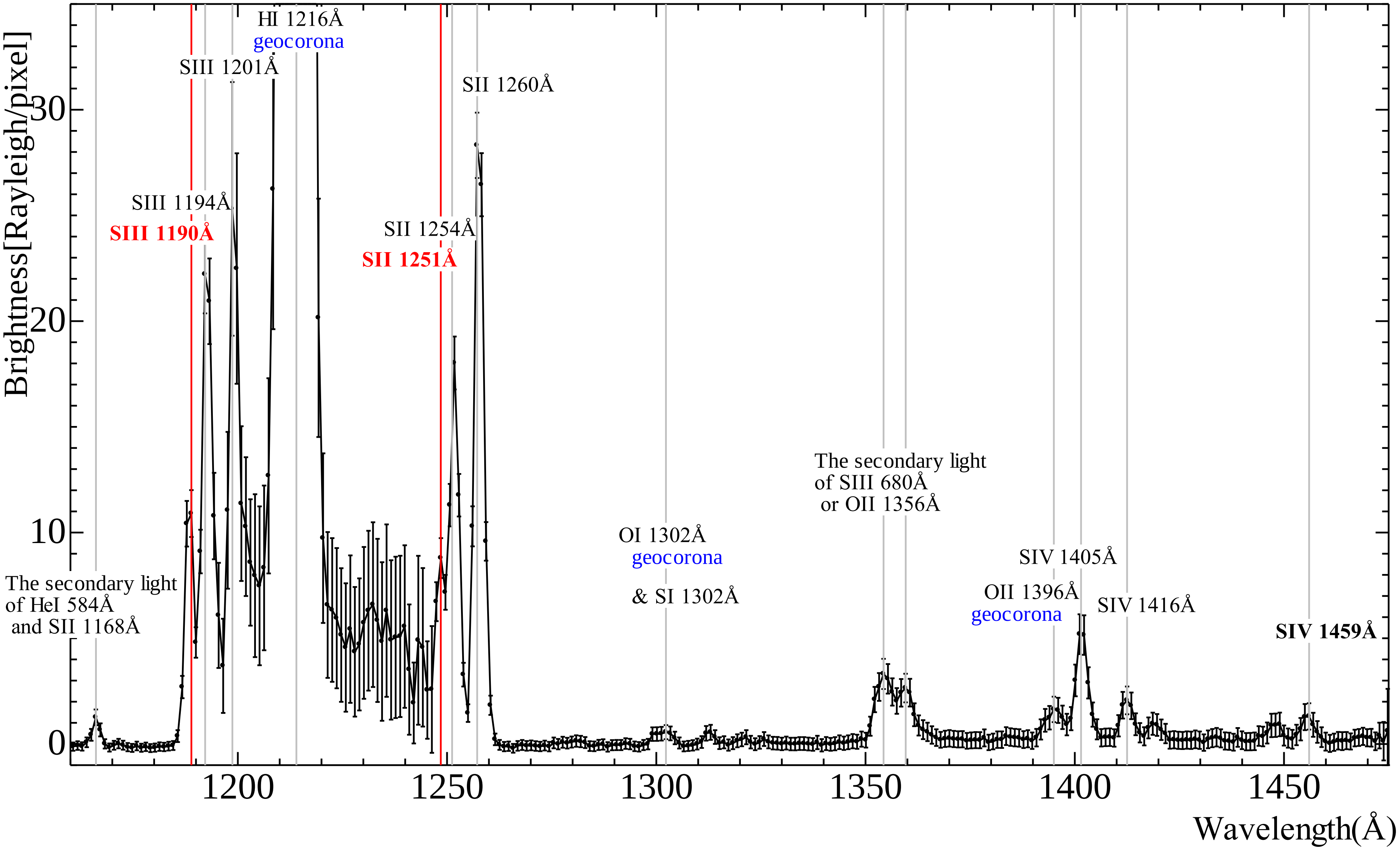
The identification of the IPT spectral lines (2/3)

Red : the newly identified spectral lines



The identification of the IPT spectral lines (3/3)

Red : the newly identified spectral lines



The data for spectral diagnosis

- We use the spectral images obtained by HISAKI/EXCEED using the 10” slit on Nov. 29.
- Spatial bins were summed over 0.4 RJ for the spectra from 5.7 to 6.1 RJ of the dusk side.

- We ignored the spectral lines that brightened slightly and implied the geocoronal emissions.

- CHIANTI database and ”KAPPA Package”(Dzifčáková et. al., 2015) were used for calculating the brightness.

- The κ value and Tκ/Th were fixed to 2.0（Meyer-Vernet, 1995) and 50 eV.

Results

・In the short wavelength range (650~820 Å), there was more difference between electron distributions than in the long wavelength range.

・The fitted spectrum of SIII 703 Å, SII 765 Å and SIII 823 Å were improved by assuming two components.

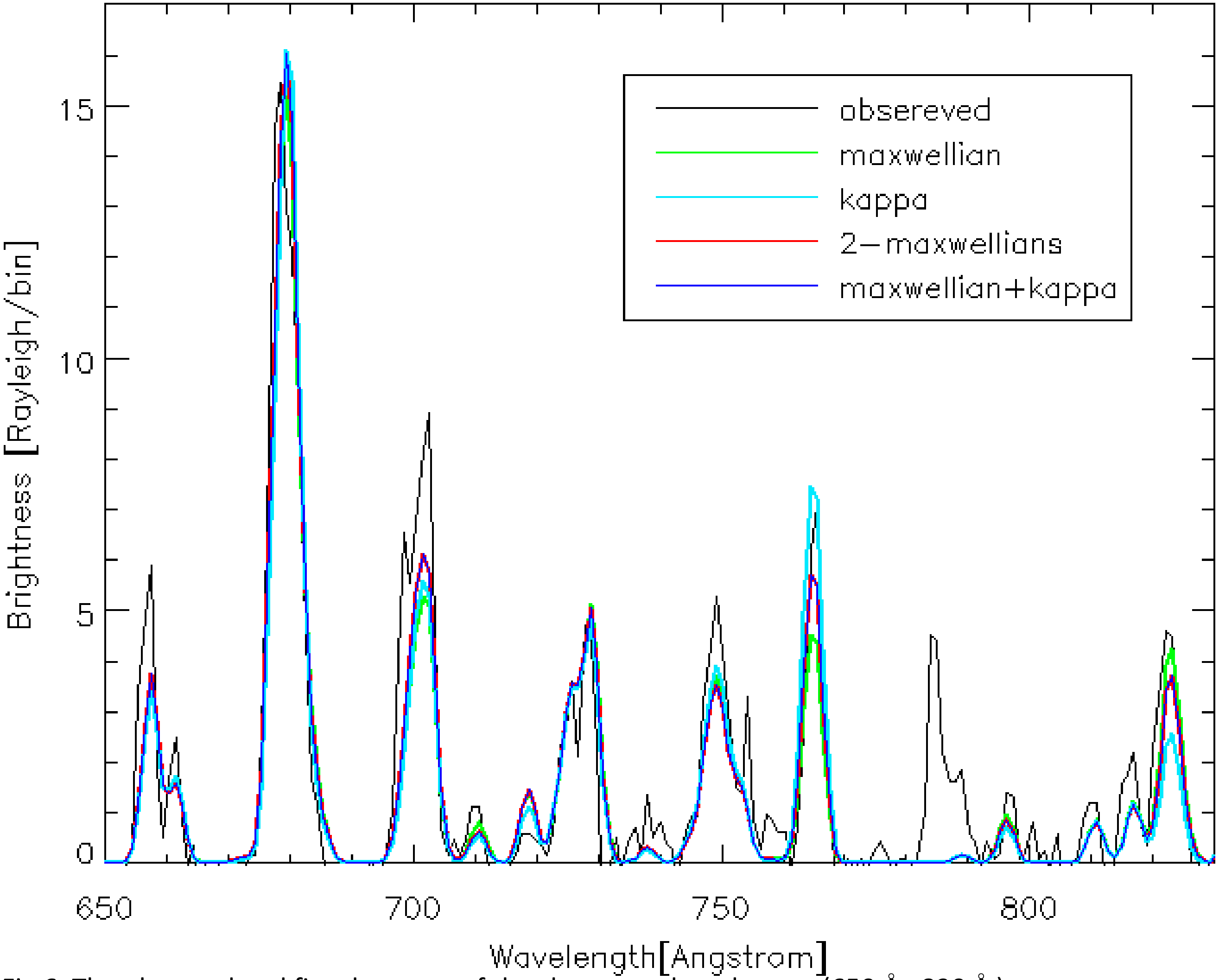


Fig 6. The observed and fitted spectra of the short wavelength range(650 Å~820 Å).

Results

	Chi square	Ele. Dens.	Core Temp.	Hot/kappa Temp.	Hot/kappa frac.
1-max.	918.4	2900±93.5	5.2±0.14		
kappa	964.1	7630±395		7.5	
2-max.	893	3714±274	3.9±0.25	50	1.89±0.2
max. + kappa	895	3703±293	3.9±0.28	50	4.69±0.51

Table 1. The Chi square value and parameters obtained by the spectral fitting

- The χ^2 value of 2-Maxwellians and Maxwell+κ distribution were less than that of Maxwellian and κ distribution.
- The electron density of κ distribution was too larger than the observed value(2000~4000 /cc (Bagenal, 1994)).

→ The sum of two components was more proper than one component.

- The difference between 2-Maxwellians and Maxwell+κ distribution was little except for the fraction of hot component.

→There may be not much difference of the electron collision excitation rate coefficient between the distributions.

Summary

- IPT spectral lines were identified by the HISAKI/EXCEED data.

- We assumed 4 electron distributions（Maxwellian, κ distribution, 2-Maxwellians, Maxwell+κ distribution）and compared the results of spectral diagnosis.

- The IPT spectrum was fitted better on the assumption of 2-Maxwellians/Maxwell+κ distribution than on that of Maxwellian/κ distribution. However, the difference between 2-Maxwellians and Maxwell+κ distribution was little.

Appendix.
The data for identifying the IPT spectral lines

- The dusk side of IPT spectrum is integrated.
- The background count rate is estimated from the counts detected in the green area in the image.

- Error bars are estimated based on Poisson statistics of photon counts and the error of the effective area. One standard deviations are indicated in graphs.

$$N_{signal} = N_{total} - N_{background}$$

$$\therefore\ \sigma_{signal} = \sqrt{\sigma_{total}^2 + \sigma_{background}^2} = \sqrt{N_{total} + N_{background}}$$

$$\text{Brightness [Rayleigh]}$$
$$= signal\ [counts/min] \times \boxed{\frac{1}{60} \times \frac{1}{\text{Effective area } A\ [cm^2]} \times \frac{4\pi}{\text{the View angle } [str/pixel]} \times \frac{1}{10^6}}$$

=Q

$$\therefore\ \sigma_{Brightness} = \sqrt{\left(\sigma_{signal} \times Q\right)^2 + \left(\sigma_A \times Q \times \frac{signal}{A}\right)^2}$$