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Jupiter H_3^+ Auroral Emission Model for Electron Energy Estimation

C. Tao (1), S. V. Badman (1), T. Uno (2), and M. Fujimoto (1)
(1) ISAS/JAXA, Japan, (2) Tohoku University, Japan
(tao@stp.isas.jaxa.jp / Fax: +81-42-759-8456)

Abstract

We investigate the feasibility of determining the properties of Jupiter's auroral electrons from infrared (IR) emission line intensities using an auroral emission model. The ratios of three H_3^+ IR emission line intensities are required to determine the electron energy and background temperature. We evaluate the accuracy of the estimates derived using this method as a function of the accuracy of the observations.

1. Introduction

Aurorae represent the plasma environment around a planet. Outer planetary aurorae are observed in various wavelengths. Since infrared (IR) wavelengths are observable from the ground with some spatial information, they can be used to monitor the plasma environment variability. The IR aurora is emitted from thermally excited H_3^+ ions, thus its intensity reflects the atmospheric temperature. H_3^+ itself is mainly produced by auroral electrons at high latitudes. Previous studies have related the IR emission to the H_3^+ column density and atmospheric temperature (e.g., [1]). This study newly attempts to test its applicability for monitoring not only the atmospheric conditions (temperature) but also the auroral electrons (energy and flux).

2. Model and Approach

We use an auroral emission model for the hydrogen-dominant outer planets [2]. Here we focus on Jupiter observations and steady state output. We estimate the IR emission intensity including atmospheric ionization by solar EUV and auroral electrons, ion chemistry, and non-LTE (local thermodynamic equilibrium) vibrational distribution of H_3^+. We use the main H_3^+ lines in the 4 μm [3] and 2 μm bands [4] detected by the ground-based observations.

Our emission model calculates emission from an H_3^+ density which is a result of auroral electron precipitation and ion chemistry. We deduce the auroral electron energy, flux, and exospheric temperature from IR lines as follows: (1) Electron energy and exospheric temperature are obtained from three emission line intensity ratios. Then (2) the absolute intensity values of lines are used to estimate the electron flux. Since process (2) is directly determined once the electron energy and temperature are fixed, here we focus on process (1), i.e., how we distinguish the electron energy and temperature.

3. Results

We selected several IR emission line sets. One example, using the ratios Q(3,0)/Q(1,0), R(3,4)/R(3,1), and R(3,4)/R(2,1), is shown in Figure 1. This is a contour map of the line intensity ratios as functions of characteristic electron energy and background temperature. The crossing point of the three different lines provides the required energy and temperature.

The observations of line intensities include errors, which bring uncertainty into the ratio map. For example, the sets of two black lines in Figure 1 show the upper and lower range of including 0.5% error in the case of 60 keV and 1200 K. We deduce the energy and temperature from the black-filled area where the three bands overlap.

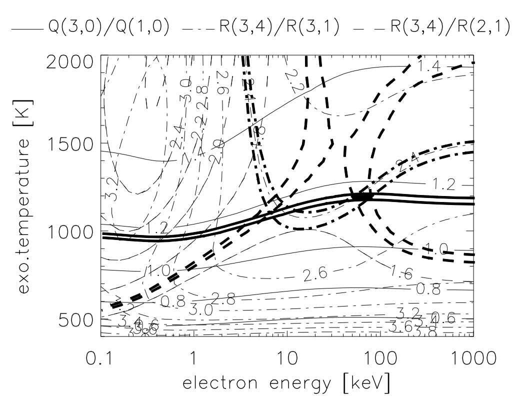

Figure 1: Map of three line ratios as functions of electron energy and exospheric temperature (thin lines) and an example of an estimation including 0.5% error in the 60 keV and 1200 K case (bold).

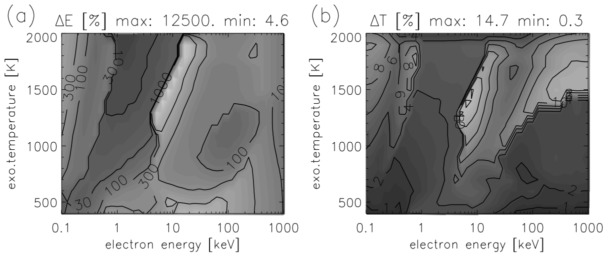

Figure 2: Variation of (a) energy and (b) temperature errors as functions of exact energy and temperature.

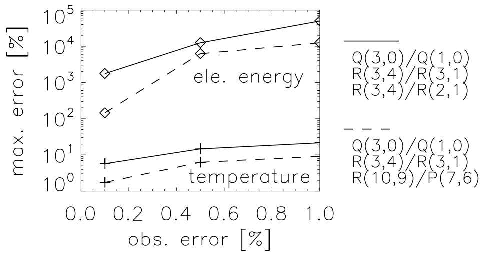

Figure 3: Variation of maximum error with obs. error.

As shown in Figure 1, the estimated energy and temperature regions are broadened by including the observational error. We obtain an error map (Figure 2). The energy estimation error becomes large around 10 keV because two overlapping areas appear in the ratio map. The temperature estimation error is much lower than the energy error. Figure 3 shows the maximum value of the errors as a function of the observational error. This shows that estimating energy and temperature with good accuracy requires small observational errors.

If different emission line ratios are included, i.e., combining 4 μm and 2 μm wavelengths using line ratios of Q(3,0)/Q(1,0), R(3,4)/R(3,1), and R(10,9)/P(7,6), we can improve the estimation accuracy as shown by the dashed lines in Figure 3.

4. Discussion

The key factor for the electron energy estimation is the different dependences of IR emission lines on energy and temperature. The dependence of emission intensity I on temperature T and altitude z is represented as

$$I(z) \propto \eta(z,T) n_{\mathrm{H}_3^+}(z) \exp\{E_\mathrm{f}/kT(z)\}, \quad (1)$$

where η is the ratio of departure from LTE, $n_{\mathrm{H}_3^+}$ is the H_3^+ density, E_f is the upper state energy of the transition, and k is the Boltzmann constant. The temperature dependence is related to E_f, which varies across the emission lines. On the other hand, the non-LTE effect, η, depends on the H_2 density in addition to temperature. The altitude profile of η varies with the upper vibrational state of transition. Since how deep electrons can penetrate affects η differently depending on the vibrational levels, the electron energy dependences can be detected. This is confirmed by the small energy dependence under constant temperature and LTE conditions.

Table 1 lists typical and required observation integrations with signal-to-noise (S/N). This model requires a S/N of at least 100 for accurate estimation (within several 100%), which constrains both the temporal- and spatial-integration. The integrations required for higher S/N are also listed in Table 1.

Table 1: Observation conditions

Emission line	Obs. Integration	S/N
Q(1,0), Q(3,0)	several min., 1 arcsec	100
R(3,4), R(3,1),	1 hour, 1 arcsec	10
R(2,1)	10 hour, 3 arcsec	100
R(10,9),P(7,6)	30 min., 1 arcsec	15
	6 hour, 3 arcsec	100

5. Summary and Conclusions

We propose a method for estimating auroral electron properties in addition to temperature using three IR emission line ratios. The energy dependence is determined by the different altitude profiles of the non-LTE effect for the IR lines. Accurate estimates require long-time and/or large spatial integration to reduce the observational errors. A system with a larger non-LTE effect, i.e., higher temperature and lower H_2 density, would provide a good estimation.

References

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