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Jupiter H_3^+ Auroral Emission Model for Electron Energy Estimation 2: Using Spectra

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Abstract

We investigate the feasibility of determining the properties of Jupiter's auroral electrons from infrared (IR) emission line spectra using our auroral emission model. This study provides the accuracy of the estimates as functions of the 4 μm- and 2 μm-observation accuracies.

1. Introduction

Auroral electron energy is a key parameter as reflecting the magnetospheric activities and controlling atmospheric heating and conductance.

We have proposed a method for estimating the characteristic energy of auroral electrons at Jupiter in addition to the atmospheric temperature using at least three H_3^+ emission line ratios, based on an emission model study [1]. This method exploits how the departure from local thermodynamic equilibrium (LTE) varies with vibrational levels and altitude, i.e., measurements of the relative emission line intensities reveals the altitude of emission and hence the electron energy. Therefore this method requires lines from different vibrational lines, thus appropriate line sets include both bright and dark lines. We estimated the error using lines with the same signal-to-noise (S/N) ratio, e.g., 100, independent of the line emission intensity. This requires long time integration for low-intensity lines.

On the other hand, the achieved S/N varies for different lines for the same integration time. In addition, Subaru/IRCS and GEMINI/GNIRS can observe several lines simultaneously due to wide-wavelength coverage. This study evaluates the accuracy of the electron energy estimation by referring to the variable S/N from different emission lines.

2. Model and Estimation Method

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 vibrational distribution of H_3^+. We use the main H_3^+ lines in the 4 μm [3] and 2 μm bands [4] detected by ground-based observations.

We estimate the line intensity using the parameter list for H_3^+ emission lines [5]. Since Subaru/IRCS and GEMINI/GNIRS cover the 4 and 2 μm bands separately, we consider separate observations to obtain the S/N for Q(1,0) in the 4 μm, termed 'SN4', and S/N for R(6,6) in the 2 μm, termed 'SN2'.

Ignoring small read out noise and dark noise, we consider noise caused by background light I_{sly}. This noise is mainly caused by the brightness of Earth's atmosphere at 4 μm and by scattering from Jupiter at 2 μm. Based on observations, we set I_{sky} for 4 μm and 2 μm cases as 1/3 $I_{\mathrm{Q}(1,0)}$ and $I_{\mathrm{sky}} \sim 1/2\ I_{\mathrm{R}(6,6)}$, respectively. Referring to these values, we can represent the S/N for other H_3^+ lines, $(\mathrm{S/N})_1$, using the line emission intensity I_1 as follows:

$$(\mathrm{S/N})_1 = (\mathrm{S/N})_0 \frac{I_1}{\sqrt{I_1+I_{\mathrm{sky}}}} \Big/ \frac{I_0}{\sqrt{I_0+I_{\mathrm{sky}}}}\,, \qquad (1)$$

where $I_0 = I_{\mathrm{Q}(1,0)}$, $(\mathrm{S/N})_0$ = SN4 for 4 μm band lines and $I_0 = I_{\mathrm{R}(6,6)}$ and $(\mathrm{S/N})_0$ = SN2 for 2 μm band lines.

We prepare a contour map for the emission intensity as functions of auroral electron energy ε and exospheric temperature T. We search for the (ε, T) region which satisfies a line intensity of expected energy $\varepsilon_{\mathrm{exact}}$ and temperature T_{exact} to be obtained within observational error. This process is applied to all 22 lines of the 4 μm and 2 μm bands. For the obtained region with $[\varepsilon_1, \varepsilon_2]$, $[T_1, T_2]$, we can obtain the estimation error for electron energy and temperature as

$$\Delta\varepsilon = \varepsilon_2/\varepsilon_1 \quad (2)$$

$$\Delta T = (T_2\text{-}T_1)/T_{\mathrm{exact}} \times 100\ [\%]. \quad (3)$$

We obtain $\Delta\varepsilon$ and ΔT for $\varepsilon_{\mathrm{exact}} = 10^0 = 1.00$, $10^{0.2} = 1.58$, …, $10^{2.4} = 251$ keV and $T_{\mathrm{exact}} = 600, 700, \ldots, 2000$ K cases, and their maximum value max($\Delta\varepsilon$) and max(ΔT) for several SN4 and SN2 cases.

3. Results

Figure 1 shows the obtained electron energy error $\Delta\varepsilon$ and temperature error ΔT as functions of SN4 and SN2. The larger SN4 and/or SN2 become, the better we can estimate them.

To distinguish the lines P(8,7) and P(6,5) in the 2 μm band requires high spectrally-resolved observations with resolution power $R > 20{,}000$. Here we also check the above estimation for the $R > 3{,}000$ observation case, i.e., excluding the P(8,7) and P(6,5) lines and find that the result is almost the same as the high-resolution case. This would be caused by the weak intensity of these lines, since small S/N due to Equation (1) increases the size of the (ε, T) region estimated from these lines and does not affect the (ε, T) restriction.

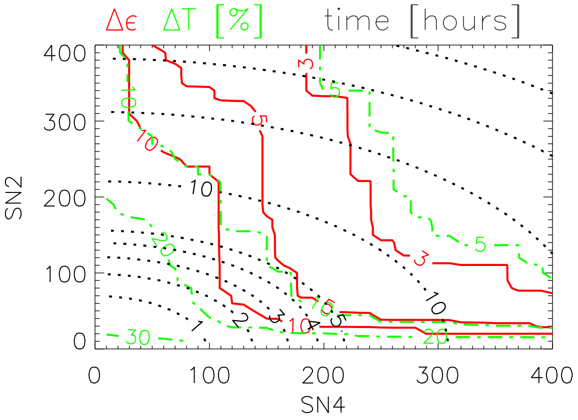

Figure 1: Contour map of energy (red solid-line) and temperature (green dashed-line) estimation errors, and required total time (black dotted-line) as functions of SN2 and SN4.

4. S/N and time estimation

Table 1 lists typical and required observation integrations with corresponding signal-to-noise (S/N). The minimum observation time to achieve $\Delta\varepsilon < 5$ is 4 hours when SN4 ~ 170 and SN2 ~ 70 for the case of no spatial binning, shown by dotted line in Figure 1. This integration time can be reduced by spatial binning, i.e., the required time becomes 1 hour for 16-pixel binning (~0.4 arcsec^2).

Table 1: Observation conditions for Subaru/IRCS.

Emission line	Obs. Integration	S/N
Q(1,0)	64 sec., 0.05x0.54 arcsec^2	13
R(6,6)	74 sec., 0.05x0.54 arcsec^2	10

5. Summary and Conclusion

Using our auroral emission model, we test the electron energy estimation method against observable spectral lines. The required integration time for this estimation method is improved (i.e., reduced) compared with the previous estimation [1]. The application and test of this method using observed data will be discussed in the presentation.

References

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