The Jovian aurora is an important diagnostic for understanding the dynamical behavior of the Jovian upper atmosphere. Because of the strong coupling between the magnetosphere and ionosphere-thermosphere due to the Jovian rapid rotation, the Jovian auroral phenomena reflect not only magnetospheric conditions but also energy transport through ion-neutral collisions in the thermosphere. Various auroral emission lines have been observed in the near infrared region, such as $\text{H}_3^+$ "fundamental" ($\nu_2 = 1 \rightarrow 0$, around the wavelength of 4 $\mu$m), $\text{H}_3^+$ "overtone" ($\nu_2 = 2 \rightarrow 0$, around 2 $\mu$m), $\text{H}_3^+$ "hot overtone" ($\nu_2 = 3 \rightarrow 1$, around 2 $\mu$m) and $\text{H}_2$ "$S_1$" ($\nu = 1 \rightarrow 0$, around 2 $\mu$m). Numerical calculation predicted that the altitudes of $\text{H}_3^+$ fundamental and $\text{H}_2$ $S_1$ are $\sim 500$ km, and $\text{H}_3^+$ overtone and hot overtone are $\sim 1500$ km above the cloud top. Because these emissions are produced via different mechanisms and energies, it is important to compare the observations at each wavelength to restrict the dynamical behaviors of neutrals and plasmas in the Jovian upper atmosphere. Although the morphological difference between $\text{H}_2$ and $\text{H}_3^+$ aurora was reported by previous studies, the detailed mechanisms that cause the difference and its interaction process remain resolved. The purpose of this study is the ground based observations of the vertical emission profiles of near infrared $\text{H}_2$ and $\text{H}_3^+$ aurora.

We present the measurement of the vertical distributions of Jovian infrared $\text{H}_3^+$ overtone, hot overtone and $\text{H}_2$ auroras by the echelle spectroscopy of Subaru/IRCS executed in December 2011. This instrument provides us the spatial resolution of 0.2 arcsec (<200 km) with the aide of new Adaptive Optics (AO), which used the Galilean satellite as a guide star (Figure 1). Using the new 3-D emission source model, which includes the vertical emission profiles based on the past model studies and latest main auroral oval morphology based on the HST observation, we evaluated the effect of horizontal morphology of the IR aurora on the result of the vertical emission structure derived by the "onion peeling" method (Figure 2). From this validation, we conclude that the horizontal morphology made little impact on the results of onion peeling: the residual less than $\sim 300$ km (Figure 3). Based on the three observed spectra with AO, cutting across the poler region and the edge of the main auroral oval, we obtain the results that the vertical emission profiles of IR $\text{H}_3^+$ overtone, hot overtone and $\text{H}_2$ auroras have similar altitude profiles, with the peak at the altitude of $\sim 500$ km (Figure 4). $\text{H}_3^+$ emission peak altitudes were found to be $\sim 500$ km lower than the past model for overtone and
Figure 1  Jovian image taken by slit viewer of IRCS on 1, Dec. 2011. K narrow band filter was used. left: without AO (normal seeing) image. Typical seeing on the night was 0.78 arcsec. right: with AO image. Effective seeing using AO was ~ 0.2 arcsec. The northern limb and small vortices are clearly seen in the with AO image.

Figure 2  (left) Polar projection of model. While lines indicate the slit position; solid lines indicate above the limb. (right) Emission profile along the slit. (top) #AO1, (bottom) #AO2.
hot overtone emissions. On the other hand, the $\text{H}_2$ emission altitudes is consistent with the 10-100 keV electron precipitation. The observed altitudes of $\text{H}_3^+$ overtone and hot overtone emission suggest that the non-Local Thermodynamic Equilibrium (LTE) effect is stronger, i.e., the scale height of the thermosphere is smaller and/or the thermospheric temperature is lower than predicted. We also evaluate the line intensity ratio of overtone R(7,7) and hot overtone.
R(5,6) lines; the ratio of R(5,6)/R(7,7) is 0.24 in average. This is consistent with the results of past observation, but is not consistent with the predicted model which showed a larger ratio than our observation. The result also suggests that the non-LTE effect is stronger than the previous model, and agrees well with the observed low peak altitude of $\text{H}_3^+$ overtone and hot overtone emission. In previous studies, it was believed that the morphological difference between $\text{H}_2$ and $\text{H}_3^+$ aurora and the relatively small velocity of neutral $\text{H}_2$ wind is due to the difference in the source altitude. However, our results imply that the emission altitudes of $\text{H}_3^+$ overtone, hot overtone aurora and $\text{H}_2$ aurora are almost the same. It potentially suggests that the coupling parameter $k$ could be derived directly from the infrared spectroscopic observation, and that our results show smaller value than previously predicted.

Reference


