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HIGH-RESOLUTION ULTRAVIOLET SPECTROSCOPY OF JUPITER'S AURORA WITH THE HUBBLE SPACE TELESCOPE

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ABSTRACT

In 1993 June and July, we obtained 18 spectra of Jupiter's aurora in the wavelength range 1586–1620 Å using the Goddard High Resolution Spectrograph on board the *Hubble Space Telescope* (HST). The field of view for each observation was 2" × 2". There were 14 spectra of the northern and four spectra of the southern auroral ovals. The spectra are dominated by vibrational-rotational lines of the H₂ Lyman band system, from which we have determined H₂ rotational temperatures which correspond to the altitude region where most of the auroral emission originates. Intense emission was observed in two spectra at longitude 155°–165°, latitude 50°–65°, at a time when the central meridian longitude was near 190°. This location coincides with a bright spot in HST Faint Object Camera images of Jupiter's northern aurora. We estimate total emission rates in the Lyman band system of ~250 kR for the bright regions and ~25–130 kR for the fainter regions. The best-fit temperatures for the bright region and fainter regions are in the ranges 200–500 K and 200–800 K, respectively. The relatively low temperatures for the bright regions may indicate that the precipitating primary particles responsible for UV emission there penetrate more deeply than do particles in the fainter regions, to altitudes where the temperatures are lower because of efficient cooling by hydrocarbons.

Subject headings: line: formation — molecular processes — planets and satellites: individual (Jupiter) — ultraviolet: solar system

1. INTRODUCTION

Ultraviolet emission from the Jovian aurora was first detected by *Voyager* (Broadfoot et al. 1979) and has been observed regularly by the *International Ultraviolet Explorer* (IUE) over the past decade (Skinner et al. 1984; Herbert, Sandel, & Broadfoot 1987; Livengood et al. 1990, 1992). The Jovian aurora is the most powerful in the solar system. Its estimated total hemispheric power input is about 10¹⁴ W, which is about 10³ times stronger than an average terrestrial aurora. This large energy input inevitably affects the thermosphere and ionosphere in the polar regions and, subsequently, the rest of the planet. The auroral UV emission in the wavelength range 1200–1800 Å consists predominantly of the H₂ Lyman ($B^1\Sigma_u^+ \rightarrow X^1\Sigma_g^+$) and Werner ($C^1\Pi_u \rightarrow X^1\Sigma_g^+$) band systems produced by direct excitation, with some cascade contribution from upper Rydberg states. By fitting IUE observations with synthetic spectra, Gladstone & Skinner (1989) found that if the precipitating particles in the Jovian auroral region are electrons, they have characteristic energies of 10–100 keV. Long-term studies with IUE show persistent maxima in UV emission near a central meridian longitude (CML) of 180° (hereafter System III) in the north and 0°–50° in the south polar regions (Skinner et al. 1984; Herbert et al.

1987; Livengood et al. 1990, 1992). Neither *Voyager* nor IUE had sufficient spectral resolution to permit the determination of ambient temperatures from H₂ rotational line analysis.

Recent observations with the Faint Object Camera (FOC) on board the HST show narrow, continuous auroral ovals around both of Jupiter's poles (Caldwell, Turgeon, & Hua 1992 and unpublished; Gérard et al. 1993). FOC images of the northern polar region show broad and bright emission near longitude 150°, especially when viewed near the western limb. Since the aperture of the IUE spectrograph is large (10" × 20"), the region of enhanced brightness in the FOC images may correspond to the longitudinal intensity maximum identified in IUE observations when the CML was near 180°.

Ground-based observations at 3.5 μm also show infrared auroral emission, but this is mainly due to H₃⁺ (Kim et al. 1991; Baron et al. 1991). Analysis of the H₃⁺ lines indicates that the auroral region is characterized by considerably higher temperatures (around 1000 K) than the nonauroral regions (Drossart et al. 1989; Miller et al. 1990). The UV (H₂) auroral emission is believed to originate from lower altitudes than the H₃⁺ emission (Yung et al. 1982; Gladstone & Skinner 1989; Livengood et al. 1990; Kim, Fox, & Porter 1992); significantly different temperatures are therefore possible at the altitudes at which these emissions originate.

The spectral resolution of the Goddard High Resolution Spectrograph (GHRS), ~0.07 Å in the mode we used, is sufficient to resolve the rotational structure in the H₂ bands, and

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the spatial resolution, $2'' \times 2''$, is small enough to isolate a significant area in the auroral regions.

GHRs observations of UV aurora have been reported recently by Trafton et al. (1994) and Clarke et al. (1994), whose analyses show rotational temperatures of 400–750 K for areas at the central meridian of the northern auroral region. Using positional information from FOC images, we have employed the GHRs to observe both the northern and southern auroral regions, including the very bright areas of the northern auroral oval which were not observed by Trafton et al. (1994), to study more comprehensively the temperature structure and intensity of the UV aurora and its variation over the auroral oval.

2. OBSERVATIONS

The observations were made on four days: 1993 June 29, July 3, July 4, and July 21, as listed in Table 1. A total of 18 spectra were obtained with the GHRs using the medium-resolution grating G160M with the $2'' \times 2''$ square Large Science Aperture (LSA). We used the "D2" Digicon detector, which has 500 spectral diodes and a CsTe cathode on a MgF₂ window (Duncan 1992). The 500 diodes cover a spectral range of ~ 35 Å in a single exposure; the width of the LSA corresponds to eight diodes. Thus, the dispersion is 0.072 Å per diode, and the spectral resolution is ~ 2780 if the aperture is fully illuminated. We observed the spectral range 1585–1621 Å, where the Lyman band emissions are brightest and two rotational line sequences are well separated.

The GHRs does have higher resolution modes than this one in both spectral and spatial dimensions, but the Jovian aurora is not bright enough to be observed by them in a time that is short compared to Jupiter's rotation.

Four substeppings of each diode (STEP-PATTERN = 5) were used with co-addition to give spectra of 200 wavelength steps. There were four substeps per diode width. The background was sampled above and below the spectrum every eighth substep cycle, resulting in a duty cycle of 94% on target. An exposure time of 761 s was used for all the spectra.

An exposure is divided into four subexposures, each with an exposure time one-quarter of the total (FP-SPLIT = 4). The

grating carousel moves the spectrum ~ 5.2 diode widths for each subexposure. This procedure minimizes problems due to individual bad diodes. The four subexposures are combined together in the reduction procedure.

Another grating/detector combination (G140L/D1) within the GHRs, which in principle could have performed the observations with a lower spectral resolution and a wider bandpass, was not operational in mid-1993. That option has been restored, however, with the late 1993 orbital repair mission of the *HST*, and it may be considered for future observations.

We obtained 14 spectra on the northern auroral oval and four on the southern oval. Polar-projected plots of the observed areas are presented in Figure 1, along with the $L = 5.9$ and 30 footprints of the O₆ magnetospheric model (Connerney 1992). The observed areas span a wide range of longitudes and latitudes. The positions reported here are in System III longitudes and Jovicentric latitudes. Most of the target areas were selected with the requirement that the aperture should include the westernmost point of the $L = 30$ footprint but no empty sky background. In addition, four spectra (702t, 802t, 102t, and m02t) were obtained near the eastern limb of northern polar regions. Areas at the central meridian were also selected for two spectra (e02t and f02t) in the southern polar region and one spectrum (g02t) in the northern polar region.

Observation times had to be known in advance to an accuracy of a few minutes in order to point at the coordinates of the desired target areas on Jupiter. In general, this is difficult within the *HST* operational system because of a combination of fundamental uncertainties in the orbital parameters of the *HST* and delays amounting to many weeks between planning and execution of an observing sequence. Pointing to a desired area on Jupiter was achieved by offsetting from Io, which was acquired before each series of spectral observations. For most of the pointings, it was possible to update target positions appropriate to the actual observation times during the uplink procedure prior to the execution of the offset. Unfortunately, we could not uplink the updated position for the target (h02t),

TABLE 1
GHRs OBSERVATIONS OF JUPITER'S AURORA

<i>HST</i> Number	Date (UT) (1993)	Time (UT)	Position (longitude, latitude)	CML	Peak Flux (counts per diode)	$4\pi I$ (kR)	T (K)
102t	Jun 29	08:25:01	(175, 58)	140°	69	55	300
m02t	Jun 29	08:46:49	(180, 60)	154	117	89	200
702t	Jul 3	10:24:24	(120, 63)	94	44	27	300
802t	Jul 3	10:46:04	(130, 63)	107	71	55	400
902t	Jul 3	11:59:58	(135, 63)	152	58	44	300
a02t	Jul 3	12:21:18	(145, 62)	165	105	97	400
202t	Jul 4	07:17:36	(120, 65)	132	46	28	600
302t	Jul 4	07:39:10	(130, 65)	145	72	56	500
402t	Jul 4	08:53:10	(155, 58)	190	201	237	400
502t	Jul 4	09:15:10	(165, 56)	203	219	242	300
c02t	Jul 21	02:31:16	(330, -68)	356	116	116	500
d02t	Jul 21	02:53:16	(340, -68)	10	117	113	400
e02t	Jul 21	04:07:31	(54, -70)	55	53	46	600
f02t	Jul 21	04:29:31	(35, -70)	68	73	74	400
g02t	Jul 21	05:44:00	(113, 70)	113	60	53	700
h02t	Jul 21	06:06:00	(216, 85) ^a	126	78	74	500
i02t	Jul 21	07:20:14	(145, 65)	171	86	89	500
j02t	Jul 21	07:42:15	(155, 65)	184	87	91	400

^a Aperture was partially off the limb.

GHRS observations in north polar region

GHRS observations in south polar region

FIG. 1.—*Top*: Polar-projected plot of areas covered by the LSA of the GHRS for observations of Jupiter's northern auroral regions. Bright UV emission was observed from areas enclosed by thick lines. The footprints of $L = 30$ (inner) and $L = 5.9$ in the magnetospheric O_6 model (Connerney 1992) are overplotted. *Bottom*: Similar to the top panel, for observations of southern auroral regions.

which was therefore observed with the aperture half-filled by empty sky background.

3. DATA REDUCTION AND ANALYSIS

The Space Telescope Science Institute (STScI) routinely executes standard “pipeline” reduction procedures on the raw data, resulting in the spectra calibrated in terms of flux versus wavelength. The calibration files are, however, frequently updated, and the pipeline material is often somewhat out of date. We rereduced our data using the STScI calibration packages with an updated vignetting function and scattered-light correction factors.

The corrected count rates for each channel were derived in the calibration package, which performs correction for paired pulses, division by exposure time, correction for the diode response function, removal of photocathode granularity (which was assumed to be uniform for low signal to noise spectra), removal of the vignetting function (which includes

low-frequency photocathode variations), and correlation for incidence angle differences through the LSA. Background count rates were determined from diodes that sample above and below the object spectrum. The mean value of the background count rates was subtracted from the corrected object count rates, resulting in a net spectrum. The absolute flux spectrum was obtained by dividing the net spectrum by a sensitivity function for the instrumental configuration. A correction factor of 0.77, which was applied by Trafton et al. (1994) to account for the extended nature of the source, has not been applied here. The wavelength scale was derived from the Pt-Ne lamp wavelengths, which were obtained immediately before each science exposure. Doppler corrections for planetary orbit motion were applied to the wavelengths to obtain heliocentric wavelengths.

Co-addition of the four substepped spectra resulted in a single spectrum of 2000 channels for each FP-SPLIT sub-exposure. The four subexposures were co-added according to their calibrated wavelength scales, rather than by correlating the spectral features. Such correlation was not warranted for the low signal-to-noise ratio (S/N) spectra.

Figure 2 (*top*) shows one of the faintest exposures (702t) of the 18 at a resolution of one diode ($0.072 \text{ \AA}$). The emission features are somewhat difficult to distinguish from the noise.

FIG. 2.—*Top*: The faintest observed spectrum of Jupiter's northern aurora, at a resolution of one diode. The exposure time was 761 s. The central position of the LSA and the CML at midexposure are labeled in System III coordinates. Ro-vibrational line positions in the Lyman band system are indicated. The numbers in parentheses are vibrational levels in the upper and lower electronic states. *Bottom*: The same spectrum as in the top panel, smoothed over four diodes, resulting in $\sim 0.3 \text{ \AA}$ resolution. Most of the ro-vibrational lines are identified at this resolution.

The spectrum was therefore smoothed over four diodes with a boxcar filter, and the result is presented in Figure 2 (*bottom*). The smoothed spectrum clearly exhibits emission peaks that correspond to ro-vibrational lines of the H_2 Lyman bands. Similar plots are presented in Figures 3 (*top*) and 3 (*bottom*) for one of the brightest exposures (502t). The auroral emission in this spectrum was so intense that even the unsmoothed spectrum clearly shows the details of the emission features. The emission lines in Figure 3 (*top*) are broader than the line spread function of the LSA for a point source, indicating that the auroral region spanned a large fraction of the aperture. Since the spectral features are already broadened in the raw spectra, little information is lost by rebinning the spectrum of 2000 channels into 500 diode bins and then smoothing over four diodes.

Figures 4–7 show the smoothed spectra for the 16 auroral regions; propagated rms errors are overplotted with dotted lines. The average S/N of the smoothed spectra ranges from 2.2 to 7.3, where exposures 202t and 702t have the lowest, and c02t and d02t the highest S/N . An average S/N larger than 3 is achieved for all the spectra except the two faintest. Two exposures, 402t and 502t, are so bright that each subexposure has an average S/N of ~ 6 when it is binned and smoothed as in Figures 4–7. The eight smoothed subexposure spectra from the two bright exposures are presented in Figures 8 and 9.

After smoothing, the 24 observed spectra (16 full exposure and two sets of four subexposures for the bright regions) were fitted with synthetic spectra constructed from theoretical volume emission rates of the H_2 Lyman band system. The

FIG. 3.—Similar to Fig. 2, for one of the two very bright spectra of Jupiter's northern aurora.

FIG. 4.—Spectra of Jupiter's northern aurora on 1993 July 4 (*first and second panels*) and June 29 (*third and fourth panels*). The spectra span 500 diodes and were smoothed over four diodes. The spectral width of each diode is 0.072 Å. Propagated rms errors are indicated with dotted lines. A synthetic spectrum, with model temperature labeled, is overplotted as a thin line on each observed spectrum (*thick line*).

volume emission rate of a molecular band (v' , v'') can be expressed as

$$I(v', v'') = g(v', E_e) A(v', v'') / \sum_{v''} A(v', v''), \quad (1)$$

where $A(v', v'')$ is the spontaneous transition probability for the band, and $g(v'; E_e)$ is the excitation rate of the level v' from the ground state $v'' = 0$ at an electron energy E_e . The transition probabilities for the H_2 $B-X$ transitions are given by Allison & Dalgarno (1970). The relative vibrational excitation rates for an excited state by electron impact can be determined from the Born approximation,

$$g(v') \propto v^{-3} A(v', v'' = 0), \quad (2)$$

where v is the transition energy.

The Born approximation is, in general, valid for impact of electrons or other particles with energies much larger than the transition energy. For example, Ajello et al. (1984) have fitted electron-impact laboratory spectra satisfactorily with synthetic spectra computed using the Born approximation. The approximation expressed by equation (2) is valid only if all the H_2 molecules are in their vibrational ground state. In the auroral regions, the relative populations of vibrational levels with

FIG. 5.—Spectra of Jupiter's northern aurora on 1993 July 3, similar to Fig. 4

$v'' > 0$ are on the order of 1% (Cravens 1987; Kim et al. 1992). The empirical values of Ajello et al. (1984) were adopted for the cascade contributions from the E and F $^1\Sigma_g^+$ states to $v' = 0-4$ in the B state.

Emission rates of the individual rotational lines in a band (v', v'') are then calculated using

$$I(v', v''; J', J'') = g(v', J') S_A(J', J'') A(v', v'') / \sum_{v''} A(v', v''), \quad (3)$$

where $S_A(J', J'')$ is the line strength based on Hönl-London factors. Note that $\sum_{J''} S_A(J', J'') = 1$. The fine-structure excitation rate is expressed as

$$g(v', J') = F_e \sigma N(X, v'' = 0, J'') S_B(J', J'') g(v') / \sum_{J''} g(v'), \quad (4)$$

where F_e and σ are the electron flux and electron-impact excitation cross section, respectively; $N(X, v'' = 0, J'')$ is the number density of H_2 molecules in the ground electronic state with vibrational quantum number $v'' = 0$ and rotational quantum number J'' ; and $S_B(J', J'')$ is the rotational absorption strength, the value of which is also computed from Hönl-London factors (cf. Festou et al. 1981). Note that $\Delta J = J' - J'' = \pm 1$, that is, only P and R branches are allowed for the $B-X$ band system. The population of rotational levels in the ground state follows a Boltzmann distribution with statistical weight $(2J'' + 1)(2S + 1)$, where S , the nuclear spin number, is 0 or 1 for even or odd values of J'' , respectively.

FIG. 6.—Spectra of Jupiter's northern aurora on 1993 July 21, similar to Fig. 4

The excitation rates of the rotational levels are modified slightly by the cascade contribution from the E and F states to $v' = 0-4$ in the B state. The rotational term values are taken from Huber & Herzberg (1979). In addition to the discrete transitions, the synthetic spectra include emission in the Lyman continuum, the shape for which was taken from Stephens & Dalgarno (1972).

Synthetic spectra were constructed for rotational temperatures between 100 and 1200 K. The observed spectra were fitted with the synthetic spectra by varying the wavelength shift, linewidth, and intensity of the Lyman band emissions for a given temperature. Wavelength shifts between the synthetic and observed spectra were very small ($\lesssim 0.15$ Å). A full width at half-maximum of 0.4 Å for a Gaussian line profile was found to be optimal for fitting the observed spectra.

Three temperatures for the Lyman band system were determined by minimizing three relative residuals,

$$R^2 = \sum_{\text{total}} (I_o - I_m)^2 / \sum_{\text{total}} I_o^2, \quad (5a)$$

$$R_1^2 = \sum_{1588-1597} (I_o - I_m)^2 / \sum_{1588-1597} I_o^2, \quad (5b)$$

$$R_2^2 = \sum_{1609-1616} (I_o - I_m)^2 / \sum_{1609-1616} I_o^2, \quad (5c)$$

where I_o is the observed and I_m is the synthetic spectral intensity.

FIG. 7.—Spectra of Jupiter's southern aurora on 1993 July 21, similar to Fig. 4

The spectral ranges 1588–1597 Å and 1609–1616 Å include rotational structures in the $(v', v'') = (3, 10)$ and $(5, 12)$ vibrational bands, respectively. The residuals have a minimum in the temperature range 100–1200 K. The minimum is, however, very shallow compared to average relative noise (inverse of S/N), which results in a large uncertainty in the derived temperature. Furthermore, temperatures determined from the different bands are not usually the same. This poor definition of temperature may indicate the presence of multiple regions of different temperatures within the field of view. It is possible that the temperature increases rapidly with altitude in the region of peak precipitation. We expect this to be the case where precipitating particles are the major source of heating.

4. RESULTS AND DISCUSSIONS

Our observation set for the northern aurora covered most of the area poleward of the Io footprints between $\lambda_{III} = 90^\circ$ and 180° . Since the aperture usually spans more than 15° of latitude at a given time, the flux variation among the observed spectra may be more closely related to their longitude than to their latitude. Figure 10 shows the flux in peak counts per diode, versus the longitude at which the LSA was centered. The two brightest spectra stand out at longitudes 155° and 165° , and there is a gradual increase in intensity from 110° to 155° regardless of the date of observation.

The July 21 spectrum (j02t), centered at longitude 155° , latitude 65° , is less than half as intense as the bright spectra which were obtained at the same longitude but at lower latitude. This

FIG. 8.—Four subexposure spectra from the exposure of a bright region in Jupiter's northern aurora on 1993 July 4. Each subexposure had one-quarter of the 761 s total exposure time. The legend is similar to that of Fig. 4.

indicates that the brightest auroral emission is confined to lower latitudes than for the target area j02t, although a temporal variation of the auroral flux can not be ruled out. Note that the spectra for other longitudes do not show a large variation in intensity over different observation times. One target area ($\lambda_{III} = 120^\circ$ – 130° , latitude $= 63^\circ$ – 65°) was observed both near the eastern limb (702t and 802t) and near the western limb (202t and 302t), and, remarkably, it exhibited nearly the same intensity despite the 27 hr that separated the observations. Neither local time nor short-term variations seem to be significant in the faint auroral areas of the north polar regions.

For the southern polar region, we obtained only four spectra, which had about the same intensity as the fainter northern auroral spectra. Among the four spectra, the intensities obtained from areas near the central meridian were smaller than those near the limb. This may be explained by the possibility that a larger fraction of the auroral oval was covered by the LSA aimed near the limb. Our observation set includes the range $\lambda_{III} = 0^\circ$ – 50° where bright UV aurorae have been reported from *IUE* observations. With only four areas probed, however, it is likely that our observations missed the southern bright regions.

Comparisons of the 16 observed spectra with the synthetic spectra are shown in Figures 4–7. The synthetic spectrum with the minimum overall residual R is shown as a thin line superposed on each observed spectrum (thick line). The synthetic

FIG. 9.—Similar to Fig. 8 for a later observation, $\sim 10^\circ$ in longitude from the position for Fig. 8 because of Jupiter's rotation.

spectrum is binned and smoothed in the same manner as the observed spectrum. All the bright spectral features in the observed spectra are accounted for by the Lyman bands, and the synthetic spectra show good agreement with the observed spectra. Nevertheless, the observed spectra do display several

FIG. 10.—Peak counts per diode vs. central longitude of the LSA for the northern aurora. Note that the two spectra at 155° – 165° are distinctly brighter than the others.

persistent discrepancies with the synthetic spectra. In particular, there is a feature at $1587.5 \text{ \AA}$ in the observed spectra that is not present in the synthetic spectra. This feature was also noted by Trafton et al. (1994). Also, the peak at $1609 \text{ \AA}$ in most of observed spectra is weaker than that in the synthetic spectra.

The temperatures derived from rotational features in the (3, 10) band (1588 – $1597 \text{ \AA}$) are systematically higher by an average of 125 K than the temperatures from rotational features in the (5, 12) band (1609 – $1616 \text{ \AA}$). The residuals from the fit of the (3, 10) band are also larger than those of the (5, 12) band.

The scaling factors obtained from the fitting provide a direct estimate of the total emission rate in the Lyman band system, which may be closely related to the energy input by precipitating particles. Assuming that electron impact is the dominant source of the auroral emission regardless of the identity of the primary particles, we have adopted the cross sections for 100 eV electron impact excitation from Ajello et al. (1989) in computing the scaling factors. The total emission rate of the Lyman band system is computed from the scaling factor for the best-fit synthetic spectrum over the entire range of the observed spectrum.

The total emission rates for the 24 spectra (16 full exposure and two sets of four subexposures for the bright regions) are plotted against best-fit temperatures in Figure 11. The error bars represent differences among the three fitting criteria explained in the previous section. The inferred emission rates for target areas 402t and 502t are in the range 210 – 260 kR , which is distinctively brighter than the other regions, which range from 25 to 120 kR .

The large difference in the emission rates between 120 and 210 kR may indicate that target areas 402t and 502t (Fig. 1, *thick lines*) have either high auroral brightnesses or very favorable geometries for the observing aperture, or both. Large differences in the filling factors are unlikely for our sample, and it is more probable that the difference is a true difference in brightness.

Note that most of our targets were chosen to cover the $L = 30$ footprint oval near Jupiter's limb. Furthermore, the two bright regions are near the western limb when $\text{CML} = 190^\circ$ and 203° ($\lambda_{\text{III}} = 155^\circ$ – 165° and latitude $= 50^\circ$ – 65°). This area has been recognized to be bright in the FOC images of Caldwell et al. (1992).

The best-fit temperatures are in the range 200 – 800 K with little correlation between temperature and emission rate. The wide range of temperatures may be due to the low signal-to-noise ratios in the fainter spectra. Nevertheless, we believe it is significant that the two brightest auroral regions have relatively low temperatures compared to the overall average. The lower inferred temperatures in the bright regions, 200 – 500 K , may signify that the precipitating particles in the bright regions penetrate to lower altitudes, where the temperature is expected to be lower due to efficient cooling by hydrocarbons. Gladstone & Skinner (1989) have shown that Jovian UV auroral emission originates from near or below the methane homopause. According to the model of Drossart et al. (1983), temperatures of 200 – 500 K occur near or just below the homopause, where strong auroral heating accompanied by the observed bright UV auroral emission may be balanced by radiative cooling by hydrocarbons. At the very least the fact that there is no temperature increase for the bright regions indicates that heating produced by the precipitating particles responsible for the bright auroral emissions is being balanced efficiently either by

FIG. 11.—Total emission rate of the Lyman band system vs. H_2 rotational temperature. The diamonds with solid-line error bars represent a full exposure, while the diamonds with dashed- and dotted-line error bars are for sub-exposures of the two bright auroral spectra.

radiative cooling or by dynamical processes such as horizontal winds in the Jovian thermosphere.

The median temperature of the fainter auroral regions in Figure 11 is 500 K, which is consistent with the value of 550 K reported by Trafton et al. (1994) for a nonbright auroral region ($\lambda_{III} = 180^\circ$, latitude = 67°). Their estimated total emission rate in the Lyman band system was 12 kR, whereas the weakest aurora in our sample has an emission rate of 25 kR. The actual difference between these two brightnesses is somewhat less than quoted because, as noted above, the intensities reported here have not been corrected by the factor 0.77 to account for an extended source (Trafton et al. 1994).

Clarke et al. (1994) derived rotational temperatures between 400 and 750 K for the northern auroral regions from GHRS spectra over 1204–1241 Å. They obtained bright spectra from about the same region ($\lambda_{III} \sim 150^\circ$, latitude $\sim 60^\circ$) as we did, but with estimated total emission rates about $\frac{2}{3}$ of ours. The difference could be due to the fact that our aperture was aimed

near the limb, not at the central meridian, and covered a wider auroral region than did theirs.

5. CONCLUSIONS

We have observed auroral UV emission from both polar regions in the wavelength range 1586–1620 Å. The observed spectra are consistent with electron impact excitation of the H_2 Lyman ($B^1\Sigma_u^+ \rightarrow X^1\Sigma_g^+$) band system. The observed spectra show minor discrepancies from the synthetic spectra, namely, a weak additional emission feature at 1587.5 Å that is inconsistent with H_2 , and an average temperature difference of 125 K for the different vibrational bands within our observed wavelength range.

Among the 18 spectra obtained during 1993 June and July, there were substantial differences in intensity that distinguished two spectra from the rest of the sample. The two brightest spectra were observed near the western limb at latitudes 50° – 65° when CML = 190° and 203° . This area has been recognized as a bright spot from the FOC images of Caldwell et al. (1992).

Assuming that electron impact excitation is a major source of the Jovian aurora, we estimate a total emission rate in the Lyman band system of about 250 kR for the two brightest spectra and 25–130 kR for the others. Best-fit temperatures for the fainter regions cover the rather wide temperature range 200–800 K with a median temperature of 500 K. This is consistent with the results of Trafton et al. (1994) and Clarke et al. (1994), which pertain to similar areas but to different wavelength ranges.

The inferred temperatures for the bright region are, however, in the range 200–500 K and are thus confined to the lower end of the temperature range of the fainter regions. We interpret the relatively low temperatures of the bright regions as an indication that the precipitating electrons or other primary particles responsible for the bright UV emissions may penetrate deeper into the atmosphere where temperatures are lower due to efficient cooling by hydrocarbons. Further observations, especially ones that are nearly simultaneous in the short and long wavelength UV spectral ranges, are needed to constrain the altitudes of the bright UV emission.

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