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JUPITER'S DAYGLOW H LY α EMISSION LINE PROFILE

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Abstract. IUE spectra of Jupiter's low latitude H Ly α emission line profile have been obtained on and off the "Ly α bulge" at the longitude of the central meridian (CML), near the limb of the planet, and at midlatitudes on the CML. All equatorial locations show line broadening beyond the IUE resolution of 0.14 Å. The equatorial lines are significantly broader than at midlatitudes on the CML, and near the limb the lines are broader than on the CML, both on and off the bulge. The observed line shapes are not consistent with pure resonant scattering of solar Ly α by upper atmospheric H atoms with a variable H abundance: calculated profiles near the limb have much less intense cores. The broadening of the bulge line profiles on the CML and limb compared with off-bulge regions demonstrates that the bulge effect is a broadening of the line, not an increase in the line core flux. We propose that there is either a substantial broadened internal source and/or the upper atmosphere has considerable Doppler broadening (winds or turbulence) to increase the resonant scattering line width.

Introduction

Jupiter's dayglow H Ly α emission has been observed since 1969, yet the contributions of different processes in producing this emission are still not known. Existing observations and their interpretations have been reviewed by Clarke et al. (1989), with the following characteristics identified:

- anomalously bright (10-20 kR) compared with solar H Ly α flux, equivalent to a ~ 40 % geometric albedo (from rocket experiments, Voyager UVS, and IUE)
- day to night brightness decrease by roughly an order of magnitude (from Voyager UVS)
- long-term (solar cycle) and short-term (days-weeks) correlation with solar Ly α/EUV emission flux (from IUE and SME)
- equatorial brightening (bulge) with longitudinal asymmetry centered along the equator of and rotating with the magnetic field (from rocket, Voyager UVS, and IUE)
- optically thin brightness variation from center to limb (from Voyager UVS and IUE).

Proposed emission processes include resonant scattering (RS) of solar H Ly α emission, charged particle collisional excitation of H and/or dissociative excitation of H_2, and hydrogenic ion recombination (either H^+ or H_3^+). The equatorial bulge is concentrated near λ_{III} = 50 - 100°, but north-south intensity scans by both the Voyager UVS (Dessler et al. 1981) and IUE (Clarke et al. 1981) reveal an equatorial brightening at all longitudes compared with midlatitudes. A specific particle excitation process near the exobase has been proposed for Jupiter (Shemansky 1985), and a process called "electroglow" has been proposed to explain the anomalously bright airglow emissions and high upper atmospheric temperatures detected on all 4 giant planets. The Ly α bulge is particularly interesting because it is fixed with respect to the magnetic field, yet also appears correlated with the EUV solar flux: these are also characteristics of electroglow.

The first observations of Jupiter's H Ly α line profile with Copernicus at 0.06 Å resolution showed a line roughly 0.10 Å FWHM at solar minimum (Atreya et al. 1977, Bertaux et al. 1980), but the long slit and single-wavelength integrations yielded low signal spectra without spatial information. Jupiter's H Ly α emission line profile has recently been modeled as a function of H column abundance (Gladstone 1988, Ben Jaffel et al. 1988). The calculated RS line profiles are greatly broadened at the limb from scattering in the wings of the linc (see Figure 3), yielding an optically thin center to limb brightness distribution. Collisional excitation processes may produce either a narrow line or a line with some broadening due to fast atom byproducts of the collisions. These differences led us to perform IUE observations of Jupiter's center and limb on and off the bulge to determine the broadening from center to limb.

Observations

The IUE observations of Jupiter's equatorial H Ly α emission line shape, listed in Table 1, were in high dispersion with the short wavelength prime (SWP) spectrograph and detector. A spectral resolution of 0.14 Å is achieved with the small (3 arc sec diameter circular) aperture; diffuse emission lines are broadened to 0.40 Å in the large (9 by 20 arc sec elliptical) aperture by the extent of the aperture. Both apertures were open during these observations, giving two images of the H Ly α emission in each spectrum. In each case the small aperture was positioned on Jupiter for maximum spectral and spatial resolution, while the large aperture recorded the brightness of the geocoronal (GEO) and interplanetary medium (IPM) emissions 40 arc sec from the small aperture. These background emissions have been subtracted from the small aperture line profiles by extrapolation from the large to small aperture in both flux (proportional to the aperture sizes) and wavelength (proportional to the angular separation of the apertures). The response to monochromatic emission has been determined from exposures of PtI 1219 Å emission from an on-board Pt-Ne hollow cathode lamp: the intrinsically narrow 1219 Å line appears comparable in width to the observed GEO line emission. Separate fits of the large aperture profile have been made to the GEO and IPM emissions, and the corresponding backgrounds subtracted from the small aperture emission. The IPM and Jovian emissions appear shifted in wavelength with respect to the GEO emission by the line of sight (LOS) components of the Earth orbital motion (30 km/sec), the IPM velocity (21 km/sec), and the Jupiter and IUE orbital velocity LOS components (1-3 km/sec). We have corrected for these shifts using the large aperture GEO line as an absolute wavelength reference. The absolute calibration at 1216 Å is derived from SWP 39952 of Jupiter at off-bulge longitudes in both high and low dispersion to relate the high dispersion sensitivity to the low dispersion calibration. We derive an inverse sensitivity at 1216 Å: $C_\lambda S_\lambda^{-1} = 8.03 \times 10^{-12}$ ergs/cm^2-Å-FN (cf. Cassatella et al. 1981).

Pointing was accomplished by offset from the Galilean satellites using the JPL NAIF program: this technique has an accuracy of 1-2 arc sec in offsets from satellite to satellite. Limb observations consisted of offsets of 70-80° in longitude from the central meridian with the aperture held at a fixed offset, thus covering a longitude range of 36 degrees/hour from Jupiter's rotation. Jupiter's equatorial diameter was 38 to

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Table 1: IUE High Dispersion SWSA Observations of Jupiter's H Ly α Emission

SWP/Date	Exp. time	Pointing	GEO/IPM 4πI	Jupiter 4πI	Solar Ly α (1AU)
38164 2/08/90	146 min.	$+10^0$ lat., 70^0 E λ_{III} = 40 - 140^0	2.1 kR 290 R	13.4 kR	3.5 x 10^{11} ph/cm^2-sec
38165 2/08/90	150 min.	$+10^0$ lat., CML λ_{III} = 75 - 170^0	1.6 kR 520 R	14.6 kR	3.5 x 10^{11}
41115 3/16/91	100 min.	0^0 lat., CML λ_{III} = 200 - 260^0	7.4 kR 380 R	13.6 kR	3.8 x 10^{11}
41116 3/16/91	150 min.	0^0 lat., 70^0 W λ_{III} = 200 - 290^0	2.1 kR 480 R	13.2 kR	3.8 x 10^{11}
41132 3/18/91	105 min.	0^0 lat., 80^0 W λ_{III} = 170 - 235^0	1.7 kR 250 R	9.6 kR	3.7 x 10^{11}
41480 4/25/91	120 min.	-30^0 lat., CML λ_{III} = 264 - 336^0	620 R 330 R	9.1 kR	3.5 x 10^{11}

44 arc sec and the west (receding) limb was sunlit during all observations.

The method of background subtraction is shown in Figure 1, and small aperture spectra of Jupiter's equatorial H Ly α emission after background subtraction are plotted in Figure 2. The rotation of Jupiter is clearly seen in the Doppler shift of the limb lines toward the blue (approaching or east limb) or toward the red (receding or west limb): the measured rotation is consistent with the system III period to within several km/sec from centroiding the lines after background subtraction. The solar Ly α fluxes listed in Table 1 have been estimated from the measured full disk He 10830 Å equivalent width (Harvey, pers. comm.) using the relation:

$$\text{(solar Ly } \alpha \text{ flux in } 10^{11} \text{ ph/cm}^2\text{-sec at 1 AU)} = 0.038 \times \text{EQW (He 10830)} + 0.851$$

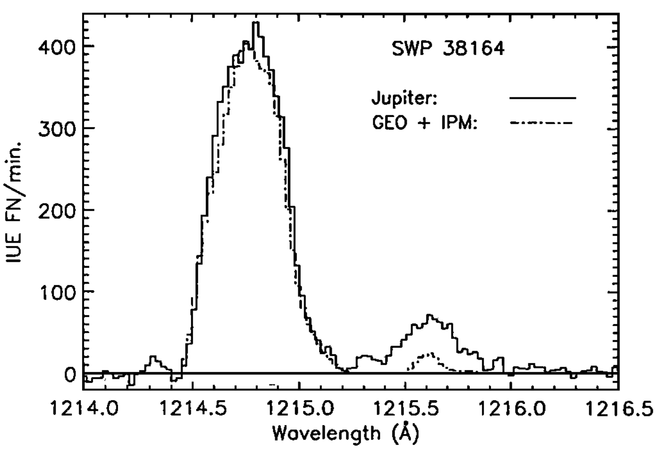

Fig. 1: H Ly α emission features from large aperture (left-hand feature, containing GEO and IPM emissions) and small aperture (right-hand feature, background plus Jupiter) in SWP 38164. The ratio of aperture areas is 30: the wavelength scale shown is for the small aperture. The GEO and IPM emissions (dashed curves) have been modeled from the large aperture background, and extrapolated to the dashed curves overplotted on the small aperture feature.

Discussion

The equatorial H Ly α line profiles show a consistent broadening beyond the IUE instrument response of 0.14 Å, although the camera noise prevents a clear determination of the wing shapes (Jupiter's rotation limits observations of specific longitude regions to 2-3 hours). SWP 41480 is clearly separated from the bulge atmosphere, since the aperture was pointed at -30^0 latitude or 40^0 south of the magnetic dip equator where the bulge is centered, and this line is narrow compared with all equatorial spectra. Spectra 38165 and 41115 are observations of equatorial bulge and off-bulge longitudes at the planet center, and the bulge line appears relatively broader (although 41115 is distorted by a large GEO subtraction). From these observations it is apparent that the bulge phenomenon is a broadening of the line more than an increase in the line core flux. McGrath (1991) shows that the bulge peak emission has recently covered an extended longitude range: whereas 41115, 41116, and 41132 are at longitudes close to the minimum equatorial emission, the bulge effect is more pronounced at all longitudes now than it has been in the past.

Comparing the center and near-limb line profiles in the bulge (38164 and 38165) and off-bulge (41115, 41116, and 41132) regions, we find that the base of the line broadens near the limb and the line core becomes less intense. This is qualitatively consistent with an increased scattering in the wings of the line due to the increased slant column near the limb, but does not match quantitative model calculations.

To demonstrate this point we have modeled the line profiles assuming RS with the parameters of Gladstone (1988): the bulge lines are shown in Figure 3. The model assumes RS of solar Ly α by H atoms as a mechanism of excitation: the line width is determined by natural and thermal broadening in combination with frequency redistribution during RS, corresponding to the atmospheric temperature and density profiles (Gladstone 1988). The midlatitude emission line on the CML can be fit both in shape and brightness assuming RS from the model atmosphere with 1-5 times the occultation-derived H abundance, plus a possible minor contribution from a narrow internal source. The bulge CML line brightness alone can be fit by increasing the amount of H in the model by a factor of 10-20, consistent with the center to limb brightness changes reported in Clarke and Gladstone (1990). However, no amount of H assumed will allow us to match the equatorial limb lines in both brightness and lineshape with RS of solar Ly

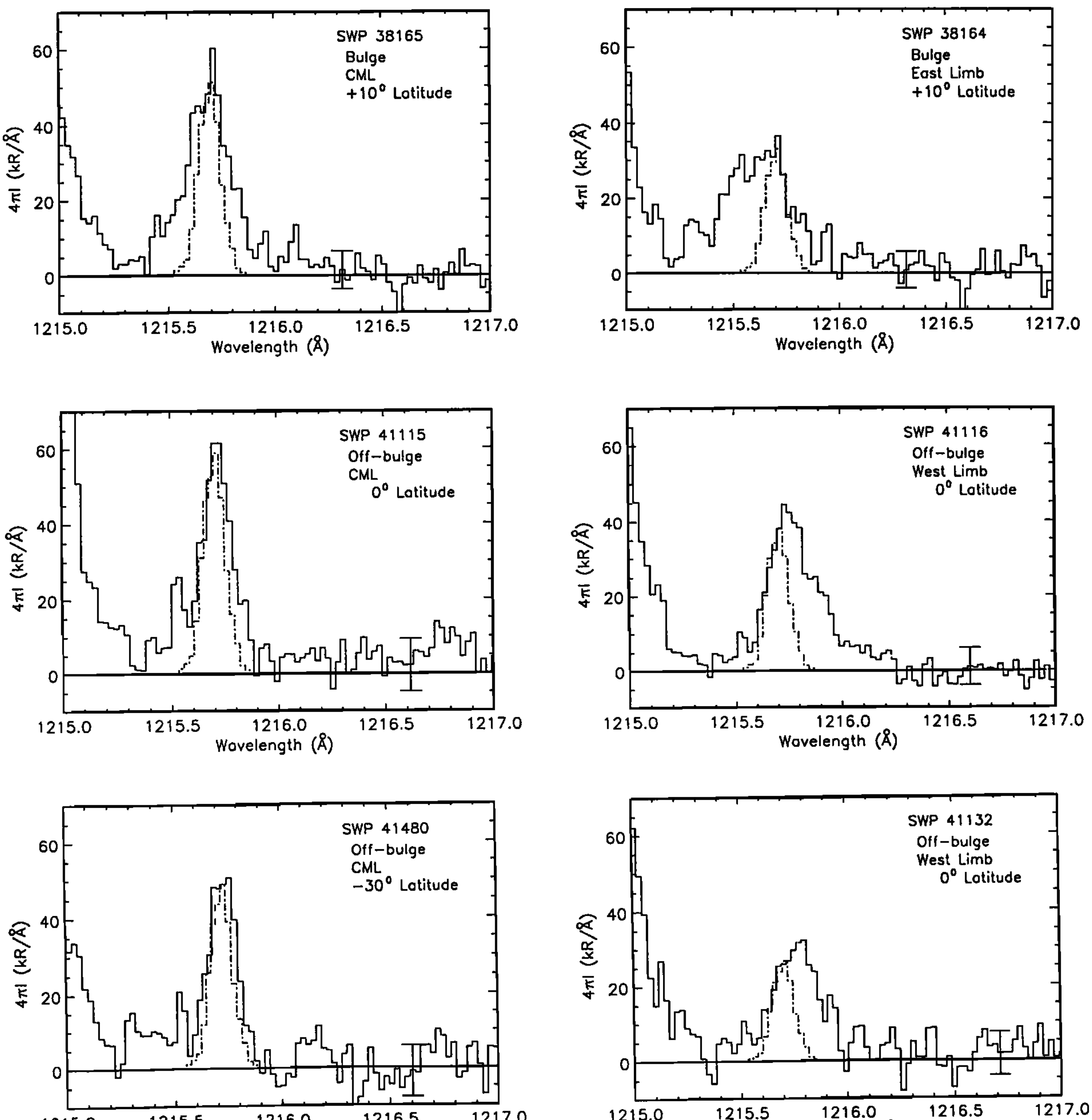

Fig. 2: Observed Jupiter Ly α line profiles after background subtraction. The IUE response to monochromatic emission at the rest wavelength of Jupiter is overplotted (dashed lines). The +/- 1 σ error bars are determined by the detector noise at adjacent wavelengths, and do not include the uncertainty in the sky background subtraction.

α alone, either in the bulge or off-bulge regions: the observed limb profiles have line cores much brighter than calculated and also broader than the instrument response. Some process of line broadening in addition to natural and thermal broadening is required to explain these lines in terms of RS. Ben Jaffel et al. (1991) have shown that the bulge lines at both the CML and limb can be fit by the inclusion of a 5-10 km/sec velocity distribution (i.e. comparable to thermal velocities) in addition to thermal motions. Although this effect is parameterized as turbulence, it is not yet clear what physical process could give rise to this additional velocity component.

An alternative explanation of the observed line broadening may be a collisional excitation process. Although an internal source of electron collisional excitation of H would produce a narrow line, dissociative excitation of H_2 produces both slow H atoms (87% at 0.5 eV) and fast atoms (13% at 5.5 eV). Initial modeling of these processes suggests a line that is 0.12 Å FWHM, which is narrow compared with the observed bulge line profiles. An additional source may be dissociative excitation and recombination of H_3^+, for which we have no line width information. Finally, fast proton charge exchange and/or recombination may produce H atoms with a range of velocities, in principle sufficient to be consistent with the observed broadenings for RS. These last processes have previously been proposed to explain the bulge in the context of an equatorial anomaly and fountain, similar to the tropical arc

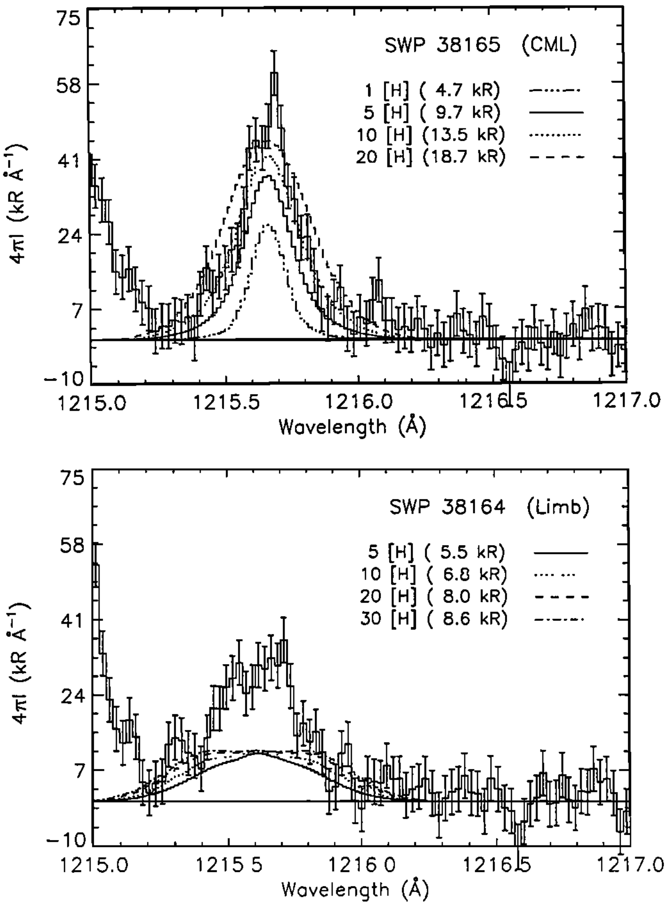

Fig. 3: Calculated resonant scattering fits for the center (upper) and limb (lower) small aperture Jupiter spectra from the bulge region, shown after background subtraction and convolved with the IUE point spread function.

emissions on the Earth (Clarke et al. 1987), and independent evidence exists for the presence of a strong equatorial anomaly on Jupiter (Mahajan 1981).

Conclusions

We report IUE observations of Jupiter's low latitude H Ly α emission line profile at 0.14 Å spectral resolution and 3 arc sec spatial resolution on the 40 arc sec disk. Observations of the equatorial bulge and off-bulge longitudes at the planet center and limb, and of mid-latitudes well separated from the magnetic dip equator, exhibit the following characteristics:

- Jupiter's equatorial H Ly α emission line is significantly broader than the IUE spectral resolution at all longitudes,
- all equatorial emission lines are broader than the midlatitude line, and the bulge lines are broader than the off-bulge lines,
- in both bulge and off-bulge regions the limb lines are broader than on the CML: the limb lines are fainter in the core but at least as bright in the wings.

We are not able to model the center to limb line profile changes with resonant scattering of solar Ly α even by increasing the H abundance, assuming the occultation-derived upper atmospheric structure. Given the observed high brightness of the emission, we propose that Jupiter's equatorial Ly α emission requires either a broad internal (collisional) source or a broadening (for RS) beyond the thermal motions in the upper atmosphere, and that the bulge brightening is due to increased broadening of the line.

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