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Evidence for Change in Particle Excitation of Jupiter's Atmosphere 1968-1979

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Analysis of the Pioneer 10 and rocket observations of disk averaged emission from the sunlit atmosphere of Jupiter indicates that the spectrally integrated EUV brightness was reduced by at least a factor of 2 relative to Voyager spacecraft observations in 1979. Most of the variation is caused by the $HLy\alpha$ component in the spectrum, which was reduced ≈ 1 order of magnitude near the time of solar minimum in 1972-1973. Although the analysis of the data does not produce entirely consistent results, the weight of evidence points to a factor of order ≈ 2 lower abundance of H in Jupiter's atmosphere in 1972-1973 relative to 1979. The low emission rate in $HLy\alpha$ near the time of solar minimum in this proposed scenario is caused by an electroglow energy deposition rate reduced by a factor of ≈ 3. The apparent reduced abundance of H implies a reduced thermospheric temperature, even under the assumption of a constant electroglow deposition rate.

INTRODUCTION

The atmosphere of Jupiter is excited by particles in two distinctly different phenomena. Auroral emissions occur in regions of the northern and southern hemispheres, corresponding roughly to the magnetic L- shell position of the Io plasma torus. The auroral deposition can be described roughly as a strip ≈ 5000 km wide in the latitudinal direction, surrounding the poles in an asymmetric distribution [*Broadfoot* et al., 1979; *Herbert et al.*; 1985; *Skinner and Moos*, 1984; *Skinner et al.*, 1984]. A second equally important phenomenon, described as a uniformly distributed particle excitation on the dayside of the planet, apparently disconnected from auroral activity [*Shemansky and Smith*, 1986] was first recognized in Voyager 1 EUV observations of H_2 band emission [*Broadfoot et al.*, 1979]. The phenomenon on Jupiter has most recently been examined in detail by *Shemansky* [1985]. The energy required for the excitation process cannot be obtained from photoionization, although the emission must be stimulated by solar photons [*Broadfoot et al.*, 1979; *Sandel et al.*, 1982; *Shemansky*, 1985; *Shemansky and Smith*, 1986]. The $HLy\alpha$ feature on Jupiter is the only observed emission showing a dependence on magnetic field strength or structure. However, direct observational evidence indicates that both the source and excitation rates of atomic hydrogen are independent of magnetic longitude. It has been suggested that the $HLy\alpha$ variation is caused by a variable ionospheric proton density which collisionally converts H(2s) atoms produced at a constant rate in respect to longitude [*Shemansky*, 1985]. The fact that the excitation process shows no apparent relationship to magnetic field strength or magnetospheric activity in comparison of the three outer planets [*Shemansky and Smith*, 1986] coupled with the absence of theoretical explanation, has prompted the introduction of a new term "electroglow" to describe the phenomenon [*Broadfoot et al.*, 1986].

An important consideration in examining the electroglow is the long-term temporal morphology of the associated EUV and FUV hydrogen emission. In particular the relationship to the major solar cycle is a matter of vital interest. In this paper we present a reexamination of early EUV/FUV observations of Jupiter in the light of the more recently acquired knowledge of the system obtained from the Voyager spacecraft and International Ultraviolet Explorer (IUE) satellite observations. The first FUV spectral measurement of Jupiter's atmospheric emission was obtained by *Moos et al.* [1969] in a rocket observation in December 1967. Observations providing positive identification of H_2 band emission were obtained by *Giles et al.* [1976] in September 1972. Measurements were obtained by the EUV photometers on the Pioneer 10 (P10) spacecraft at encounter with Jupiter in December, 1973 [*Judge and Carlson*, 1974; *Carlson and Judge*, 1976]. The reanalysis of this early data using accurate model calculations of excited hydrogen is presented below, suggesting a large variation in $HLy\alpha$ brightness between 1972 and 1979, while disk averaged H_2 band emission shows relatively little variation. We briefly discuss the implications of these results, and suggest two plausible explanations: (1) a reduced energy deposition rate in the electroglow near the time of solar minimum, or (2) a variation in the mean altitude of energy deposition. Both scenarios lead to a reduced thermospheric temperature at solar minimum.

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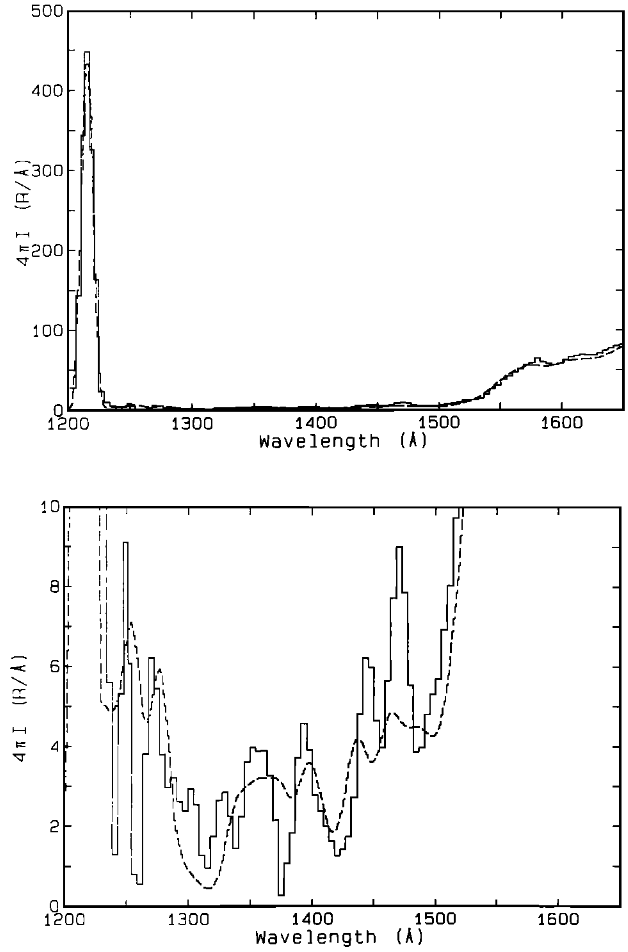

Fig. 1. The FUV spectrum of Jupiter obtained by *Giles et al.* [1976] compared to a model calculation. The solid curve is the digitized merged rocket spectrum; the dashed curve is a hydrogen model calculation, which includes the effect of CH_4 foreground absorption $[CH_4]l = 3.5 \times 10^{16}$ cm^{-2}, and the solar reflection continuum (see text, Table 1).

Analysis of Observational Data

The critical observational data examined here in detail are those obtained by *Giles et al.* [1976] (September 1972) and in the Jupiter encounter period (December 1973) of the P10 spacecraft [*Judge and Carlson*, 1974]. One of the uncertainties in the reduction of the P10 encounter data is the exact nature of the spectral distribution included in the photometer. The important point in this regard is the fact that the $HLy\alpha$ line shows a drastically different relationship to the H_2 bands in the *Giles et al.* [1976] rocket spectrum compared to the equatorial spectra obtained from the Voyager instruments in 1979. The relationship of atomic and molecular hydrogen emission brightness obtained from the *Giles et al.* [1976] observation is used in the model analysis of the P10 instrument to obtain emission brightness from the (P10) encounter measurements in December 1973. A further complication in the analysis is introduced by the fact that the early observations of Jupiter did not have high spatial resolution and only provide a measure of disk average brightness. Consequently, the spectra are composed of a mix of auroral and electroglow emissions. The critical question in this matter is whether or not the mix of disk averaged emissions changed between 1972 and 1979. For these reasons we first describe the analysis of the *Giles et al.* [1976] spectrum, followed by the P10 data.

Rocket Observation 1971-1972

The spectrum measured by *Giles et al.* [1976] has been analyzed using the original compilation of the data provided by H. W. Moos (private communication, 1985). A description of the content of the model is given by *Shemansky and Ajello* [1983] and *Shemansky* [1985]. The model calculation contains three essential components; electron excited H_2 Rydberg bands including appropriate extinction effects, the solar continuum reflection spectrum above ≈ 1500 Å, and the $HLy\alpha$ line excited by a combination of particles and photons. The model calculations were carried out using the characteristics of the instrumental transmission function described by *Giles et al.* [1976; 1975] and *Giles* [1974], as applied to the construction of the merged spectrum defined by *Giles et al.* [1976]. The model thus accounts for the strong variation of instrument resolution as a function of wavelength. Figure 1 shows the model calculation plotted against the digitized merged spectrum derived from the *Giles et al.* [1976] data. The model calculations assume a temperature for the exciting electrons of Te=50 eV [see *Shemansky* 1985], leaving the intensity scale factor of the $HLy\alpha$ line, the H_2 Rydberg band systems, the solar reflection spectrum, and the abundance of CH_4 foreground absorbers as free parameters in the fitting process. The results of the analysis are tabulated in Table 1. The most remarkable characteristic of the results is the weakness of the $HLy\alpha$ line relative to the H_2 Rydberg bands, based on expectation from Voyager UVS results obtained in 1979. In order to achieve a good fit to the spectrum over the entire spectral region, it was necessary to introduce a foreground CH_4 abundance of $[CH_4]$ l =3.5× 10^{16} cm^{-2} (Table 1). This is not a surprising result because the auroral component in the H_2 Rydberg system in the spectrum is expected to be seriously affected by hydrocarbon and other absorbers [*Shemansky*, 1985]. The inclusion of foreground absorbers in the model calculations allows the estimation of source brightness, as opposed to the directly measured brightness, and all values quoted in the tables for H_2 Rydberg bands refer to source values. The H_2 band spectrum is affected by CH_4 absorption at wavelengths shortward of 1400 Å. The relative emission rate at 1250 Å is reduced by a factor of 2 because of the assumed CH_4 absorber. The effect of CH_4 in the applied abundance at 1400 Å is negligible. The integrated brightness over the range

Table 1. Analysis of the *Giles et al.* [1976] Merged Spectrum of Jupiter

	$I(HLy\alpha)$, kR	$I_S(H_2$ Ly+Wr), kR	I(1600 Å) (R/ Å)	Y_{IS}
Analysed spectrum[b]	4.6	5.8	45	
Disk Average	2.2[a]	5.8[b]	45	0.4[c]
Subsolar point			67[d]	
Aurora disk average		3.6[e]		
		5.0[f]		
Electroglow disk average		2.2[e]		
		0.8[f]		
Geometric albedo; subsolar point			0.31[g]	

[a] After removal of foreground as in *Giles et al.* [1976]; statistical uncertainty $\pm$29%.
[b] Model fit to data; $[CH_4]l$ = 3.5x10^{16} cm^{-2}; Te=50eV; statistical uncertainty $\pm$20%.
[c] $Y_{IS} = I(HLy\alpha)/I_S(H_2$ Ly+Wr); see *Shemansky and Smith* [1986].
[d] Calculated on basis of a Lambertian surface.
[e] Disk averaged brightness partitioned according to Voyager 1979 observations.
[f] Disk averaged brightness partitioned as described in the text.
[g] Solar flux as measured by *Rottman* [1981]; πF = 1.47 x 10^9/Ph cm^{-2} s^{-1} A^{-1}

1250Å- 1500 Å quoted by *Giles et al.* is 740 R. However, we find a value about 18% larger, 870 R, from the digitized spectrum. The total source brightness of the H_2 bands derived from the model data is I_S(H$_2$ Ly+Wr) = 5.8 kR, and corresponds to a calculated brightness of 870 R at the top of the atmosphere integrated over the 1250 Å- 1500 Å range, conforming to the observed spectrum. The statistical uncertainty in this quantity is $\pm$20% according to *Giles et al.* [1976] (Table1). The 95% probable uncertainty in absolute value was $\pm$50% [*Giles et al.*, 1976], but the solar reflection brightness at 1600 Å, translated into a sub solar quantity agrees with values obtained from the later Voyager and IUE data to $\pm$10%. As discussed below, the solar flux at this wavelength appears to be constant, and it seems reasonable to assume the Jupiter reflective property would not change.

Two earlier rocket observations in the FUV region have been reported by *Moos et al.* [1969] (Dec. 1967) and *Rottman et al.* [1973] (Jan. 1971), but only the latter measurements included the H_2 band region. For this case, we have estimated the H_2 band intensities using the model and the integral brightness between 1250 Å and 1500 Å provided by *Rottman et al.* [1973] (Table 2).

Pioneer 10, Voyager Spacecraft and IUE Observations

The P10 photometer observations of Jupiter have been reduced by assuming the $HLy\alpha$ and H_2 band emission rates were in the same relationship as the measured values in the *Giles et al.* [1976] rocket observation obtained approximately one year earlier. The P10 photometer has been cross calibrated against the Voyager EUV instruments through near simultaneous measurements of the local interstellar medium (LISM) in $HLy\alpha$ and He 584 Å radiation [*Shemansky et al.*, 1984]. Previously published $HLy\alpha$ brightness from P10 data must be multiplied by the factor 4.4 in order to produce equivalence with Voyager data. At 584 Å the P10 and Voyager instruments are found to have equivalent calibrations [*Shemansky et al.*, 1984]. The model calculations on this basis produce the estimated brightness values shown in Table 2. We include in Table 2 the Voyager observations in March 1979 and IUE observations of $HLy\alpha$ containing recent corrections for aperture size and extinction in the LISM. Differences between IUE and Voyager measurements of the $HLy\alpha$ line appear to depend on the observed object and it has been suggested that this effect is caused by extinction in the LISM or uncertainty in correction for geocoronal effects (D. E. Shemansky, et al., manuscript in preparation, 1987). Recent work by T. E. Skinner (private communication, 1986) indicates the IUE and Voyager calibrations are within their calibration uncertainties at 1216 Å.

As noted above, the disk averaged data includes a mix of auroral and electroglow emissions. The auroral and equatorial emissions are directly separable in the Voyager encounter EUV data. Table 2 shows the auroral brightness mean values for H and H_2 emissions obtained from Voyager 1. The brightness of the aurora averaged over the disk is $I(HLy\alpha)$ = 2.8 kR and I_S (H_2 Ly+Wr) = 3.7 kR, with Y_{IS} = 0.75 (Table2).

Table 2. Jupiter Dayside Emissions

	Parameter	Y_{IS}	I(H $Ly\alpha$), kR	$I_S(H_2$ Ly+Wr) kR	He(584Å), R
Jan. 25, 1971	rocket; disk average[a]	0.5	4.4	9.7	
Sept. 1, 1972	rocket; disk average; λ_{III} 110° [b]	0.4	2.2	5.8	
Dec. 1, 1973	Pioneer 10; disk average[c]		1.0	1.0	2-3
March 1, 1979	Voyager 1				
	aurora	0.75	60.	80.	
	aurora disk average	0.75	2.8	3.7	
	subsolar equator; λ_{III} ≈100° [d]	7.3	22.	3.0	
	electroglow disk average[e]	5.8	14	2.4	4.0
	aurora plus electroglow disk average	2.8	17.	6.1	
1979/02-06	IUE				
	subsolar equator; λ_{III} ≈ 100° [f]		16-20		

[a] *Rottman et al.* [1973]; authors state factor of 3 uncertainty in I_S (H_2 Ly+Wr); no LISM extinction correction.

[b] Analysis of *Giles et al.* [1976] observations; see Table 1; no LISM extinction correction.

[c] Model calculations using data from footnote b; see text.

[d] *Shemansky* [1985].

[e] $[I_S(H_2 \text{ Ly} + \text{Wr}) \text{ subsolar equator}] \cdot \frac{\pi}{4}$

[f] From *Skinner et al.* [1983] scaled by factor of 1.3 to correct for LISM extinction.

The disk average electroglow brightness from Voyager 1 has a degree of uncertainty because measurements of latitudinal brightness variation are not available. However, the mean brightness in the east-west direction has been measured near the equator and for the $HLy\alpha$ line and H_2 (Ly+Wr) bands the values are 0.80 and 1.0, respectively, of the brightness at the subsolar point [*Shemansky*, 1985] at the CML of the $HLy\alpha$ bulge. It has been assumed that the $HLy\alpha$ bulge distribution is roughly symmetric in determining a disk average of 14 kR as given in Table 2. It has been assumed that the H_2 Rydberg systems follow a cosine distribution in latitude, but it is quite possible that the disk average value is equal to the subsolar brightness. The resultant Voyager disk averaged emission rate contains 40% electroglow and 60% aurora in H_2 bands and only 16% aurora in $HLy\alpha$ (Table2). According to Table 2 the disk averaged H_2 emission rates in the rocket observation in 1972 and the Voyager result in 1979 are about equal. In contrast, the $HLy\alpha$ brightness in 1972 was about an order of magnitude below the Voyager and IUE results in 1979 (Table 2). Although the Voyager 1 data allows the relatively accurate separation of auroral and equatorial contributions, this facility is not available in the early rocket results because of low spatial resolution. The separation of the different sources in the rocket data then requires the use of different spectral characteristics in the differentiation process. The basic difference between auroral and equatorial spectra is in the apparent depth of the H_2 band emission and in the value of Y_{IS} (Table2). Jupiter auroral spectra all show the effect of hydrocarbon and possibly other absorbers [*Shemansky*, 1985], and show a distinctly different spectral shape in comparison to equatorial emission. We therefore discuss the H_2 band observations in terms of the required amount of absorber in the model fitting process.

It has been found that Jupiter auroral spectra cannot be modeled satisfactorily using a simple combination of hydrocarbon absorbers [*Shemansky*, 1985]. However, if one restricts the analysis to the spectral region longward of 1220 Å, a rough fit to many Voyager and IUE auroral observations can be obtained by including CH_4 alone as an absorber. The fractional amount of extinction (I/Io) in the 1250Å region is a convenient measure of the effect of the absorber. IUE auroral data obtained by *Durrance et al.* [1982] are shown in Figure 2, compared to the present model. The abundance of CH_4 required in this typical spectrum is $[CH_4]l = 6.7\times10^{16}\ cm^{-2}$ (I/Io(1259Å) = 0.53), somewhat larger than the quantity ($[CH_4]l = 3.5\times10^{16}\ cm^2$, I/Io(1250Å) = 0.30) required for the *Giles et al.* [1976] spectrum. A difference of this magnitude is expected, if roughly 1/2 of the H_2 band emission in the *Giles et al.* [1976] spectrum is attributed to electroglow, which has no involvement with hydrocarbon absorbers [*Shemansky, 1985*]. The *Giles et al.* [1976] spectrum is therefore consistent in both quality and magnitude with the mix

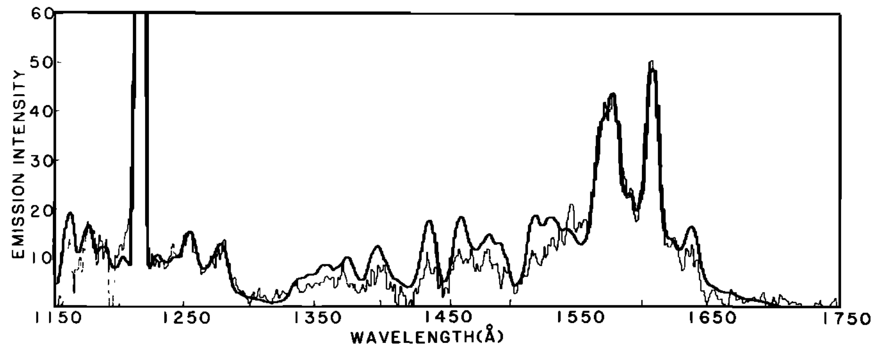

Fig. 2. The IUE spectrum of a Jupiter aurora obtained by *Durrance et al.* [1982] compared to a model calculation. The heavy curve is the model which includes CH_4 foreground absorption $[CH_4]l = 6.7\text{x}10^{16} cm^{-2}$, but no measurable component of the solar reflection continuum.

of H_2 band contributions from auroral and electroglow disk averaged emission, obtained from Voyager observations in 1979 (Table 2). However, the data quality and variability of auroral depth allows a fairly wide latitude in the derived mix, and it is possible to produce a satisfactory fit to the data over a broad range of electroglow and auroral ratios.

This lack of definition in the relative contributions of the auroral and equatorial emissions is a source of uncertainty in the conclusions drawn below. There is no doubt that the rocket spectrum is distinctly different from the later Voyager data. If we take an extreme alternative and assume the rocket disk average results to be dominated by aurora, then the spectrum would be basically compatible with present day auroral measurements in Y_{IS}, and within a factor of 2 in absolute brightness (Table 2). If there were no auroral contribution the differences in Y_{IS} between the *Giles et al.* [1976] data and Voyager in relation to electroglow emission would be at an extreme limit, and very difficult to explain as discussed below.

Solar Reflection Continuum; Absolute Calibration

Estimates of the solar continuum reflection intensity of the subsolar point at 1600 Å are shown in Table 3 as a calibration reference. Values are obtained from 1972 rocket data [*Giles et al.*, 1976], 1978-1979 IUE satellite data [*Gladstone and Yung*, 1983; see also *Wagener et al.*, 1985], 1979 Voyager data [*Shemansky*, 1985], 1980 IUE data (present work), and 1985 IUE data (D. E. Shemansky manuscript in preparation, 1987). All of the intensity measurements fall within 10% of the same value (Table 3). The solar flux at 1600 Å is dominated by continuum emission basically associated with the color temperature of the Sun. It is therefore not expected to show the large variability of the shorter wavelength emissions. *Rottman* [1981] reports rocket measurements over the 1972-1977 period showing scatter of ≈ 20% in absolute emission rate from the disk averaged sun at 1600 Å. Measurements from the SME satellite in the 1981-1986 period show a much smaller scatter and an absolute value in agreement with the mean from 1972 to 1977. However, *Mount and Rottman* [1981] in measurements on June 5, 1979, and July 15, 1980, obtain values about 1.7 larger at 1600 Å than the earlier and later results. This would indicate an apparent decrease in albedo at 1600 Å in the Voyager observation relative to the earlier and later measurements. However, the constancy and equality of the earlier and later solar flux over 5-year periods in our view suggests that a variation of this magnitude in 1979 and 1980 is unlikely. If we assume a constant value for the solar source as indicated in Table 3, the inferred albedo at Jupiter is constant over time. The albedo calculated using the measurements of solar flux in the epochs before and after the *Mount and Rottman* [1981] measurements, is given in Table 3 as a value that is assumed to be basically constant from 1972 through 1985. The connection of the Voyager, IUE, and rocket observations through measurements of Jupiter's albedo at 1600 Å, thus gives a measure of confidence that instrument calibrations are equivalent in the data considered in this paper. As noted above, the P10 photometer has been scaled to equivalence with the Voyager EUV instruments through comparison of LISM measurements, in order to remove calibration differences.

Discussion

The striking difference between measurements of the EUV spectrum of Jupiter's sunlit atmosphere in 1972-1973 and 1979 appears to be in the intensity of the $HLy\alpha$ line. There is little doubt, from the nature of the spectrum obtained by *Giles et al.* [1976], that the ratio of $HLy\alpha$ to H_2 band brightness ($Y_{IS} = I(H)$ Ly α)/ I_S (H_2 Ly+Wr)), as defined by *Shemansky and Smith* [1986] is drastically lower than the value obtained from Voyager data in 1979 (Table 2). The earlier *Rottman et al.* [1973] measurements support these results although the absolute brightness is higher. The ratio Y_{IS} in these results, in fact, is typical of auroral spectra [*Sheman-*

Table 3. Reflection of the Solar Continuum at 1600 Å

	Parameter	I (160C Å), R/Å	Albedo[f]
Sept. 1, 1972	rocket; disk average;	45	
	subsolar point[a]	67	0.31
Dec. 1978 to June 1979	IUE; subsolar point[b]	68	0.31
March 1, 1979	Voyager 1; subsolar point[c]	70	0.32
June 11, 1980	IUE; subsolar point[d]	73	0.34
April 9, 1985	IUE; subsolar point[e]	73	0.34

[a)] See Table 1.
[b)] From *Gladstone and Yung* [1983].
[c)] From *Shemansky* [1985]; note misprint in Table 3 "1600 Å" should read "1660 Å."
[d)] Analysis of SWP 9488.
[e)] From D. E. Shemansky, et al., (manuscript in preparation, 1987).
[f)] πF from *Rottman* [1981]; SME data 1981-1985.
Solar flux assumed constant 1972-1985;
$\pi F = 1.47 \times 10.^9$ Ph $cm^{-3} A^{-1}$ at 1AU.

sky and Smith, 1986]. The P10 results, whether they are interpreted in terms of Y_{IS} as obtained from the rocket spectra (Table 2) or not, show a very low emission brightness from the sunlit atmosphere in late 1973 near the time of minimum in the major solar cycle. It should be noted that the Zurich sunspot number was at an exceptionally low value at the time of the P10 encounter [*Giles et al.*, 1976].

The mix of auroral and electroglow emission in the 1972-1973 disk averaged data is not a well-determined quantity. Analysis of the *Giles et al.* [1976] data shown in Table 1 is compatible with a range of values of the auroral to electroglow emission ratio. The data can be interpreted as having the same emission mix as the Voyager 1979 data (Table 2). This appears to be reasonable based on the amount of foreground CH_4 required to fit the *Giles et al.* [1976] spectrum, compared to the analysis of typical IUE and Voyager auroral data. On this basis the brightness of the H_2 Rydberg systems was approximately the same in 1972 as it was in 1979 in both auroral and electroglow components. However, this line of analysis leads to a difficult position in reconciling the result with understandable physical processes in the upper atmosphere, because constancy in excitation processes imply a constant source and sink rate for H, leaving little or no room for a large variation in abundance. We therefore raise other possible interpretations of the content of the early data.

The electroglow process dominates the production of atomic hydrogen in Jupiter's upper atmosphere. If the production rate of H is constant over time, the abundance should also be constant unless some mechanism produces a variation in loss rate. The loss rate of H can be altered by a few processes, but it tends to be dominated by eddy diffusion to the homosphere [see *Wallace and Hunten*, 1973]. A variation of the altitude distribution of the source could modify the H loss rate to some degree, and in addition diffusive separation would change the $[H]/[H_2]$ ratio at the source altitude. The mechanism for the electroglow is not understood and so no strong constraint can be placed on the source altitude, although analysis of electroglow on the three outer planets show substantial excitation in the exosphere. Two body chemical reactions at high altitude, in particular associative detachment of H^- [*Bieniek and Dalgarno*, 1979], can remove H. The associative reaction rate is moderately fast, but the production of H^- is a limiting factor [*Dalgarno and Kingston*, 1963]. A rough estimate using measured ionospheric parameters at Jupiter indicates that H^- is about 4 orders of magnitude short of being a controlling factor for the atomic hydrogen population; eddy diffusion to the homosphere is the controlling factor. It therefore appears unlikely that the abundance of H could vary significantly if the source brightness of the H_2 electroglow was constant over the 1/2 period of the solar cycle. A variation in the ratio Y_{IS} under these conditions then requires a significant change in the electroglow source altitude.

An alternative explanation for the low Y_{IS} ratio in the early disk averaged observations enters through the uncertainty of the relative contributions of auroral and electroglow H_2 emission. We have assumed that the contributions of the two sources in the early rocket and P10 data are in the same ratio as the Voyager encounter results in 1979. If on the contrary, most of the H_2 band emissions in the early data were attributed to aurora, then a lower source rate for the production of H could be inferred, providing a direct explanation for a low Y_{IS} value. This requires a disk averaged brightness in auroral H_2 bands approximately 50% greater than the value obtained in 1979. Table 1 shows this alternate mix of H_2 auroral and electroglow emission. The maximum auroral brightness based on morphology obtained from Voyager spacecraft observations occur at $\approx$ $180\lambda_{III}$ CML, with a modulation of $\approx$ 50% averaged over the disk [F. Herbert, private communication, 1986; *Skinner and Moos*, 1984; *Skinner et al.*, 1984]. The *Giles et al.* [1976] rocket observation was obtained at $110°\lambda_{III}$ CML, the location of the maximum in the H Ly α equatorial bulge. This is a region expected to show relatively lower auroral disk averaged brightness [see *Skinner et al.*, 1984]. The 1972 rocket observation on this basis would require the aurora to be generally brighter than at the time of Voyager encounter in 1979. This does not correlate well with a low level of activity in the Io plasma torus as indicated by the P10 observations in 1973 [*Shemansky and Judge*, 1985], although relationships are not necessarily linear. It is generally assumed that there is a connection between Jupiter auroral activity and the flow of mass through the Io plasma torus. Thus neither scenario presented here for the weakness of the $HLy\ \alpha$ line (low Y_{IS}) in 1972-1973 has clear support from theoretical and observational considerations. Possibly the answer lies somewhere between the two extremes presented in this discussion, with a moderately reduced brightness of the H_2 band electroglow source (see Table 1). Comparison of the P10 and rocket results (Table 2) suggest that the disk averaged spectrally integrated brightness of the planet was variable in the early part of the 1970 decade. The P10 observations in particular indicate an all-time low in the history of observations in the EUV, in spite of a large upward correction in calibration factor. As noted above, the P10 observations also coincide with a remarkable low in the Zurich sunspot number.

The absolute brightness of the $HLy\alpha$ line in the P10 and even in the *Giles et al.* [1976] rocket observations is low enough to suggest that the abundance of atomic hydrogen was reduced at that time relative to Voyager and IUE observations in 1979. A solar $HLy\alpha$ resonance scattering component of $\approx$ 5 kR in 1979, reduces to $\approx$ 2.5 kR in 1972-1973 assuming the same abundance of atomic hydrogen in each case. Electron excitation of pure H_2 in the 1972 [*Giles et al.*, 1976] rocket observation produces a minimum of 1 kR in $HLy\alpha$ emission. The implication appears to be that the abundance of atomic hydrogen was reduced at least in the 1972-1973 period of the rocket and P10 observations. On this basis the weight of evidence seems to point to a reduced electroglow production rate of atomic hydrogen at the time of the early observations, although the available data is not uniformly in support of this conclusion. In this discussion, we have assumed that the eddy diffusion coefficient is basically constant. This is supported to some degree by the P10 and Voyager observations of the He 584 Å line. *Carlson and Judge* [1975] reported an He 584 Å brightness of 5.1 R. This quantity must be reduced somewhat because of the inclusion of H_2 band emission in the P10 short- wavelength photometer signal. Our estimate of the actual He 584 Å brightness (2-3 R) is shown in Table 2 along with the Voyager disk averaged value (4 R). The solar He 584 Å source was weaker in 1973 relative to 1979 by a factor of $\approx$ 2, indicating that the HeI atmospheric distribution was about the same in 1973 and 1979. The $HLy\ \alpha$ emission in the equatorial region of Jupiter is dominated by electron excitation of H. A reduction of energy deposition rate in the electroglow of a factor of $\approx$ 3 would therefore result in an order of magnitude reduced emission rate in $HLy\alpha$. This scenario in our view presents the most plausible explanation for the strong variation in $HLy\alpha$ brightness. The fact that the $HLy\alpha$ emission in the electroglow is dominated by electron excitation of H, and the production of atomic hydrogen is controlled by the same electrons [*Shemansky*, 1985], leaves the H $Ly\alpha$ brightness roughly dependent on the square of the density of the exciting electrons. The proposed variation of H abundance would not affect radiative transfer effects [see *Gladstone*, 1985] to an extent large enough to cause an additional dependence of brightness on optical thickness of the $HLy\alpha$ line.

Independent of possible variations in electroglow energy deposition rate, a reduced abundance of H implies a lower thermospheric temperature. If the electroglow deposition rate is in fact constant over time, then the present results imply that the deposition must occur at substantially lower mean altitudes in the atmosphere in order to account for a reduced H abundance. In this case the shorter thermal conductive path to the mesopause will lead to lower temperatures at the top of the thermosphere. The fact that the thermospheric temperature appears to be controlled by the electroglow [*Smith et al.*, 1983; *Shemansky*, 1985, 1986; Strobel and Shemansky, unpublished report, 1986] then indicates an accompanying strong variation in temperature [see *Smith et al.*, 1983].

SUMMARY

Analysis of the early rocket and P10 [1972-1973] observations of EUV/FUV emission from Jupiter indicate that the total emission brightness was reduced by $\approx$ 2 relative to Voyager measurements in 1979. Most of this variation was caused by an order of magnitude change in the emission rate of the H $Ly\alpha$ line. We suggest that the most plausible explanation for the variation is a factor of $\approx$ 3 reduction in energy deposition rate in the electroglow. The order of magnitude variation in H $Ly\alpha$ brightness would then be caused by the relation

$$I(H\,Ly\alpha)\alpha[e]_h^2 \quad (1)$$

where $[e]_h$ is the density of the electroglow exciting electron population. The basis of eq. (1) depends on the fact that the abundance of H in the atmosphere is controlled by the electroglow process. The establishment of a direct relationship of variation in the flux of solar ionizing radiation during the solar cycle, with the magnitude of the electroglow will require further correlative observations. The observed variation in H abundance implies a relatively strong variation in thermospheric temperature.

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