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# CONSISTENCY BETWEEN SC#21REF SOLAR XUV ENERGY INPUT AND THE 1973 PIONEER 10 OBSERVATIONS OF THE JOVIAN PHOTOELECTRON EXCITED $H_2$ AIRGLOW

IN-91-CR

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**ABSTRACT** It has been suggested in the literature that the F74113 solar spectrum for the solar minimum condition needs to be modified to explain the production of photoelectrons in the Earth's atmosphere. We have studied here the effect of another solar minimum spectrum, SC#21REF, on the Jovian upper atmosphere emissions and we have compared the predicted photoelectron excited $H_2$ airglow with the 1973 Pioneer 10 observations, analyzed according to the methodology of Shemansky and Judge (1988). In this model calculation we find that in 1973, the Jovian $H_2$ band emissions can be accounted for almost entirely by photoelectron excitation, if the preflight calibration of the Pioneer 10 ultraviolet photometer is adopted. If the SC#21REF flux shortward of 250 Å is multiplied by 2 as proposed by Richards and Torr (1988) then the Pioneer 10 calibration and/or the airglow model used must be modified in order to have a self consistent set of observations.

## INTRODUCTION

The solar extreme ultraviolet radiation (XUV) and far ultraviolet radiation (FUV) play an important role in determining solar-planetary atmosphere relationships. The solar XUV is the principal energy source producing the characteristics of planetary ionospheres, the thermal structure of the upper atmosphere, and the mid-latitude airglow emissions. Unfortunately, the highly time dependent absolute solar XUV flux is not well known, even for solar minimum conditions. Accordingly, only general correlations between airglow emissions and solar emissions have been possible based on the several compilations of the solar spectrum available in the literature: R74113 (Heroux and Higgins, 1977), F74113 (Heroux and Hinteregger, 1978), SC#21REFW and SC#21REF (Hinteregger et al., 1981). The first two spectra are slight modifications of the same spectrum. Similarly the latter two are likewise related to each other. However, these two sets do not agree very well with each other even though both are referred to as a "solar minimum" spectrum. Perhaps this is at least partially due to the ambiguity of establishing the time when solar minimum occurs, and/or because these spectra were constructed from many observations which were not obtained simultaneously. It is thus not surprising that the adopted representative solar spectra are not consistent with atmosphere airglow observations. For example, Richards and Torr (1984) found that the F74113 solar spectrum shortward of 250 Å needs to be doubled to overcome an inconsistency between the measured solar XUV fluxes and the measured photoelectron flux in the upper atmosphere of the Earth. Furthermore, shortward of 250 Å the solar XUV flux in the solar spectrum SC#21REFW is even lower than that in the F74113 spectrum. According to Richards and Torr (1988), however, given the uncertainties in the solar XUV fluxes and the uncertainties in the total electron impact cross sections, both the 1974 (F74113) and the 1976 (SC#21REFW) spectra remain legitimate inputs to their model.

In this paper, we have carried out related studies on Jupiter's atmosphere by varying the SC#21REF solar reference spectrum, and thereby the photoelectron flux, to determine the effect on Jovian $H_2$ emissions excited by electron impact. The Lyman and Werner band emissions from molecular hydrogen are a dominant feature in the XUV/FUV sunlit hemisphere of Jupiter. However, understanding these emissions has been made difficult following the 1979 Voyager 1 and 2 observations. These two spacecraft observed extraordinarily intense (~ 2.4 kR) disk averaged equatorial emissions (Shemansky and Judge, 1988). This intensity is many times that which can be supplied by purely unaccelerated photoelectron excitation of $H_2$ molecules. Similar excess intensity has been reported during the Voyager FUV observations of Uranus and Saturn. In fact a new process called the "electroglow" has been proposed by Broadfoot et al. (1986). The mechanism powering this electroglow remains unknown. There has been a recent suggestion that fluorescence might account for a substantial fraction of these emissions (Yelle, 1988). Such an explanation, however, requires unusually high solar fluxes. During the Pioneer 10 encounter the emissions in the spectral region of the Lyman and Werner bands were much less than those observed during the Voyager encounters, suggesting that any electroglow which might have been present in 1973 (Shemansky and Judge, 1988) was much weaker than that observed by the Voyager spacecraft. Hence, a study of the Pioneer 10 observations of Jupiter during solar minimum ($F_{10.7}=87\text{x}10^{-22}$ W $M^{-2}$ $Hz^{-1}$, Dec. 1, 1973) was carried out to determine whether or not the SC#21REF solar XUV energy input is consistent with the present estimate of the Pioneer 10 photoelectron excited $H_2$ glow.

## PIONEER 10 OBSERVATIONS

Pioneer 10 during its encounter with Jupiter in December 1973 observed a significantly reduced disk averaged $H_2$ emission (< 400 Rayleighs by Carlson and Judge, 1974) and any possible electroglow contribution was estimated to be significantly smaller than that observed in 1979 (Shemansky and Judge, 1988). In the following analysis it must be recognized, however, that the Pioneer 10 UV photometer is a broadband detector, and that it's field of view sampled the entire planet. Furthermore, the Pioneer 10 long wavelength channel is not sensitive to radiation longward of about 1300 Å. In order to obtain the equatorial (non-auroral) contribution of the $H_2$ bands to the disk averaged Pioneer 10 data we have followed the methodology of Shemansky and Judge (1988), who have assumed that the following processes, appropriately weighted, contribute to the observed emissions:

$H_2$ bands(auroral) + $H_2$ bands(non auroral) + H Ly $\alpha$(auroral) + H Ly $\alpha$(non auroral) = 400 R.

Using the prescription given by Shemansky and Judge (1988), which will be discussed in detail in a subsequent paper, the Pioneer 10 $H_2$ band disk averaged (non auroral) brightness is ~ 94 Rayleighs.

## PHOTOELECTRON EXCITATION OF THE $H_2$ BANDS

We have calculated the disk averaged $H_2$ band emissions from photoelectron excitation for two different model atmospheres (Figs. 1A, 1B). Model A has been obtained from McConnell et al. (1982) and Model B is an isothermal (300° K) atmosphere. The temperatures of the upper atmosphere for the two models are shown in Figs. 2A and 2B. As a first step we calculated the local equilibrium photoelectron flux using the SC#21REF solar XUV reference spectrum between 50 and 900 Å and the methodology of Nagy and Banks (1970), but with the reasonable assumption of zero net transport for the regions deep in the upper atmosphere where most of the $H_2$ band emissions originate. The results of this calculation are shown in Figs. 3A, 3B, and 4A, 4B. Here the variation of the photoelectron flux with energy and altitude (25 eV electrons) is given for the two atmospheric models considered. We also show the volume excitation rates of the B and C states of $H_2$ in Figs. 5A, 5B. The spectral glow intensities of the Lyman and Werner Bands are given in Figs. 6A, 6B and 7A, 7B, respectively. The disk averaged integrated glow intensity of the combined Lyman and Werner band emissions in the 850 - 1300 Å range was computed to be 97 Rayleighs. The Model A and B atmospheres yielded nearly identical amounts of $H_2$ band intensities (within 1 R) in the Pioneer 10 spectral range. When the solar flux shortward of 250 Å was increased by a factor of 2, as suggested by Richards and Torr (1984), the computed disk averaged intensity increased by nearly 60% to 152 Rayleighs.

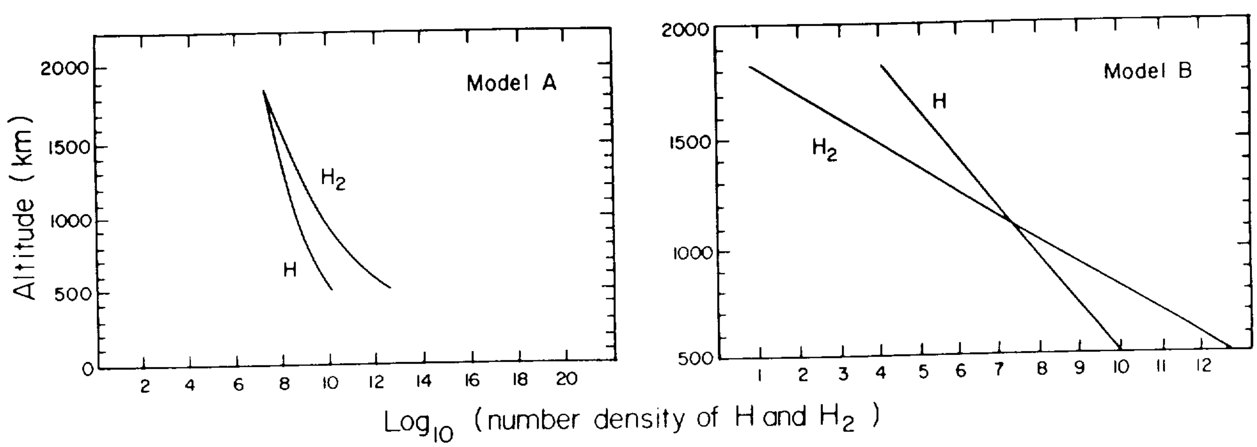


Figure 1A. H and $H_2$ density variation with height for Jupiter.

Figure 1B. Same as in Fig. 1A but for an isothermal atmosphere.

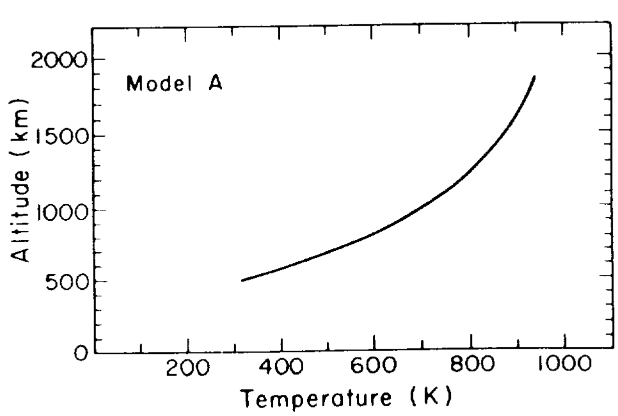


Figure 2A. Temperature variation with height in the Jovian upper atmosphere.

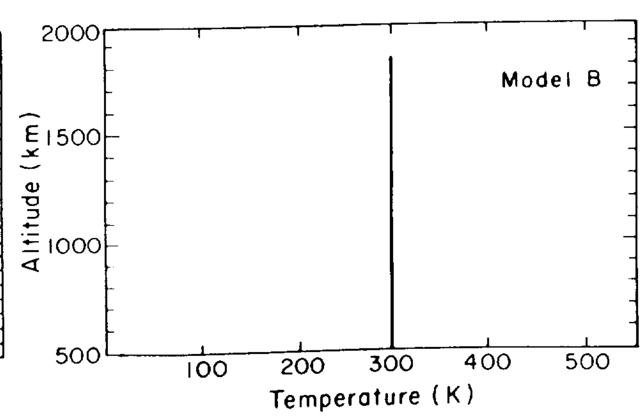


Figure 2B. Isothermal temperature.

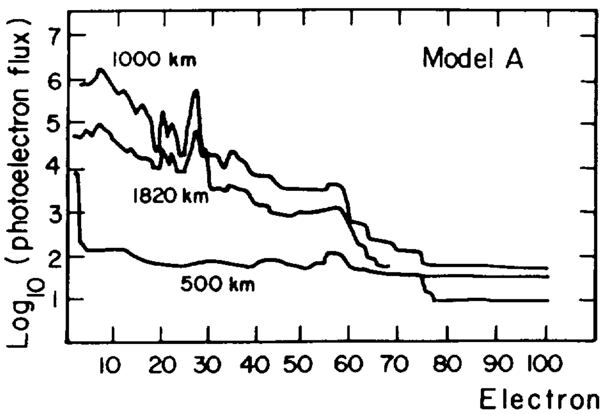


Figure 3A. The photoelectron flux in units of electrons $cm^{-2}$ $s^{-1}$ $eV^{-1}$ plotted against energy (eV) for three different depths of the atmosphere.

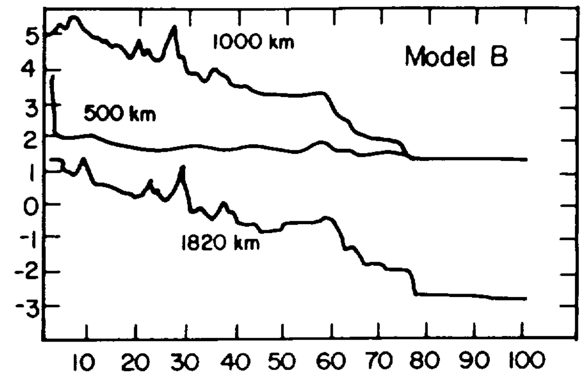


Figure 3B. Same as Figure 3A but for the Model B atmosphere.

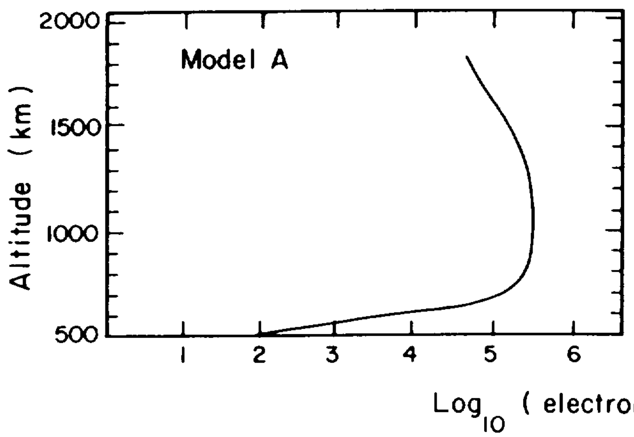


Figure 4A. Variation of the photoelectron flux in units of electrons $cm^{-2}$ $s^{-1}$ $eV^{-1}$ with the Model A atmospheric depth for a single energy E = 25 eV.

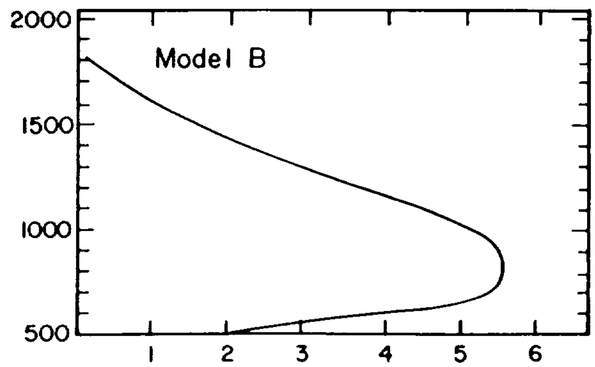


Figure 4B. Same as Figure 4A but using the Model B atmosphere.

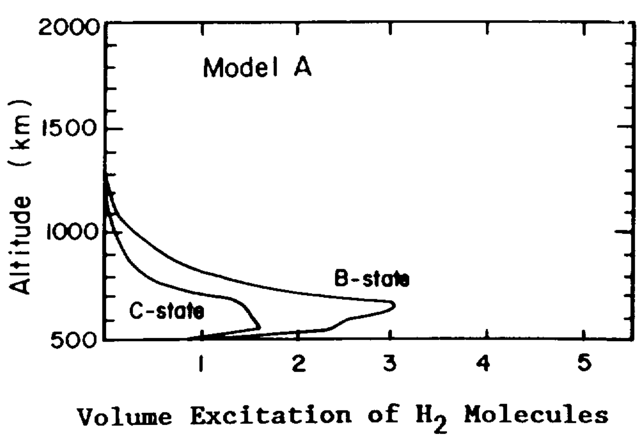


Figure 5A. Variation of the volume excitation rate of the B-state and C-state of $H_2$ in units of molecules $cm^{-3}$ $s^{-1}$ with atmospheric depth.

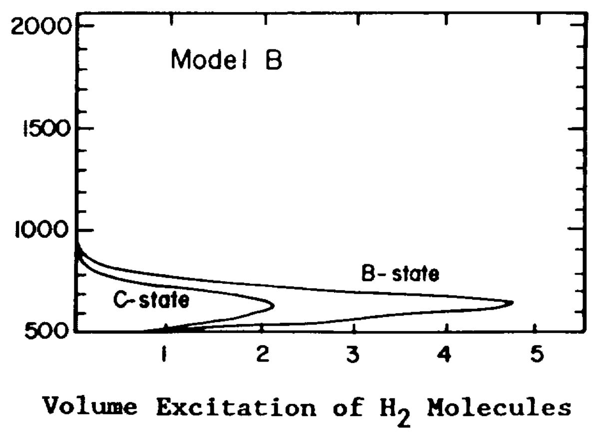


Figure 5B. Same as in Figure 5A but for Model B.

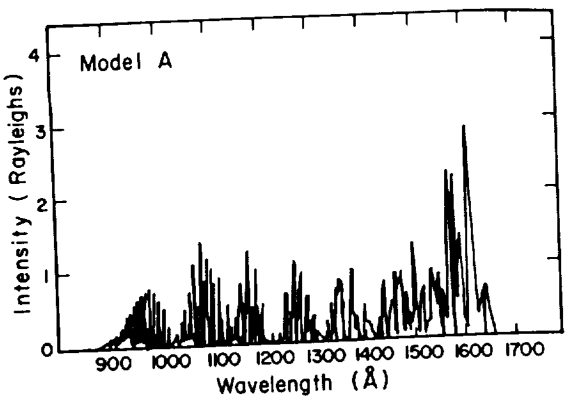


Figure 6A. Lyman band intensities in Rayleighs are plotted against wavelength for the Model A atmosphere.

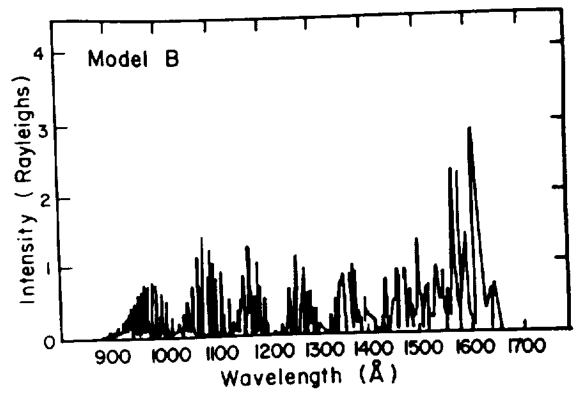


Figure 6B. Same as in Figure 6A but for the Model B atmosphere.

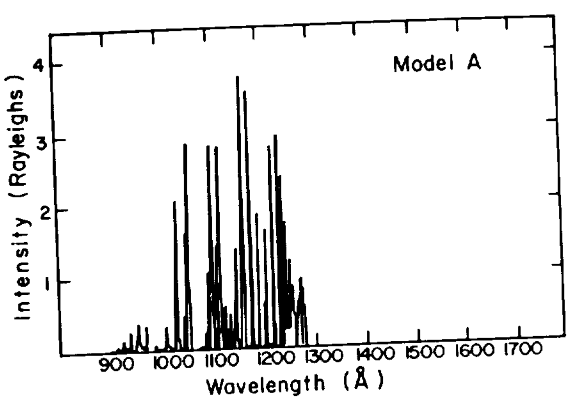


Figure 7A. Werner band intensities in Rayleighs are plotted against wavelength for the Model A atmosphere.

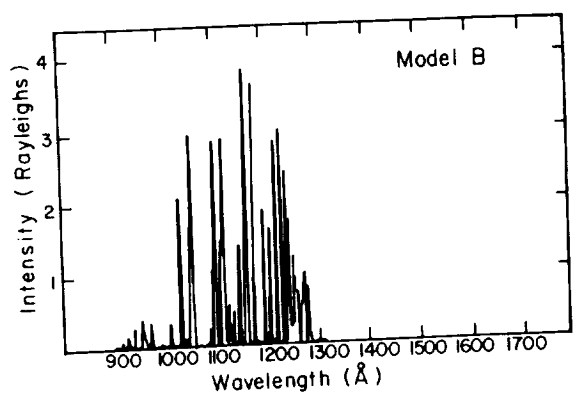


Figure 7B. Same as in Figure 7A but for the Model B atmosphere.

## DISCUSSION

The present photoelectron excitation calculation suggests that the Jovian $H_2$ band emissions in 1973 can be satisfactorily explained as due to the photoelectron flux produced by the SC#21REF solar spectrum. It is not necessary to increase the solar flux shortward of 250 Å as required to explain some Earth atmosphere observations of photoelectron flux (Richards and Torr, 1984), based on the Pioneer 10 preflight calibration. It is known, however, that the Pioneer 10 instrument calibration differs from that of the Voyager instruments by a factor of 4.4 at 1216 Å (Shemansky, Judge and Jessen, 1984), but it is not clear at this time how much of this factor should be attributed to each instrument. Thus, a calibration factor of ~ 1.5 relative to the original preflight calibration of the UV photometer which would be needed to explain the 152 Rayleigh glow cannot be ruled out, although it is clear from stellar observations, for example, that the instrument has been stable since launch. Whether a calibration factor of ~ 1.5 is reasonable or not requires further investigation since there are unavoidable uncertainties both in our model calculation and in our estimation of the measured equatorial $H_2$ glow. A calibration factor much larger than ~ 1.5 would clearly be hard to reconcile with a variety of local interstellar hydrogen density measurements. Wu et al., 1988 analyzed the Pioneer 10 UV photometer interstellar cruise data and determined that the local neutral interstellar H density is 0.06/cc in the downwind direction of the interstellar gas flow. A factor of 1.5 would increase the local H density to a value of 0.09/cc. The nominal very local interstellar H density from other observations is found to be ~ 0.1/cc (Ajello et al., 1987). Thus, increasing the calibration factor far beyond ~ 1.5 would lead to density values for the very local interstellar medium which are much higher than any reported to date.

## CONCLUSION

The SC#21REF solar spectrum is consistent with a Pioneer 10 calibration factor of 1, and a predominant photoelectron excitation process. The modified SC#21REF spectrum would require a calibration factor of ~ 1.5 or model modification to explain the Pioneer 10 data. Thus, both the SC#21REF solar spectrum and the modified version can explain the Pioneer 10 observations of Jupiter with only modest changes in the calibration factor and/or the model. A better estimate of the absolute solar flux and its temporal variation is required to improve our understanding not only of the terrestrial atmosphere, but also of the distant planetary gas giants.

## ACKNOWLEDGEMENT

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