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Ms. Genevieve Wiseman
Grants Officer, Code 200.3
National Aeronautics and
 Space Administration
Goddard Space Flight Center
Greenbelt, MD 20771

Dear Ms. Wiseman:

Enclosed please find the Final Technical Report for the IUE program SUGSD - "Variability Time Scale of H Ly-α from Uranus," by myself, J. T. Clarke, H. W. Moss, and S. Boyer. I am sorry for the long delay in getting this report to you. If there is anything else needed for me to close out our NASA grant NAG 5-435, please let me know and I will do my best to comply.

Sincerely,

Samuel T. Durrance

Samuel T. Durrance

cc: Dr. Kondo/684
NSTIF

(NASA-CR-182706) IUE PROGRAM SUGSD: VARIABILITY TIME SCALE OF H Ly-ALPHA FROM URANUS Final Technical Report (Johns Hopkins Univ.) 14 p CSCL 03B

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Final Technical Report

IUE Program SUGSD: Variability Time Scale of H Ly-α From Uranus

P.I.: Samuel T. Durrance, *The Johns Hopkins University*

The scientific motivation for this program was to determine the time scale for the variability of the H Ly-α emission from Uranus. It has previously been shown to be variable on time scales as short as one day which, coupled with its unusually high brightness, indicates that it must be excited by magnetospheric activity. The purpose of this series of observations is to determine its variability on shorter time scales. This will provide information on the timescale for changes in the level of particle precipitation in the Uranian magnetosphere. If this "auroral" emission appears to be modulated by the rotation of the planet, as has been observed on Jupiter and possibly Saturn, this would provide fundamental information on the nature of the interaction between the Uranian magnetosphere and the solar wind. It may also indicate the tilt of the magnetic pole with respect to the spin axis and provide information on the rotation of the planetary core.

A series of observations was carried out in coordination with ESA to cover as completely as possible one 24 hour period of the Uranian H Ly-α emission. The observations were obtained on April the 23*rd* and 24*th*. Two additional observations on April the 25*th* and 26*th* were obtained to search for longer term trends. A small modulation in the brightness was observed and the results presented in two publications; copies of which are attached to this report. The first publication (Durrance, S. T. and J. T. Clarke, "Lyman α Aurora, in Uranus and Neptune," edited by J. T. Bergstralh, NASA CP-2330, p. 559, 1984) presents these data for the first time and shows a variation on a time scale of 18 hours, the rotation period of the planet. The second publication (Clarke, J. T., S. T. Durrance *et. al.*, "Continued Observations of the H Ly-α Emission from Uranus," *J. Geophys. Res.*, **91**, p. 8771, 1986) presents a comprehensive compilation of all the IUE observations of Uranus to date with the results from this grant included.

LYMAN-ALPHA AURORA

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Abstract

The existence of intense and variable H Ly a emission from Uranus is demonstrated utilizing the monochromatic imaging capabilities of the International Ultraviolet Explorer satellite. A series of 14 observations, using the IUE short wavelength spectrograph in low dispersion and covering the period from 3 March 1982 through 2 September 1983, shows the disk averaged Ly a brightness of Uranus to vary between 690 and 2230 Rayleighs. Model calculations indicates that < 400 R of this emission can be attributed to resonant scattering of solar Ly a radiation. An upper limit of 100 R is obtained for the Raman scattering of solar Ly a by H_2 (1280 A). This implies that < 300 R is contributed to the planetary Ly a emission by Rayleigh scattering. In addition to being unexpectedly strong, the Uranian Ly a emission has been observed to vary by a factor of two in one 24 hr period and by about 50% in one 5 hr period. These data thus

offer the first strong evidence for the presence of aurora and therefore a magnetic field on Uranus.

Introduction

Spectroscopy of the outer planets at far ultraviolet wavelengths has progressed rapidly over the past few years with the advent of the International Ultraviolet Explorer satellite and the Voyager flybys of Jupiter and Saturn. Measurements of H Ly a emission (1216 Å) from these planets has been a particularly useful tool to understand the physical conditions in their upper atmospheres and magnetospheres. The three principal excitation mechanisms to produce H Ly a emission from the outer planets are (a) resonant scattering of solar Ly a radiation, (b) Rayleigh scattering of solar Ly a radiation, and (c) charged particle excitation of atmospheric H and H_2. Each of these mechanisms provides complementary information on the physical state of the atmosphere.

Resonant scattering of solar Ly a photons by atmospheric H provides a direct measure of the atomic hydrogen column abundance above the lower UV absorbing layers. Atomic hydrogen is produced in the upper atmosphere by photodissociative processes and mixed downward by eddy diffusion. Methane is also produced photochemically in the upper atmosphere and mixed downward. The column abundance of H above an absorbing CH_4 layer can thus be used, in conjunction with model calculations, to determine the eddy diffusion coefficient and the level of the homopause in the atmosphere. Resonant scattering of solar Ly a photons has been observed from both Jupetir and Saturn.

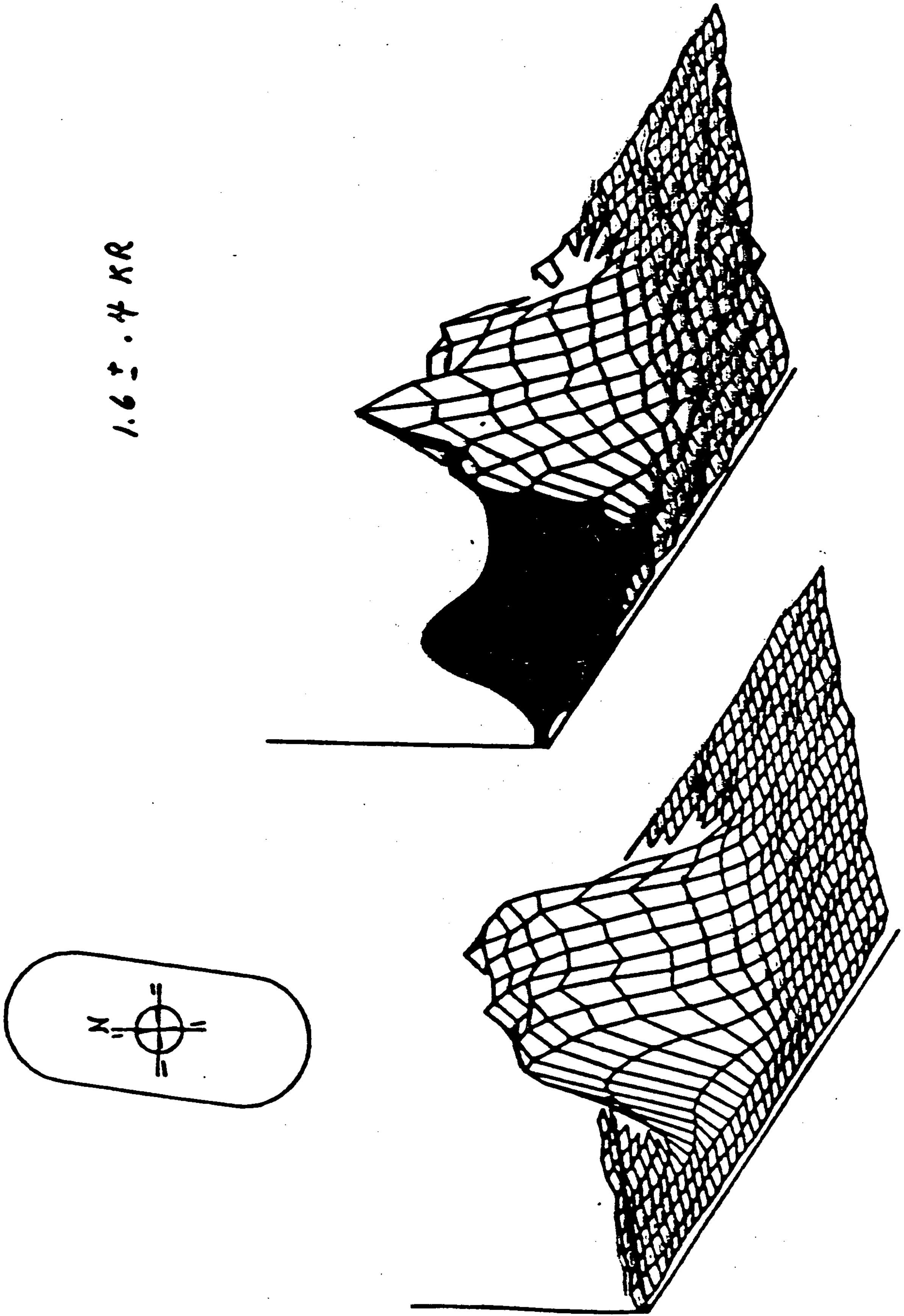
Rayleigh scattering of solar Ly a photons by atmospheric H_2 is another plausible mechanism to produce planetary Ly a emission. At low spectral resolution (>2 A) this emission is indistinguishable from that produced by resonant scattering. Rayleigh scattering will, however, produce a Raman-shifted line at 1280 A with about 1/3 the intensity of the Rayleigh scattered line (Dalgarno and Williams, 1962, and Brandt, 1963). This Raman-shifted line can be used to determine the amount of Rayleigh scattering present at 1216 A. The Rayleigh scattering cross section is low ($\sim 10^{-24}$ cm^2), so it requires a large H^2 column density ($\sim 10^{24}$ cm^{-2}) above the absorbing CH_4 layer. Such large H^2 columns are not present on Jupiter of Saturn and the Raman-shifted emission at 1280 A has not been detected.

Charged particle excitation can produce Ly a emission by direct excitation of H or by dissociative excitation of H^2. On Jupiter and Saturn this type of emission has been observed in both the polar aurorae and in the equatorial regions. Its presence is indicated by H_2 band emission and by the more varriable nature of particle precipation. This emission is a usefull indicator the level of magnetospheric activity and as a tool to study the dynamics of the magnetosphere.

Recently H Ly a emission from Uranus has been detected by three independent groups (Frike and Dauius, 1982, Durrance and Moos, 1982 and Clarke, 1982). Frike and Darius interpret their measurements as most likely due to resonant scattering of solar Ly a by H. The Hopkins and Berkely grogps, however, interpret their data as most likely due to auroral excitation. These data will be reviewed and newer observations will be presented in a hope to clarify the situation.

Observations

In the spring of 1982 two research groups, one at Johns Hopkins University and one at the University of California Berkely, began observational programs to search for H Ly a emission from Uranus and Neptune. The observational techniques used take advantage of the monochromatic imaging capabilities of the IUE short wavelength spectrograph. The large entrance aperture of the spectrograph has a projection onto the sky of about 10 x 20 arc sec as indicated in the upper portion of figure 1. The disk of Uranus, which has a diameter of about 3.8 arc sec, was imaged into the center of this aperture as is also indicated in figure 1. The background geocoronal and interplanetary Ly a emissions are varriable on both short and long time scales; however, they are spatially uniform over scale lengths comparable to that of the aperture so it should be possible to resolve the planetary Ly a emission from that of the background. The file with line by line spectra from the standard NASA/IUE data package (in which a data point corresponds to an area 1.1 arc sec in the dispersion direction and 2.1 arc sec high) was used to obtain a two-dimensional plot of the focal plane flux. A projection of the resulting data set at Ly a is shown in figure 1. The dispersion direction is parallel to the axes pointing downward and to the right. Figure 1a shows an exposure taken about 3 arc min south-west of the planet and thus contains background Ly a emission only. Figure 1b shows an exposure with Uranus centered in the aperture, so it contains both planetary and background Ly a emissions. The planetary emission is clearly resolved from the background emission. There are curently about 30 Uranus observations of

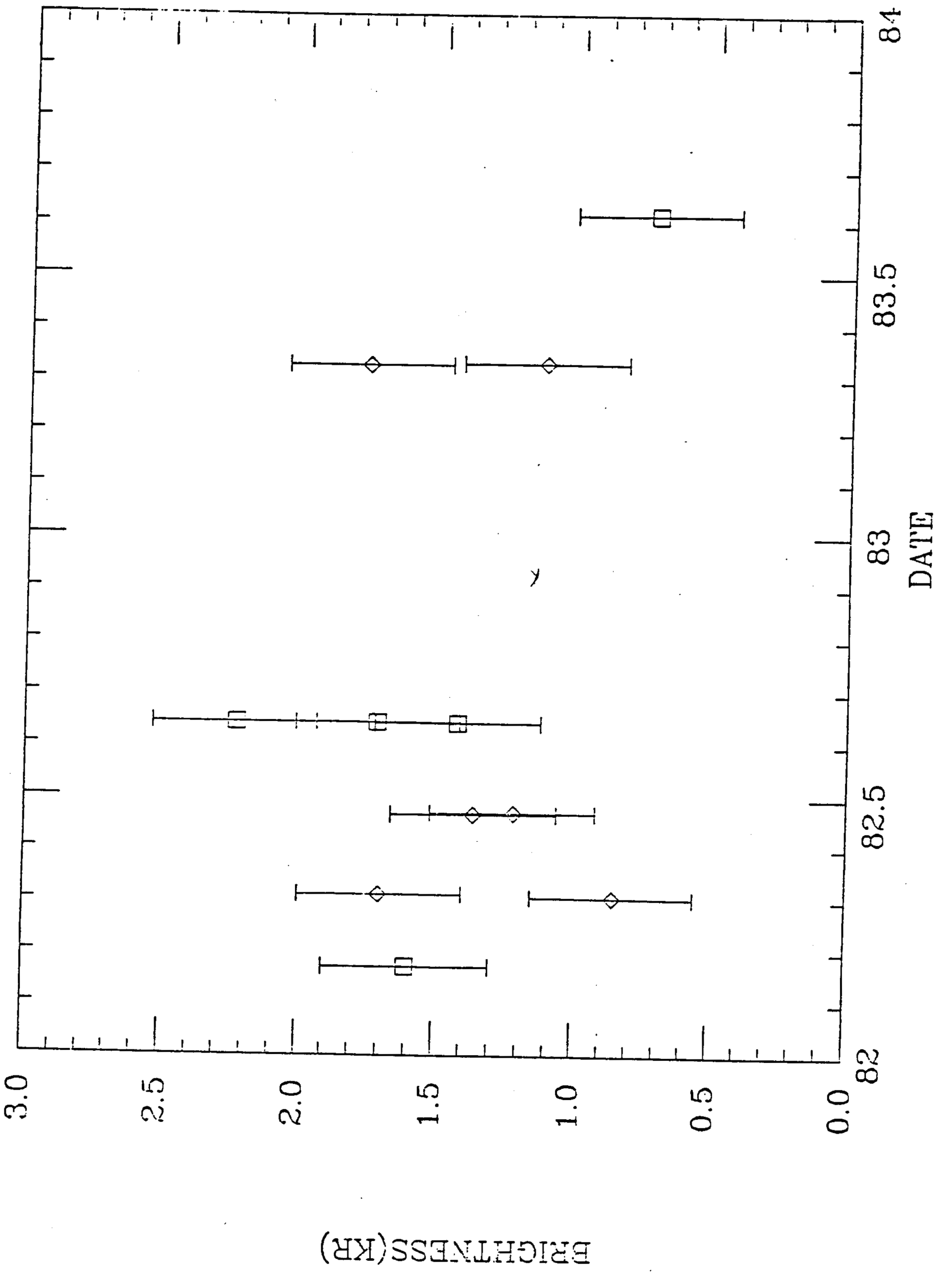

1.6 ± .4 KR
N

this type scattered throughout the period from 3 March 1982 to 2 september.

The Uranian Ly a brightness is obtained from these data by the following process. The two or three uranus exposures obtained in a given 8 hr IUE shift are combined into one. The exposure with background emission only is scaled to match the background contribution to this combined exposure and the two data sets are subtracted. The resulting array is summed over a region about 9 arc sec diameter, which is centered on the planetary emission, to give the total measured planetary Ly a signal in IUE flux numbers. This summing region is chosen to include all of the flux from the ~ 4 arc sec planetary disk after convolution with the ~ 5 arc sec point spread function of the instrument. This is converted to a disk averaged brightness using the absolute calibration of the SWP camera given by Bolin et al (1980) and the size of the Uranian disk at the time of the observations as given in the Astronomical Almanac.

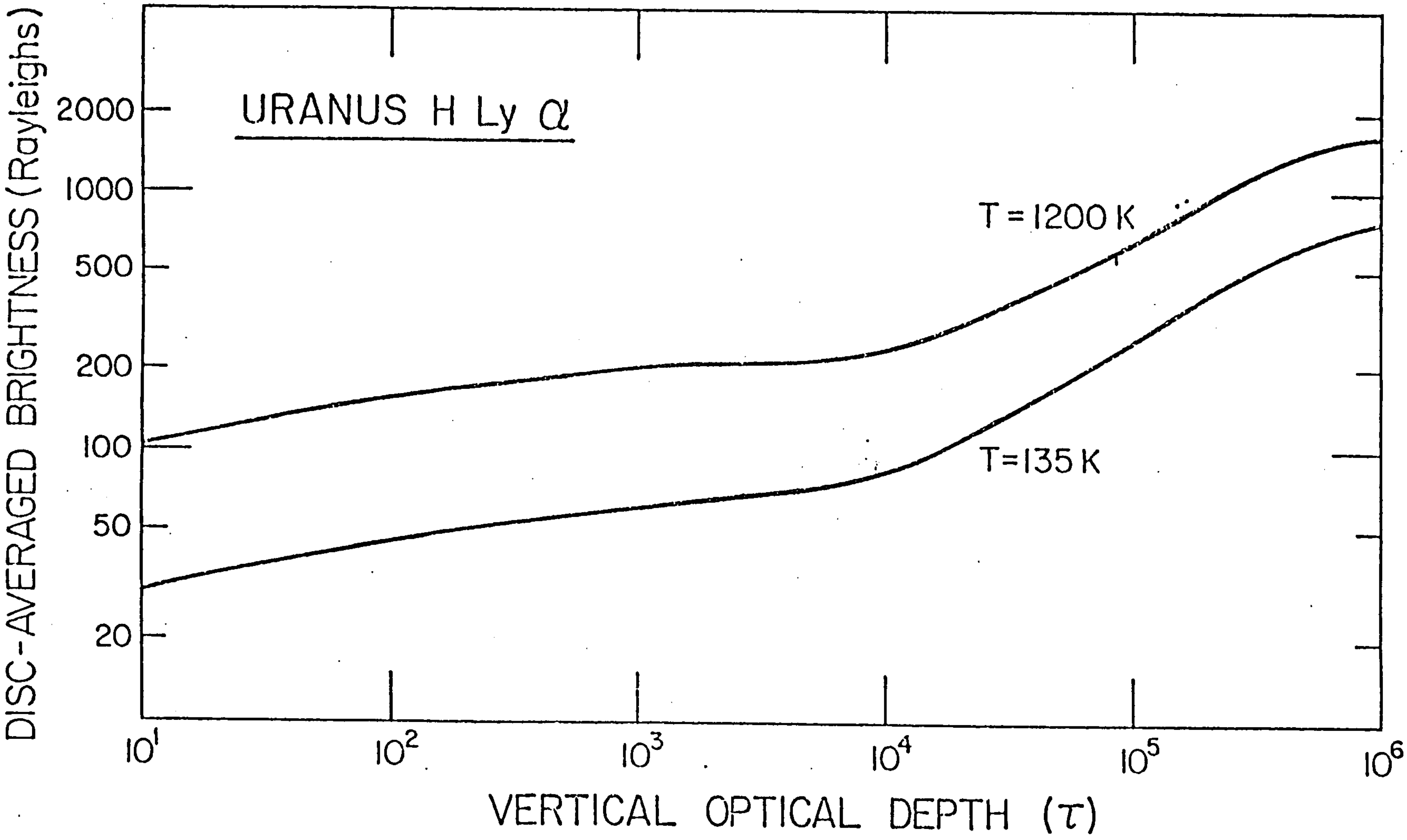
The data from Clarke (1982) were analized in a somewhat different manner. The photometrically corrected image segment from the standard NASA/IUE data package was used instead of the line by line file. This file should provide somewhat better spatial resolution. There is, however, a transformation necessary to convert the photometrically corrected image data into the IUE flux numbers in which the absolute calibration is given. When the IUE image processing system was changed in 1980 to increace the digitation of the low dispersion spectra by a factor of 2 this transformation was normalized by a factor of 2 (Turnrose, 1980) so that the same calibration could be used. The Ly a brightnesses of Uranus given by Clarke (1982) should thus be increaced by a factor of 2 to account for this.

The Ly a brightness of Uranus from the above analysis is plotted as a function of time in figure 2. The data shown as squares are from Durrance and Moos (1982) and several subsequent observations analyzed using the same technique. The data shown as diamonds are from Clarke (1982) but they have been increaced by a factor of 2 to account for the propper normalization. Two additional observations by Clarke are also shown as diamonds. The largest uncertianty in these measurements is a systematic error introduced by the background subtraction and is estimated to be + 20%. However, it is estimated that extracting different images by this method introduces a relative error of < 10%. The quoted uncertainty in the IUE calibration is 2s = 15% in a 25 A band at 1216 A (Bolin, et al. 1980), and the instrument has been determined to be stable in time to within this uncertainty by observing standard stars. The systematic error in the background subtraction and the uncertainty in absolute calibration are not shown in figure 2; only the relative error between different observations is shown. A variability by as much as a factor of 3 on relativly short time scales is clearly indicated by these data.


BRIGHTNESS(KR)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
82
82.5
83
83.5
84
DATE

Discussion

The data presented here clearly show Uranus to be an intense and highly variable source of H Ly a radiation. To understand this emmision we will now address the three most plausable excitation mechanisms. First consider the resonant scattering of solar H Ly a photons by an optically thick layer of atomic hydrogen in the upper atmosphere. There is evidence that CH_4 is condensed out of the atmosphere on Uranus at the temperature minimum (danielson, 1977). This could provide a larger column of H than one would expect based on analogy with Jupiter and Saturn. However, since both H and CH_4 are produced photochemically in the upper atmosphere and mixed downward and since the solar flux at Uranus is relatively weaker, it is difficult to produce the large H column required to explain the high Ly a brightness by resonant scattering. Detailed model calculations by Atreya and Ponthieu (1983) and by Atreya (this volumn) show that for a range of model parameters the expected H column density above an absorbing CH_4 layer is ~ 5 x 10^{15} cm^2. A simple model for the resonantly scattered emission was presented by Clarke (1982). The two curves of growth from that model are presented in figure 3; this model assumes monochromatic scattering in a plane-parallel isothermal layer with a completely absorbing lower boundry. This is an idealization but should b adaquate for our purposes here. For the lower temperature model, which appears more reasonable, the above column of H would produce a Ly a brightness of ~ 100 R considerably less than the 2.1 KR of the highest brightness observed. To produce this level of Ly a emission via resonant scattering would require an H column density in excess of 10^{18} cm^2 which seems unlikely.


URANUS H Ly α
T = 1200 K
T = 135 K
DISC-AVERAGED BRIGHTNESS (Rayleighs)
2000
1000
500
200
100
50
20
VERTICAL OPTICAL DEPTH (τ)
10¹
10²
10³
10⁴
10⁵
10⁶

If an extended H atmosphere existed, as a result of a hot hydrogen corona for example, then our conversion of the measured flux to a disk averaged brightness would be an over estimate. Two things argue against this. First, the size of Uranus' image in these observations is ~ 5 arc sec which is the same size as the point spread function of the telescope. If Uranus were emitting over an area much larger than the visible disk then it would show up as a more extended image. Second, calculations using a 60,000 K hydrogen corona (Shemansky and Smith, private communication) show that the optically thick H column would extend out to $< 1.1\ R_u$. This would reduce the derived disk averaged brightness by only about 15%.

If CH_4 is condensed out of the atmosphere, Uranus may have a deep H_2 atmosphere and thus Rayleigh scattering could be an important contributer to the Ly a brightness. However, the Rayleigh scattering cross section is $\sim 10^{-24}$ cm^2 (Dalgarno and Williams, 1962) and the model calculations of Atreya (this volumn) give $N(H_2) \sim 10^{15}$ cm^{-2} so this mechanism is probably not important. Also, in a sum of several long low dispersion IUE exposures using the small aperture an upper limit to the Raman-shifted emission of < 30 R is set (Frike and Darius, 1982). This sets an upper limit to the Rayleigh scattered Ly a emission of < 100 R.

Charged particle excitation by direct impact of solar wind particles on the Uranian disk could also produce H Ly a emission. If one assumes an average velocity of 400 Km/sec for solar wind protons and an average excitation energy of 12 eV per emitted photon and in addition that the entire disk captures and converts these protons to UV photons with 100% efficiency, then the resulting Ly a bribhtness would be < 50 R. There does not appear to be enough energy available for this process to be important.

An auroral emission from a zone between 80 and 90 degrees latitude and centered on the Earth facing pole would be able to produce the observed Ly a emission if the average surface brightness of this aurora were ~ 15 KR. This is comparable in brightness to the aurora observed on Jupiter and Saturn. Recent theoretical calculations by Hill, Dessler and Rassbach (1983) indicate that, if Uranus has a magnetic field, it will have an aurora that is highly variable in response to variations in the solar wind velocity. The highly variable nature of the Uranian emission is indicative of this type of emission. If the brightest emission observed is interpreted as intitely due to auroral particle precipatation, the required power is estimated to be ~ 3×10^{11} W using a 5% conversion efficiency (Gerard and Sing, 1981). This amount of power could be supplied by a magnetospheric interaction with the solar wind (Hill, Dessler, and Rassbach).

Conclusions

Intense and highly variable H Ly a emission has been observed fron Uranus. The disk averaged brightness is seen to vary between 717 R and 2.1 KR. Resonant scattering of solar Ly a by atmospheric H appears insufficient to explain this emission; model calculations limit this contribution to the Uranian Ly a brightness to < 400 R. Rayleigh scattering also is insufficient and an upper limit to this contrabution was derived to be < 100 R. Auroral precipatation of charged particles is the most likely cause of this emission. This implys that Uranus has a magnetic field and thus a magnetosphere. The required input power to the aurora is about 3 x 10^{11} W.