N90-26757

HIGH RESOLUTION, LOW TEMPERATURE PHOTOABSORPTION CROSS-SECTION OF C_2H_2, WITH APPLICATION TO SATURN'S ATMOSPHERE

JOHN CALDWELL*, C.Y.R. WU**, T.J. XIA**, D.L. JUDGE** AND R. WAGENER*

* Space Astrophysics Laboratory, Institute for Space and Terrestrial Science, 2700 Steeles Ave. West, Concord, Ontario L4K 3C8, Canada

** Space Science Center and Dept. of Physics, University of Southern California, Los Angeles, California 90089-1341

ABSTRACT

New laboratory observations of the VUV absorption cross-section of C_2H_2, obtained under physical conditions approximating stratospheres of the giant planets, have been combined with IUE observations of the albedo of Saturn, for which improved data reduction techniques have been used, to produce new models for that atmosphere. When the effects of C_2H_2 absorption are accounted for, additonal absorption by other molecules is required. The best-fitting model also includes absorption by PH_3, H_2O, C_2H_6 and CH_4. A small residual disagreement near 1600 Å suggests that an additional trace species may be required to complete the model.

INTRODUCTION

Extensive solar system observations of absorption and emission spectra have been obtained from a diverse collection of Earth-orbital satellites, interplanetary probes and ground-based telescopes. The pressures and temperatures of the various planetary environments being observed are generally very different from the usual laboratory conditions. There has been little incentive for the laboratory workers to go to the extra trouble of emulating the planetary conditions, and this has led to a situation where much of the laboratory spectral data which are required to interpret the planetary observations are obtained under conditions that are inappropriate for direct application to planetary modelling.

In the ultraviolet, planetary observations have been obtained for more than a decade by the NASA/ESA International Ultraviolet Explorer satellite. In the near future, it is expected that data from the Hubble Space Telescope will be available. The IUE data have provided significant new insights to the composition and auroral processes in planetary atmospheres. However, it is universally recognized that the advent of the HST will produce spectra that are greatly superior to the IUE data with respect to spatial resolution, spectral resolution, dynamic range and signal-to-noise. Whereas existing laboratory data are marginally acceptable for interpreting data of the quality produced by the IUE, it is clear that they are absolutely inadequate for modelling HST data.

Motivated by this mismatch between laboratory and observatory capabilities, we have implemented an experimental program to investigate systematically the temperature- and pressure-dependent absorption cross-sections of gases of interest for studying planetary atmospheres. Our first species is C_2H_2, chosen because it is one of the most important UV absorbers in the stratospheres of the giant planets. We have applied the new data to previous

IUE observations of Saturn, where C_2H_2 is clearly the dominant absorber. The reduction of the IUE spectra has been improved over previously published versions, as discussed below. After the effects of C_2H_2 absorption have been accounted for, other gases have been added to the model to optimize agreement with the planetary spectra.

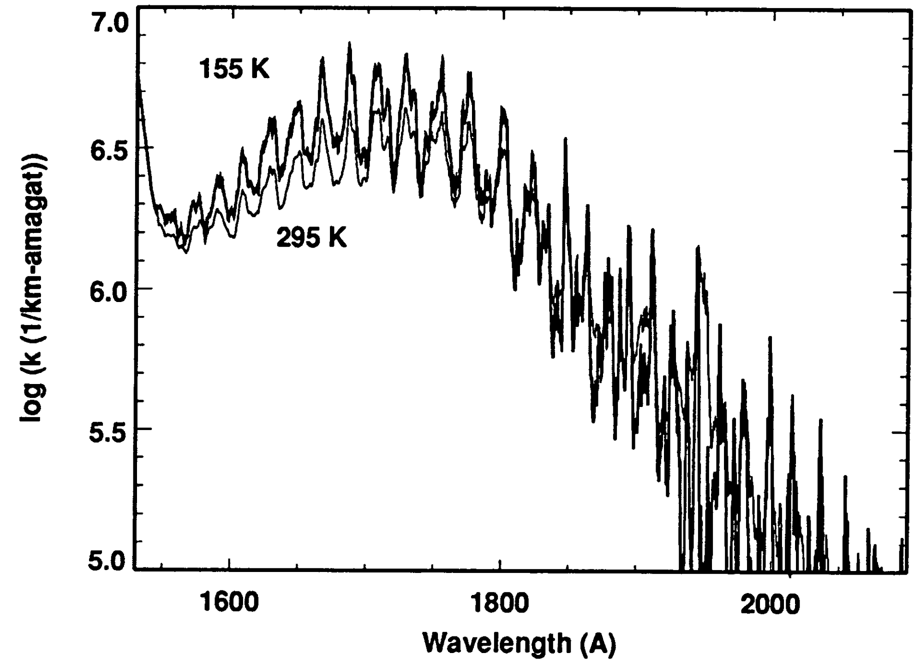

Fig. 1: New absorption coefficients, obtained by Wu *et al.*[1] at two temperatures.

LABORATORY RESULTS

The VUV photoabsorption cross-section measurements of C_2H_2 were performed at the Synchrotron Radiation Center at the University of Wisconsin-Madison. The data were obtained at a spectral resolution of 0.07 Å FWHM. The absorption coefficient spectra shown in Fig. 1 were smoothed by a 5 point gaussian filter to reduce high frequency noise. In the region between 1530 and 1800 Å the absorptions at low temperature (155K) compared to the room temperature data show stronger peaks (10 to 50%) and some enhancement in the valleys (up to 20%). In the region between 1900 and 2100 Å hot bands due to the $\tilde{A}\,^1A_u - \tilde{X}\,^1\Sigma_g^+$ transition are observed in the room temperature data. Further details are given in Ref. 1. The lower temperature absorption coefficients are more applicable to outer planet stratospheres and are used for the first time in the following reanalysis of the UV spectrum of Saturn.

IMPROVEMENTS IN IUE DATA ANALYSIS

Since the study of Saturn's UV spectrum by Winkelstein *et al.*[2] a number of improvements have been made in the IUE data reduction. All of the data taken between 1978 and 1980 was reprocessed by the IUE Standard Image Processing System at Goddard Space Flight Center using the latest software and the new Intensity Transfer Functions (ITF), in particular correcting for a known error in the ITF of the short wavelength prime camera (SWP, 1100 to 1980 Å) at low exposure levels.

Because of the very limited dynamic range of the IUE cameras and because of the rapidly decreasing planetary flux from long to short wavelengths, it is necessary to combine a large number of individual spectra, having a wide range in exposure times, from seconds to hours, to cover the useful range of the IUE. The individual spectra are normalized in the overlapping region and averaged together.

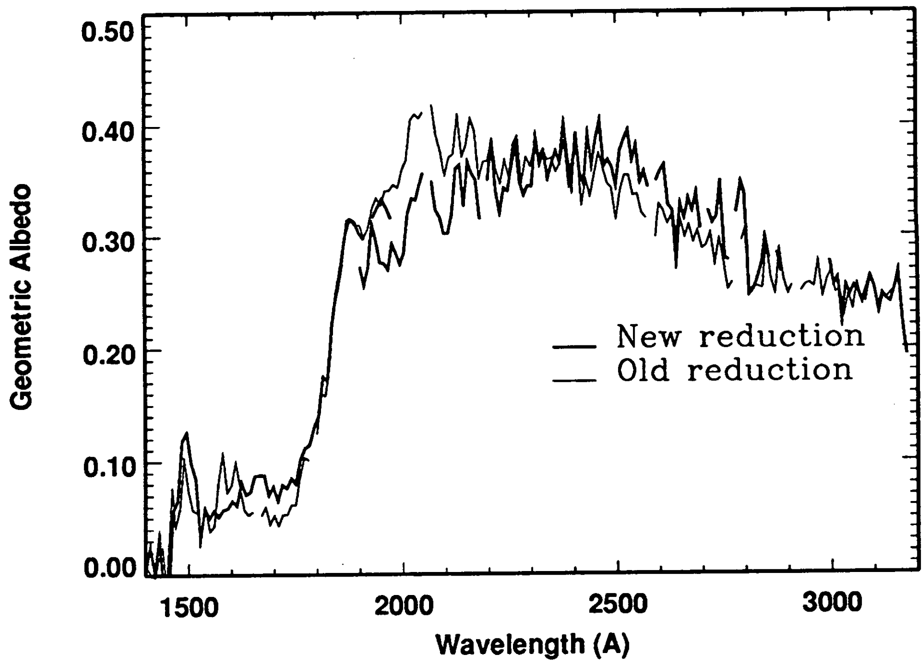

Fig. 2: The composite Saturn spectrum obtained by the IUE. The older extraction process is shown by the lighter line, the newer, improved one by the darker line.

Since the SWP camera is sensitive to longer wavelength photons, some contribution due to long wavelength light scattered within the spectrograph has to be corrected for in solar type spectra. An improved algorithm was used in this analysis that explicitly included the contribution of H_2 emission. The newly derived albedo spectrum is shown in Fig. 2 together with the previous version of Winkelstein *et al.*.

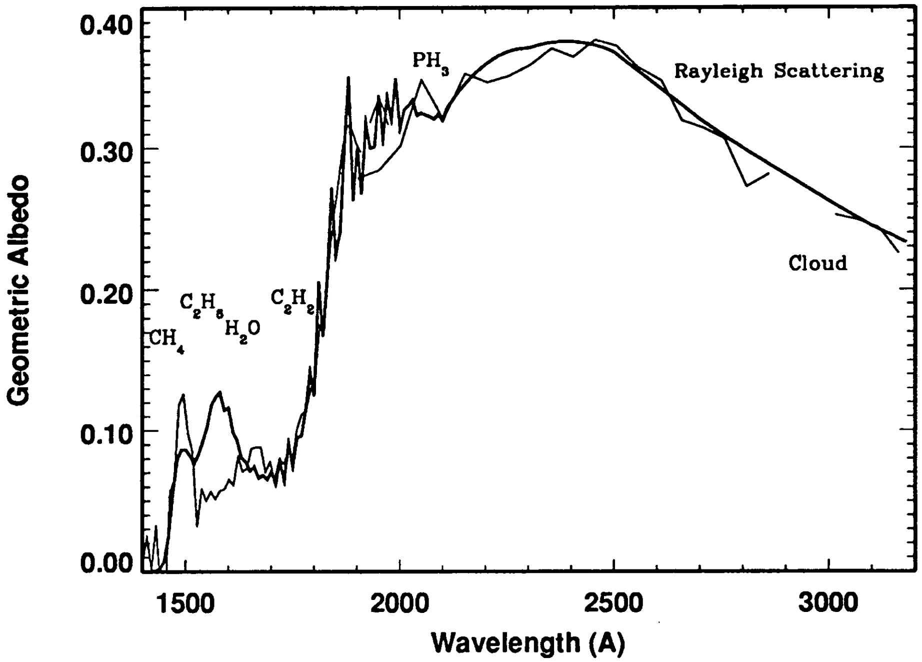

Fig. 3: The Saturn albedo spectrum (thin line) with the best-fitting model obtained to date (thick line), showing the regions where various absorbers are thought to be important.

MODELS OF THE ULTRAVIOLET ALBEDO OF SATURN

The new extraction process has introduced a relative albedo maximum near 2500 Å, in good agreement with OAO albedos obtained in the early 1970s[3]. The low albedo at 3000 Å must be due to some absorbing cloud at a pressure level of about 170 mbar in the Saturnian atmosphere (Fig. 3). The rise in reflectivity at shorter wavelengths is due to Rayleigh scattering from overlying H_2. The decreasing albedo below 2500 Å can be explained by PH_3 absorption. The best fitting model in Fig. 3 had no PH_3 at pressure levels $p < 60$ mbar, a mixing ratio of 5×10^{-7} between 60 and 120 mbar and 1.5×10^{-6} for $p > 120$ mbar, consistent with the distribution of Tokunaga *et al.*[4], but incompatible with the distribution of Courtin *et al.*[5].

Below 2000 Å, the spectrum (Fig. 4) is dominated by C_2H_2 absorption. Our best fitting model has C_2H_2 distributed between 2 and 20 mbar at a mixing ratio of 1.2×10^{-7}. A model with C_2H_2 alone is unsatisfactory, an additional continuum absorber in the top 2 mbar is required. We have examined the following candidate species C_2H_4, C_3H_4, C_4H_2, and H_2O and find that H_2O at a mixing ratio of 1.5×10^{-7} provides the best fit, although still unsatisfactory between 1550 and 1600 Å. The same conclusion was reached by Winkelstein *et al.*, but the abundance of H_2O is reduced by a factor of 2 as a direct consequence of the new low temperature absorption coefficients of C_2H_2.

Since we restricted the C_2H_6 distribution to follow the C_2H_2, i.e. uniform between 2 and 20 mbar, the influence of C_2H_6 is felt only weakly near 1500 Å. CH_4 causes the drop to essentially zero albedo near 1450 Å.

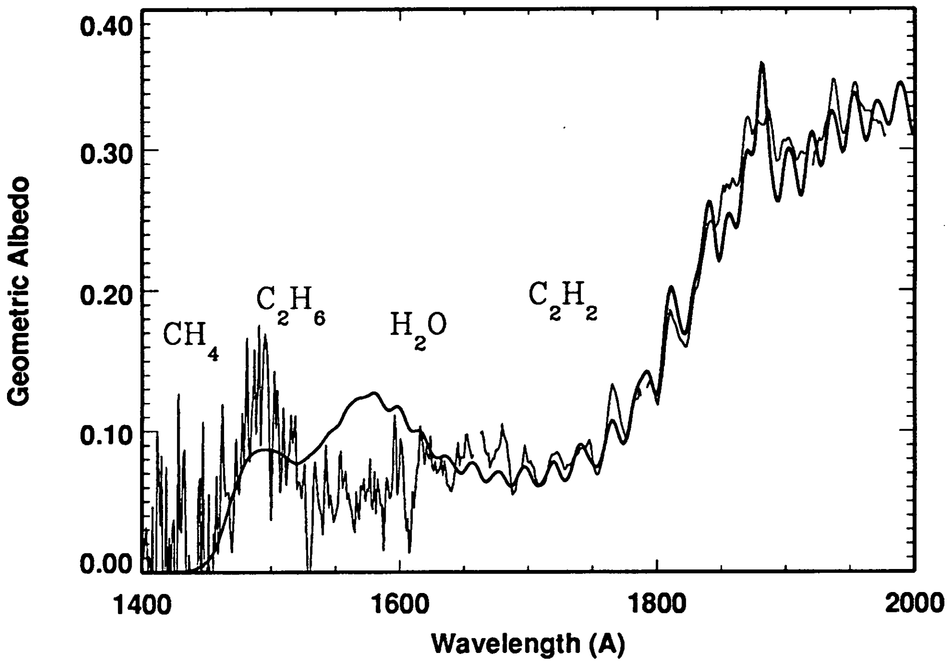

Fig. 4: Details of the best-fitting model below 2000 Å, with the regions where several absorbers may be important.

To conclude, we speculate on the possible cause of the remaining discrepancy between the model and the observations, near 1600 Å, and indicate where future laboratory effort may be required. The discrepancy suggests that another gas may be present on Saturn but not yet recognized in the modelling. One possibility for the missing gas is arsine, recently detected in Saturn's mid-infrared spectrum by Bézard *et al.*[6]. The observed mole fraction is of order several parts per billion, with the clear indication that the abundance is decreasing with increasing altitude, "a possible consequence of UV photolysis". If that is indeed the explanation for the vertical distribution of AsH_3 on Saturn, then it is reasonable to expect that some effect of that absorption may be visible in the UV spectrum. Unfortunately, no relevant laboratory observations of AsH_3 have been made, and it will be a prime candidate for future work in our program.

1. C.Y.R. Wu, T.S. Chien, G.S. Liu, D.L. Judge and J.J. Caldwell, *J. Chem. Phys.* **91**, 272 (1989).
2. P. Winkelstein, J. Caldwell, T. Owen, M. Combes, Th. Encrenaz, G. Hunt and V. Moore, *Icarus* **54**, 309 (1983).
3. L. Wallace, J. Caldwell and B.D. Savage, *Astrophys. J.* **172**, 755 (1972).
4. A.T. Tokunaga, H.L. Dinerstein, D.F. Lester and D.M. Rank, *Icarus* **42**, 79 (1980); *Icarus* **48**, 540 (1981).
5. R. Courtin, J.P. Baluteau, D. Gautier, A. Marten and W. Maguire, *Saturn Conference*, Tucson, AZ, May 1982.
6. B. Bézard, P. Drossart, E. Lellouch, G. Tarrago and J.-P. Maillard, *Astrophys. J.* **346**, 509 (1989).