HYDROCARBON PHOTOCHEMISTRY AND LYMAN ALPHA ALBEDO OF JUPITER

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ABSTRACT

A combined study of hydrocarbon and atomic hydrogen photochemistry is made to calculate self-consistently the Lα albedo of Jupiter. It is shown that the Lα emissions observed by Voyagers I and II can be explained by resonance scattering of sunlight. Precipitation of energetic particles from the magnetosphere can provide the large required source of atomic hydrogen, although the contribution of direct particle excitation to the disk-averaged brightness is insignificant. The variability of the Lα brightness inferred from many observations in recent years is examined. The large difference in the brightness of the He 584Å resonance line observed by Pioneer and Voyager is briefly discussed. Driving the photochemistry by solar ultraviolet radiation alone yields a maximum mixing ratio of C₂H₆ + C₂H₂ at 10⁻² atm of about 4 × 10⁻⁶. The possibility of additional CH₄ dissociation from precipitation of magnetospheric particles is discussed. The photochemistry of C₂H₃ and C₂H₃ is sufficiently uncertain not to permit accurate calculations of their densities and the ratio C₂H₆/C₂H₂.

Subject headings: molecular processes — planets: abundances — planets: Jupiter

I. INTRODUCTION

The Lα brightness of Jupiter has been measured by a number of workers (Moos and Fastie 1969; Rottman, Mount, and Freer 1973; Giles, Moos, and McKinney 1976; Carlson and Judge 1974; Bertaux et al. 1979; Broadfoot et al. 1979; Clarke et al. 1979; see Table 1). All observations previous to 1976 were summarized and discussed by Giles, Moos, and McKinney (1976). More recent observations were compared by Bertaux et al. (1979). The most interesting question is why the brightness is so variable. Analysis by Carlson and Judge (1971) and Wallace and Hunten (1973) have shown that the Lα brightness of Jupiter is primarily due to resonance scattering of incident sunlight by atomic hydrogen. The Lα albedo depends on at least the following: (a) production of H atoms from H₂ and CH₄ dissociation, (b) vertical eddy mixing in the atmosphere, (c) photochemistry of the hydrocarbons, and (d) thermal structure of the atmosphere. Each of the above factors has been considered in some approximate manner in the previous models, but never all at once on a self-consistent basis.

The photochemistry of hydrocarbons in the atmosphere of Jupiter has been studied by one of the authors (Strobel 1969, 1973, 1974) whose prediction of abundant C₂H₆ and C₂H₂ concentrations has been borne out by recent observations (Ridgway 1974; Combes et al. 1974; Tokunaga, Knacke, and Owen 1976; Orton and Aumann 1977; Hanel et al. 1979). A number of recent advances justify another examination of the hydrocarbon photochemistry in the Jovian atmosphere, in addition to the requirement of a self-consistent calculation of the Lα albedo. Calculations of the chemical composition of the deep atmosphere by Barshay and Lewis (1978) enable us now to select a more appropriate boundary condition for C₂H₆. There is strong evidence that the C/H ratio for Jupiter must be significantly higher than the solar value, which was used in previous photochemical calculations (Wallace and Hunten 1978; Sato and Hansen 1979). In addition, there have been important revisions in CH₄ and C₂H₆ photoabsorption cross sections (Mount, Warden, and Moos 1977; Mount and Moos 1978) and in the rate coefficients for three-body reactions H + CH₃ + M → CH₄ + M and CH₃ + CH₄ + M → C₂H₆ + M at low pressure (Van den Bergh 1976; Troe 1977). The detection of extensive polar emissions by Broadfoot et al. (1979) suggests that a large flux of energetic particles precipitates into the upper atmosphere. This magnetospheric interaction can provide a large source of atomic hydrogen and possibly hydrocarbons. In this paper we assess the possible importance of this interaction on the Lα albedo and hydrocarbon abundances observed by Voyager.
II. PHOTOCHEMICAL MODEL

The details of the photochemical model were presented in Tables 2–5 in Strobel (1973), whose notation we follow. The standard model atmosphere, model A, is shown in Figure 1. (We also consider a colder isothermal atmosphere, model B, with temperature equal to 150 K, as described in Strobel 1973.) Altitude 0 km corresponds to a neutral number density of \( 1 \times 10^{15} \text{ cm}^{-3} \). The model assumes a bulk He/H\(_2\) ratio equal to 0.11 by volume. We adopt a CH\(_4\)/H\(_2\) mixing ratio of 1.7 \( \times 10^{-3} \), as required to interpret the visible and near-infrared CH\(_4\) bands of Jupiter (Sato and Yung 1979). The temperature at \( z = 0 \) km is 110 K and varies linearly with \( z \) to 385 K at \( z = 500 \) km. This choice is consistent with the Voyager 1 IR results in the 0–150 km region (Hanel et al. 1979). Above this height, the temperature rises to an asymptotic value of 1200 K at \( \sim 1500 \) km. The vertical structure of the upper atmosphere is described by the simple analytic representation of Bates and Patterson (1961). In a one-dimensional photochemical model vertical transport for long-lived species is conveniently described by eddy diffusion. The magnitude of the eddy diffusion coefficients \( K(z) \) in the lower stratosphere is constrained by the requirement that it be compatible with the NH\(_3\) and PH\(_3\) photochemical destruction rate (Strobel 1977) and the CO abundance in the lower stratosphere (Strobel and Yung 1979). In the upper stratosphere, estimates of mixing rates can be derived from the L\(_2\) albedo of the planet (Wallace and Hunten 1973; Carlson and Judge 1976), if solar radiation determines the production rate of H. However, in view of the large variability of the observed L\(_2\) brightness, other factors may contribute. Eddy mixing in the upper atmosphere is considered an adjustable parameter in this work. The eddy diffusivity profile is expressed as

\[
K(z) = \frac{K_1(z)K_2}{K_1(z) + K_2},
\]

where

\[
K_1(z) = K_0 \left( \frac{n(0)}{n(z)} \right) \gamma.
\]

\( n(z) \) is the number density of the atmosphere at \( z \), and \( \gamma \) is a dimensionless number of order unity which measures the rate of increase of \( K_1(z) \) with altitude. Realistic choices of the constants \( K_0 \) and \( K_2 \) for the Jovian atmosphere require \( K_2 > K_0 \). Hence, in the lower atmosphere \( K(z) \approx K_1(z) \). In the upper atmosphere \( K_1(z) \gg K_2 \) and in this limit \( K(z) \approx K_2 \). The functional form of \( K(z) \) was chosen to ensure continuous derivatives everywhere and to limit \( K(z) \) as \( z \to \infty \) to be much less than the molecular diffusion coefficients.

The major differences between the previous and the current models are summarized in Table 2; they represent the most important updates to the photochemical model since 1974. The adoption of the extremely slow reaction rate for R10 creates a problem as to the fate of C\(_3\)H\(_3\) radicals in Jupiter’s atmosphere. Since reaction R9 is much faster than R10 at all altitudes,

\[
C_3H_3 + H \rightarrow C_2H_2 + H_2,
\]

(R9)

FIG. 1.—Number density and temperature profile for model A
the catalytic cycle of R8 + R9 is essentially unbroken and no significant conversion of C2H2 to C2H4 results (cf. Strobel 1973). We did not include a reaction suggested by Prasad, Capone, and Schneck (1975),

\[ \text{C}_2 \text{H}_3 + \text{C}_2 \text{H}_2 \rightarrow \text{C}_4 \text{H}_4 + \text{H}. \] (3)

The heats of formation of C2H3 and C4H4 are not accurately enough known to determine whether this reaction is exothermic or endothermic. Even if this reaction were exothermic, it is estimated to be slow at Jovian temperatures, since its preexponential factor is \( \sim 10^{-12} \text{ cm}^{-3} \text{ s}^{-1} \) with an activation energy of \( \sim 2 \) kcal mole\(^{-1}\) (Benson and Haugen 1967). We should also point out that Prasad, Capone, and Schneck (1975) did not treat the photochemistry of C2H4 produced in reaction (3) to determine whether it is recycled back to C2H2.

The photolysis of C2H2 is not completely understood, but Payne and Stief (1976) estimate that the quantum yield for C2H is \( \sim 0.1 \). The subsequent chemistry of C2H has recently been investigated by Laufer and Bass (1979). From their laboratory results, C2H should react preferentially with H2 in the stratosphere to form C2H2 and H. The net result of C2H2 is

\[ \text{H}_2 + \text{e} \rightarrow 2 \text{H} + e, \] (5)

\[ \text{H}_2 + \text{e} \rightarrow \text{H}^+ + \text{H} + 2e, \] (6)

\[ \text{H}_2 + \text{e} \rightarrow \text{H}_2^+ + 2e, \] (7)

followed by

\[ \text{H}^+ + \text{H}_2 \rightarrow \text{H}_3^+ + \text{H}, \] (8a)

\[ \text{H}_2^+ + \text{H}_2 \rightarrow \text{H}_3^+ + \text{H}, \] (8b)

\[ \text{H}_3^+ + \text{e} \rightarrow \text{H}_2 + \text{H}. \] (9)

Detailed modeling (Gladstone and Yung 1979) of the auroral observations by Broadfoot et al. (1979) suggests that the globally averaged flux of hydrogen atoms produced in the auroras could greatly exceed \( \phi_0 \).
Hydrogen atoms are destroyed mainly by
\[
\text{CH}_3 + H + M \rightarrow \text{CH}_4 + M, \quad (R5)
\]
\[
H + H + M \rightarrow H_2 + M, \quad (R7)
\]
and the \( \text{C}_2\text{H}_2 \) catalytic cycle
\[
\text{C}_2\text{H}_2 + H + M \rightarrow \text{C}_2\text{H}_3 + M, \quad (R8)
\]
\[
\text{C}_2\text{H}_3 + H \rightarrow \text{C}_2\text{H}_2 + H_2, \quad (R9)
\]
net \( H + H \rightarrow H_2 \).

R5 is the most important reaction for destruction of hydrogen. R8 and R9 become important below the \( r(L_\text{IX}) = 1 \) level for \( \text{CH}_4 \). R7 limits the buildup of excessively large number densities of hydrogen.

The effect of energetic particles on the hydrocarbons is less clear. If the energy of the incident electrons exceeds \( 10^5 \) eV, most of the particles are stopped below the homopause, where they can dissociate \( \text{CH}_4 \). Direct reactions, such as
\[
\text{CH}_4 + e^- \rightarrow \text{CH}_i + H + e, \quad (10)
\]
\[
\text{CH}_4 + e^- \rightarrow \text{CH}_4 + + e, \quad (11)
\]
\[
\text{CH}_4 + + e^- \rightarrow \text{CH}_3 + H, \quad (12)
\]
are not important since \( C/H \approx 10^{-3} \). Secondary processes via a \( L_\text{IX} \) photon could become marginally important:
\[
H_2 + e \rightarrow H^* + H + e, \quad (13)
\]
\[
H^* \rightarrow H + h\nu(L_\text{IX}), \quad (14)
\]
\[
\text{CH}_4 + h\nu(L_\text{IX}) \rightarrow \text{CH}_2 + H_2. \quad (15)
\]

Probably most important is the following sequence of reactions based on Munson and Field (1969) and Huntress (1977):
\[
\begin{align*}
H_2 + e & \rightarrow H^* + H + 2e, \quad (7) \\
H^* + H_2 & \rightarrow H_3^* + H, \quad (8) \\
H_3^* + \text{CH}_4 & \rightarrow \text{CH}_3^* + \text{H}_2, \quad (16) \\
\text{CH}_5^* + \text{C}_2\text{H}_2 & \rightarrow \text{C}_3\text{H}_5^* + \text{H}_2 \quad \quad (16a) \\
\text{CH}_4^* + \text{C}_2\text{H}_4 & \rightarrow \text{C}_2\text{H}_5^* + \text{CH}_3 \quad \quad (17a) \\
\text{C}_2\text{H}_5^* + \text{C}_2\text{H}_2 & \rightarrow \text{C}_3\text{H}_5^* + \text{CH}_4 \quad \quad (17a) \\
\text{C}_2\text{H}_5^* + \text{C}_2\text{H}_4 & \rightarrow \text{C}_3\text{H}_5^* + \text{CH}_4 \quad \quad (17b) \\
\text{C}_2\text{H}_5^* + \text{C}_2\text{H}_4 & \rightarrow \text{C}_3\text{H}_5^* + \text{CH}_4 \quad \quad (17b)
\end{align*}
\]

Recombination of these complex hydrocarbon ions will lead to the formation of a variety of heavier hydrocarbons. Until further laboratory kinetics studies become available, we can only consider this scheme for additional destruction of \( \text{CH}_4 \) and subsequent production of \( \text{C}_2\text{H}_6 \) and \( \text{C}_2\text{H}_5 \) in a qualitative manner:
\[
\text{C}_4\text{H}_7^* + e \rightarrow \text{C}_2\text{H}_2, \text{C}_2\text{H}_4, \text{C}_2\text{H}_6, \text{etc.} \quad (17c)
\]
is due solely to solar EUV radiation, estimated by Strobel (1973) to be $7 \times 10^{10}$ atoms cm$^{-2}$ s$^{-1}$. The C series explores the consequence of atomic hydrogen production associated with energetic particle precipitation observed by Broadfoot et al. (1979). The possible impact of reactions (17c) on the abundances of C$_2$H$_6$ and C$_2$H$_2$ is investigated in the D runs. The net result is enhanced dissociation of CH$_4$, which is equivalent to an increased incident solar flux.

Our discussion of the numerical results will concentrate on observable constituents: C$_2$H$_6$, C$_2$H$_2$, and H. Figure 2 illustrates altitude profiles for the major hydrocarbon species computed in model A13 with solar UV radiation as the only source and an "average" Lz reflectivity (cf. Fig. 5). The results would have been a plausible prediction for the Voyager encounter. The eddy diffusion coefficients were $K_0 = 10^3$ cm$^2$ s$^{-1}$ and $K_2 = 10^7$ cm$^2$ s$^{-1}$. Figure 3 shows the dependence of C$_2$H$_6$ on the choice of various input parameters. The C$_2$H$_6$ concentration increases with higher $K$ in the upper atmosphere and lower $K$ at the lower boundary, with lower temperatures in the inversion region, and enhanced production by particle precipitation. The C$_2$H$_6$ dissociation rate is not neglig-

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### TABLE 3

**SUMMARY OF INPUT ASSUMPTIONS FOR MODEL RUNS**

<table>
<thead>
<tr>
<th>Model</th>
<th>Model Atmosphere</th>
<th>$K_0$</th>
<th>$K_2$</th>
<th>$\phi_{en}$</th>
<th>Solar Lz Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>A11</td>
<td>A</td>
<td>1 (3)</td>
<td>1 (5)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>A12</td>
<td>A</td>
<td>1 (3)</td>
<td>1 (6)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>A13</td>
<td>A</td>
<td>1 (3)</td>
<td>1 (7)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>A14</td>
<td>A</td>
<td>1 (3)</td>
<td>1 (8)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>A15</td>
<td>A</td>
<td>1 (3)</td>
<td>1 (9)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>A21</td>
<td>A</td>
<td>3 (2)</td>
<td>1 (5)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>A22</td>
<td>A</td>
<td>3 (2)</td>
<td>1 (7)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>A23</td>
<td>A</td>
<td>3 (2)</td>
<td>1 (9)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>B11</td>
<td>B</td>
<td>1 (3)</td>
<td>1 (5)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>B12</td>
<td>B</td>
<td>1 (3)</td>
<td>1 (6)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>B13</td>
<td>B</td>
<td>1 (3)</td>
<td>1 (7)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>B14</td>
<td>B</td>
<td>1 (3)</td>
<td>1 (8)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>B15</td>
<td>B</td>
<td>1 (3)</td>
<td>1 (9)</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

$^a$ $K_0$ and $K_2$ are as defined by equations (1) and (2) in units of cm$^2$ s$^{-1}$. The parameter $\phi_{en}$ is the total column production of hydrogen atoms in the units $7 \times 10^8$ atoms cm$^{-2}$ s$^{-1}$. The solar Lz flux refers to the integrated flux of photons at 1 AU in units $3.5 \times 10^{11}$ photons cm$^{-2}$ s$^{-1}$. Model A is a warm atmosphere as described in Figure 1. Model B is an isothermal atmosphere at 150 K as described in Strobel 1973. The numbers a,b read as $a \times 10^b$.

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### IV. DISCUSSION OF RESULTS

A fairly comprehensive set of models has been generated to understand the sensitivity of the major observable constituents, C$_2$H$_6$, C$_2$H$_2$, and H to the input parameters. The essential features of the models are summarized in Table 3. The A and B series are designed to explore the dependence on eddy diffusion coefficient and temperature when the production of H...
Available in comparison to the mixing rate for small \( K \). With the \( \text{CH}_4 \) absorption cross sections based on Mount, Warden, and Moos (1977), we find that \( \text{CH}_4 \) does not effectively shield \( \text{C}_2\text{H}_6 \) from dissociation as in previous calculations (Strobel 1973, 1974). Consequently the \( \text{C}_2\text{H}_6 \) density is sensitive to \( K(z) \) in the lower stratosphere. Also, at the lower boundary, downward mixing of \( \text{C}_2\text{H}_6 \) from its source region is a major sink. Our calculations suggest an upper limit on the \( \text{C}_2\text{H}_6 \) mixing ratio of \( 3 \times 10^{-6} \) at the \( p = 10^{-2} \) atm level. We emphasize that our lower mixing ratio (compared to the large mixing ratio of Strobel 1974 with \( \varphi = 0 \) lower boundary condition) results from the boundary condition (5) and the larger \( \text{C}_2\text{H}_6 \) dissociation rate. According to Tokunaga, Knacke, and Owen (1976) their observations would require an inversion layer at \( 190 \) K if the \( \text{C}_2\text{H}_6 \) mixing ratio were only \( \sim 5 \times 10^{-7} \). However, an inversion layer at \( 150 \) K requires a mixing ratio of \( 10^{-5} \) to be in accord with their observations. Indeed, Orton and Aumann (1977) prefer a warm inversion layer with \( T > 155 \) K and increasing with height to \( \sim 200 \) K at \( p = 10^{-4} \) atm. The results of Figure 3 in conjunction with mixing ratios of \( \text{C}_2\text{H}_6 \) inferred from \( \text{Voyager} \) IR data may indicate sources of \( \text{C}_2\text{H}_6 \) and \( \text{C}_2\text{H}_2 \) in addition to solar UV dissociation (Hanel 1979). It is important to recognize the time constants for various processes in the upper atmosphere. The lifetime associated with the column integrated hydrocarbon abundance (\( \text{C}_2\text{H}_6 + \text{C}_2\text{H}_2 \)) exceeds 100 yr and thus should not vary significantly in response to changes in auroral activity and the column integrated atomic hydrogen abundance. The lifetime associated with the column integrated atomic hydrogen abundance is of order 100 days. Steady state calculations of \( \text{C}_2\text{H}_6 \) and \( \text{C}_2\text{H}_2 \) densities in the lower stratosphere for \( \text{Voyager} \) conditions may be underestimated as a consequence of the large H atom concentration which suppresses recombination of \( \text{CH}_3 \) radicals to \( \text{C}_2\text{H}_6 \).

Figure 4 shows the distribution of H in a number of models. The abundance of H above the methane absorption layer is a sensitive function of the eddy diffusion coefficient in the upper atmosphere \( K_2 \) and the flux of hydrogen atoms produced from particle precipitation. The reflectivity \( 4I/F_J \), as defined by Wallace and Hunten (1973), is calculated for the various models and summarized in Figure 5. The curves A and B roughly reproduce the results previously obtained by Wallace and Hunten (1973), but
are consistently higher by ~30%. This may be partly due to the use of a Rayleigh phase function rather than an isotropic phase function for scattering of Lx photons by H atoms. We conclude that the Lx albedo increases slightly with temperature, and the exceedingly high temperature (~1200 K) in the thermosphere of model A has practically no effect. The reason is that most of the photons are scattered deep in the atmosphere from the Lorentz wings of the Lx line. The curve C was computed to test the sensitivity of the brightness of 14 kR. Although no measurement of the solar Lx intensity was made during the Voyager encounter, a solar Lx flux of 3.75 × 10^{11} photons cm^{-2} s^{-1} Å^{-1} is estimated on the basis of the solar 10.4 cm flux (Vidal-Madjar 1975). A slightly higher flux of 5.1 × 10^{11} photons cm^{-2} s^{-1} Å^{-1} was measured by Rottman and Mount (1980) on 1979 June 5. Only a small fraction of the 14 kR can be due to direct excitation by energetic particles. Our reasons are twofold. First, the night-side Lx intensity is less than 1 kR (Sandel et al. 1979). Second, the center-to-limb variation of the observed Lx intensities is in good agreement with that predicted for resonance scattering, but not with that due to particle excitation as shown in Figure 6 (Canahan and Zipf 1977; Gladstone and Yung 1979). The center-to-limb variation of Lx intensities could offer additional confirmation of the scattering in the Lorentz wing. The dashed line in Figure 6 was computed by arbitrarily restricting the scattering to within 6 Doppler units from the core and is not in good agreement with observation. However, we need higher-quality data before we can settle this issue.

The observed variability of the Lx brightness (cf. Table 1 and Bertaux et al. 1979) suggests that the lifetime of atomic hydrogen in the Jovian thermosphere is less than a year. This implies an eddy diffusion coefficient at the homopause of more than ~10^6 cm^2 s^{-1}. From the results of Figure 5 we are forced to conclude that the Voyager Lx brightness requires energetic particle dissociation of H_2 rather than a very low eddy diffusion coefficient. The principal problem in understanding the variability of Jupiter's upper atmosphere is the Pioneer 10 UV photometer results (Carlson and Judge 1974). From Table 1 we note the reflectivity varies by a factor of 2 about a central value of 0.4 Å, with the exception of the Pioneer 10 results. From Figure 5 we infer that modest changes in H production, temperature, and eddy diffusion coefficient would easily explain this factor of 2 variability. However, the very large increase in K_2 and possibly temperature decrease required to understand Pioneer 10 UV results is puzzling. It should be noted that the Pioneer results are at least internally self-consistent. Assuming a He/H_2 ratio equal to 0.11 (Hanel et al. 1979), a very high eddy diffusion coefficient (K_2 ≳ 10^8 cm^2 s^{-1}) is required to account for the Pioneer observation of 5.2 R emission in the short-wavelength channel. Broadfoot et al. (1979) reported an upper limit of 0.1 R for the 584 Å resonance emission of He. If confirmed, this would imply a much lower K_2 ≳ 10^5 cm^2 s^{-1}. It is conceivable that the atmosphere had undergone orders of magnitude of change in K_2 in the last few years. But until further evidence becomes available on the variability of the upper atmosphere, the Pioneer 10 results should be taken with reservation.

V. CONCLUSIONS

The high disk-averaged Lx emission observed by Broadfoot et al. (1979) can be explained by resonance scattering of sunlight by hydrogen atoms. These observations require a larger source of H than solar EUV radiation. We suggest precipitation of magnetospheric particles to dissociate H_2 and heat the upper atmosphere and estimate an average column production rate of at least 7 × 10^9 atoms cm^{-2} s^{-1}, about 10 times more than solar EUV can produce. This is consistent with auroral emissions observed by Voyager. A low eddy diffusion coefficient alone cannot account for the observed Lx brightness; our calculations suggest K_2 ≳ 10^6 - 10^7 cm^2 s^{-1}. A value of K_2 ≳ 10^6 requires an H column production rate of 7 × 10^9, whereas, K_2 ≳ 10^7 requires a production rate of ~7 × 10^{10} to obtain the Voyager observed albedo. For the average reflectivity, 4I/F_0 ≈ 0.4 Å in Table 1, we infer K_2 ≳ 10^7 cm^2 s^{-1} for solar production of H only.

To account for the inferred abundances of the hydrocarbons (C_2H_6 + C_2H_2) our updated model
requires a low eddy coefficient at the tropopause (10^{-1} \text{ atm}) \( K_0 \approx 10^3 \text{ cm}^2 \text{s}^{-1} \) and a fairly high eddy coefficient at the homopause \( K_2 \approx 10^7 \text{ cm}^2 \text{s}^{-1} \). Since the lifetime for total (column integrated) \( c_2 \) compounds in the stratosphere exceeds 10 yr, the values for \( K_0 \) and \( K_2 \) deduced from our calculations are an average over this period of time. This is consistent with average conditions inferred from \( Lz \) albedo observations. We also suggest that magnetospheric particle precipitation may produce \( \text{CH}_4 \) dissociation rates in excess of solar UV radiation during a certain portion of this period when solar activity is high.

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