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Energy deposition and primary chemical products in Titan's upper atmosphere

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Abstract

Based on Cassini observations, solar photons are the dominant energy source in Titan's upper atmosphere. These dissociate and ionize nitrogen and methane, and drive the subsequent complex organic chemistry. In order to quantify the role of solar radiation in the primary chemical production, we performed detailed calculations for the energy deposition of photons and photoelectrons and we validated our results with Cassini measurements for the electron fluxes and the EUV/FUV emissions. Our results demonstrate that use of high-resolution cross sections for the neutral N_2 photodissociation provides a significantly different picture of energy deposition compared to results obtained from low-resolution cross sections. This effect has further ramifications for the altitude production profiles of the ions and neutral fragments.

Methods

Photons with wavelengths $\lambda < 1500$ Å are absorbed in Titan's upper atmosphere by N_2 and CH_4. We perform calculations of energy deposition under spherical geometry and calculate the production rates for neutral and ion photolysis fragments. For N_2, we use high-resolution theoretical calculations for the strongly structured neutral dissociation cross sections [1, 2, 3], which we convolute with a high resolution solar spectrum. The new cross sections allow more photons to penetrate at lower altitudes, thus enhancing the photolysis of CH_4 (Fig. 1). For the energetic electrons we developed a model of photoelectron energy degradation based on the local deposition approximation, which generates electron distributions that are in good agreement with calculations including transport [4], in the altitude region below 1200 km, where the effects of transport are negligible.

Results & Conclusions

We compare our results with Cassini measurements of suprathermal electron distribution from CAPS [5], and EUV/FUV emission from UVIS [6, 7]. Our calculated suprathermal electron fluxes are in good agreement with the measured fluxes during the T40 flyby (Fig. 2), while the calculated emission rates from excited N_2 states, induced by both photons and suprathermal electrons, are in excellent agreement with the UVIS measurements from the TB flyby (Table 1). Thus, the validation of the model calculations against Cassini observations confirms the correct reproduction of the energetic processes in Titan's upper atmosphere by our calculations. The resulting production rates for the photolysis fragments have the signature of the energy sources producing them: photoionization provides the peak close to 1000 km, while the electron impact by secondary electrons provides the shoulder in the production rates observed between 700 and 800 km

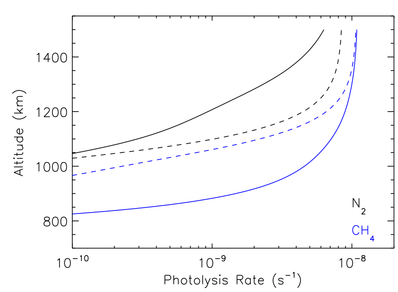

Figure 1: Photolysis of N_2 (black lines) and CH_4 (blue lines) for the cases of high (solid lines) and low resolution (dashed lines) cross sections for molecular nitrogen in the spectral region between 80 and 100 nm. The solar zenith angle for these calculations is 60°.

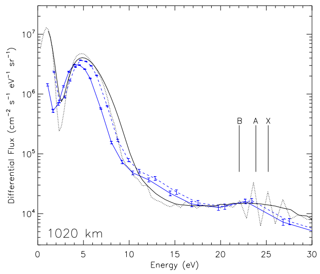

Figure 2: Comparison among measured and calculated differential fluxes at 1020 km. The dotted and solid lines correspond to the model results for the high resolution energy spectrum and the calculated spectrum convoluted to the CAPS energy resolution. The blue lines correspond to the measurements assuming a spacecraft potential of -0.5 ev (solid blue line) and -1.2 eV (dashed blue line). The three vertical lines mark the energy of photoelectrons produced by the photoionization of N_2 in the X, A and B states.

(Fig. 3). Thus, both energy sources need to be considered for the correct description of the primary photolysis products. Our results can be used as basis for any further photochemical calculations.

Acknowledgements

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Table 1: Calculated and observed emissions from Titan's disk due to photons (Ph) and electrons (El).

Band/Line		MODEL		UVIS
(Å)	Ph	El	Total	(Rayleigh)
1085	1.92	0.35	2.27	2.31
1135	0.88	0.09	0.96	1.33
1200	6.62	1.03	7.65	6.8
1243	0.75	0.26	1.01	0.6
1493	2.35	0.73	3.08	3.0
1743	0.90	0.87	1.77	1.6
Total NI	14.70	3.64	18.34	16
LBH	-	41.24	41.24	43±7

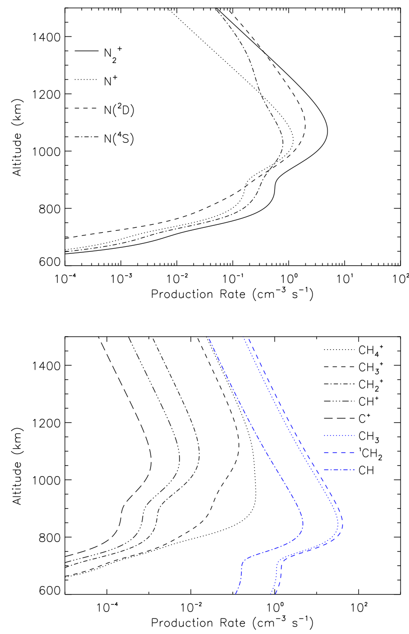

Figure 3: Daily-averaged production rates for different dissociation products of N_2 and CH_4 due to photons and suprathermal electrons.

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