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The Ionization Lifetime of Carbon and the Dissociative Lifetime of CO as Determined by *GALEX* FUV Observations of Comet C/2004 Q2 (Machholz)

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Abstract

We have measured the ionization lifetime of ground state atomic carbon using wide-field far ultra-violet images of comet C/2004 Q2 (Machholz) recorded by the Galaxy Evolution Explorer (*GALEX*) satellite. The measured lifetime is $7.1 - 9.6\times10^5$ s (ionization rate of $1.0 - 1.4\times10^{-6}$ s^{-1}) when scaled to 1 AU. This lifetime is short compared to that calculated for solar photoionization alone, suggesting that solar wind ionization processes contribute significantly, particularly for a comet embedded in the slow solar wind. Preliminary results suggest a similar effect is occurring for CO, which has a calculated photodissociative lifetime of 5×10^5 s, but which our data suggests lives on the order of 3×10^5 s.

1. Introduction

Comets are excellent laboratories for the study of fundamental atomic and molecular properties, such as the lifetime against ionization and dissociation. Due to their small size and volatile content, comets deliver material into the interplanetary medium with almost no perturbation from the comet nucleus itself. For a comet with a production rate in the range of Machholz, the motion of neutral gas is entirely ballistic at distances greater than a few thousand kilometers from the nucleus. The bulk radial outflow velocity of material from comets has been studied using the observed line shape of the OH 18 cm transition (e.g., Tseng et al., 2007). For most comets at 1 AU, the outflow velocity of material is on the order of 1 km s^{-1}. Quantum mechanical calculations of the excess energy of dissociation show that for the major carbon-containing molecules the ejection velocity of carbon is within 25% of 4 km s^{-1}. The coincidence of carbon ejection velocities and their large value compared to the bulk outflow velocity makes it possible to extract the lifetime of carbon using a simple two-component Haser model.

The data we use, recorded by the Galaxy Evolution Explorer (*GALEX*) satellite, also contain emission from the Fourth Positive band system of CO in the same far ultraviolet (FUV) bandpass. After characterizing and removing the C I emission, we are able to study isolated CO emission and measure its total lifetime against dissociative and ionization processes.

2. Results

GALEX recorded an FUV image of comet Machholz on 2005-01-30 UT 03:04:42. Figure 1 shows radial profiles of the image after background subtraction. The behavior of the profiles at cometocentric distances $> 3\times10^5$ km is highly sensitive to the residual airglow in the upper atmosphere, detected by *GALEX*. Two independent techniques, which gave comparable answers, were used to remove the airglow (Morgenthaler et al., 2011). As discussed in §1, a simple two-component Haser model provides an excellent physical description of the emission. The lifetime of carbon is then the daughter scale length divided by the 4 km s^{-1} average ejection velocity. The results, compared to lifetimes (rates) of the major ionization processes known to occur in the interplanetary medium for quiet sun, slow solar wind conditions are shown in Table 1. The calculated lifetimes (rates) are taken from Rubin et al. (2009). Note that solar wind proton charge exchange is the dominant mechanism.

Figure 2 shows the *GALEX* grism-mode observations of comet Machholz after subtraction of C I emission from two primary parent molecules: CO and CH_4. The production rates of these parent molecules were taken from the literature (Bonev et al., 2009; Kobayashi & Kawakita, 2009), with final adjustments made using the inner portions of the image-mode ra-

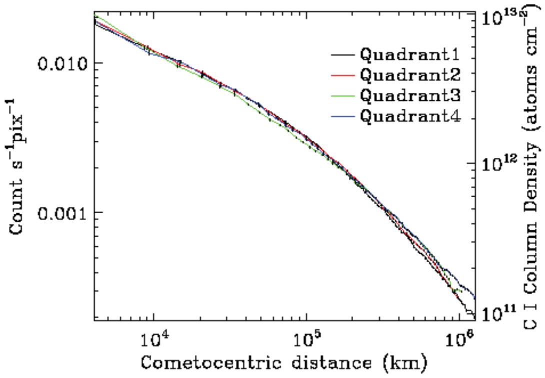

Figure 1: Quadrant-by-quadrant radial profiles of the *GALEX* FUV image of comet C/2004 Q2 (Machholz). Quadrant 4 is centered on the dust tail.

Table 1: Carbon Ionization Lifetimes (Rates)

Process	1 AU Lifetime $\times 10^5$ s (Rate $\times 10^{-6}$ s^{-1})
$C + h\nu \rightarrow C^+ + e^-$	24 (0.41)
$C + H^+ \rightarrow C^+ + H$	17 (0.59)
$C + e^- \rightarrow C^+ + 2e^-$	48 (0.21)
Total predicted	8.2 (1.21)
Measured	7.1 – 9.6 (1.0 – 1.4)

dial profile (Morgenthaler et al., 2011). The CO solar photodestruction lifetime calculated by Tozzi et al. (1998) is 5×10^5 s. Huebner et al. (1992) quote a value of 13×10^5 s. Preliminary results show the *GALEX* measured distribution is $\sim 3 \times 10^5$ s, which is consistent with the Tozzi et al. photo rates when combined with a contribution from solar wind processes (Rubin et al., 2009). Given the prevalent use of the Huebner et al. value in the current literature, this is a significant result. Future work will include computation of the accuracy of our CO lifetime estimate using simultaneous analyses of the *GALEX* image and grism-mode data. *GALEX* also detected C and CO emission from comets 8P/Tuttle and C/2007 N3 (Lulin). Machholz, Tuttle, Lulin, 9P/Tempel 1, and 73P/Schwassmann-Wachmann 3 (B and C) were also observed in the NUV, with clear detections of extended emission from CS and OH. All these observations will be used to independently measure lifetimes and production rates of C, CO, CS and OH.

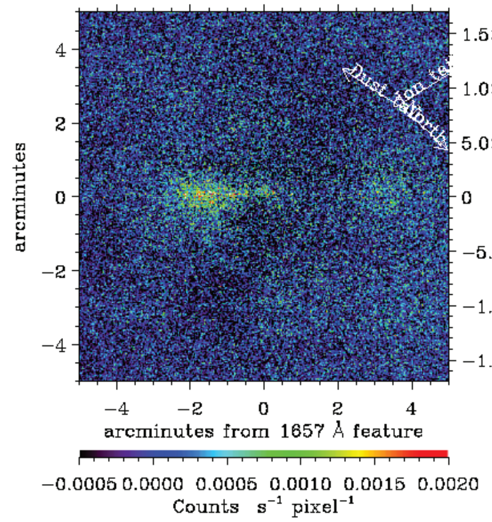

Figure 2: *GALEX* grism-mode FUV image after subtraction of C I 1561 Å and 1657 Å emission. The residual is more than 80 lines of the CO Fourth Positive band system. Dispersion runs left to right.

Acknowledgments

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