IO: ESCAPE AND IONIZATION OF ATMOSPHERIC GASES

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16. Abstract

Progress in obtaining a description for the partitioning of the major ion densities throughout the torus is reported. This description is required as input information for the Io oxygen and sulfur cloud models. In the radial interval from 4.9 to 5.4 R_j ion partitioning information obtained from Bagenal (1983) is used to initially explore the impact of charge exchange reactions between the neutral gas clouds and the plasma torus ions. Because of the spatial distribution of torus ions, these reactions may be able to introduce a magnetic longitudinal effect in the plasma torus properties. Modeling efforts for the Io oxygen and sulfur clouds and for the sodium cloud data scheduled during the second half of this project year are also discussed.

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I. SUMMARY OF RESEARCH PROGRESS FIRST AND SECOND QUARTER

Introduction

Emphasis during the first two quarters has been carefully limited and, in particular, restricted to seeking the spatial distribution of ion densities in the Io plasma torus and to determining the impact of these ions on the OI and SI cloud models. The specification of these ion densities throughout the plasma torus is required as input information for the oxygen and sulfur cloud models, without which calculations including the effects of charge exchange reactions cannot be performed. Because this information has been only partially available (with more information expected in the near future), modeling efforts have, where possible, been conserved until the second half of the project year. Progress made in the first two quarters is summarized below.

Ion Partitioning Data

During the first two quarters, a two-dimensional (radial and vertical) description for the densities of the major ions in the plasma torus within the radial interval from 4.9 to 5.4 R_J was obtained from Bagenal (1983). These ion densities were determined from a recent re-analysis of the Voyager PLS data that properly accounted for the different vertical distributions of various ions and of the electrons along the magnetic field lines. The ion densities throughout the remaining plasma torus are to be approximately defined in the near future by combining an extended analysis of the Voyager PLS data by Bagenal (1983) with a new analysis of the Voyager UVS data undertaken by Shemansky (1983).

Impact of Charge Exchange Reactions

Using the limited ion partitioning data, the impact of charge exchange reactions between the neutral clouds and the plasma torus ions has been initially explored. The lifetime of atomic oxygen and sulfur in the plasma torus is determined by the charge exchange reactions and the electron impact ionization reactions summarized in Table 1. The charge exchange cross sections are velocity dependent and are determined in accordance with Johnson and Strobel (1982) and Johnson (1983). Using the ion data of Bagenal in the radial interval of 4.9 to 5.4 R_J together with these cross sections to deduce

TABLE 1

Charge-Exchange and Electron Impact Reactions for Neutral Oxygen and Sulfur

	Reaction
1.	$O^+ + O \rightarrow O + O^+$
2.	$O^+ + S \rightarrow O(^3P) + S^+(^2P)$
	$\rightarrow O(^1D) + S^+(^2D)$
3.	$S^+ + S \rightarrow S + S^+$
4.	$S^+ + O \rightarrow S + O^+$
5.	$S^{++} + S \rightarrow S + S^{++}$
	$\rightarrow S^+(^4S) + S^+(3s,\ 3p^4;\ ^4P)$
6.	$S^{++} + O \rightarrow S^+(^2P) + O^+(^2D)$
	$\rightarrow S^+(^2D) + O^+(^2D)$
	$\rightarrow S^+(^2D) + O^+(^2P)$
	$\rightarrow S^+(^4S) + O^+(^2P)$
7.	$O^{++} + O \rightarrow O + O^{++}$
	$\rightarrow O^+(^4S) + O^+(2s,\ 2p^4;\ ^4P)$
	$\rightarrow O^+(^2D) + O^+(2s,\ 2p^4;\ ^4P)$
8.	$O^{++} + S \rightarrow O^+(^4S) + (S^+)^*$
	$\rightarrow O^+(^2D) + (S^+)^*$
	$\rightarrow O^+(^2P) + (S^+)^*$
	$\rightarrow O(^2D^\circ\ 3d,\ ^3P^\circ) + S^{++} \rightarrow O^+ + S^{++} + e$
9.	$S^{+++} + O \rightarrow S^{++}(3d,\ ^3P) + O^+(^4S)$
	$\rightarrow S^{++}(4s,\ ^3P) + O^+(^4S)$
	$\rightarrow S^+(^2P) + O^{++}(^3P)$
	$\rightarrow S^+(^2D) + O^{++}(^1D)$
	$\rightarrow S^+(^4S) + O^{++}(^1D)$
10.	$S^{+++} + S \rightarrow S^{++}(4p,\ ^3D) + S^+(^4S)$
	$\rightarrow S^{++}(3d,\ ^3P) + S^+(^2P)$
	$\rightarrow (S^{++})^* + S^+(^2D)$
	$\rightarrow (S^+)^* + S^{++}$
11.	$e + O \rightarrow O^+ + 2e$
12.	$e + S \rightarrow S^+ + 2e$
13.	$O^+ + e \rightarrow O + h\nu$
14.	$S^+ + e \rightarrow S + h\nu$

charge exchange rates and using the electron impact ionization rate of Smyth and Shemansky (1983), the lifetimes of OI and SI in the centrifugal plasma plane have been calculated and are compared for these two processes in Figure 1. As can be seen, the minimum charge exchange lifetimes at 5.2 R_j for OI and SI, occurring in the cool inner torus where the electrons have no ionizing capability, are comparable to the minimum electron impact lifetimes at 7.2 R_j occurring in the warm outer portion of the plasma torus.

The charge exchange lifetimes in Figure 1 are, however, effective only near the centrifugal plane as illustrated in the two-dimensional lifetime plots for OI ad SI shown respectively in Figure 2 and Figure 3. This occurs because ions are cool and thereby energetically confined close to the centrifugal plane. The temperature of the ions, however, increases rapidly as one moves from 5.2 R_j to Io's orbital position at 5.9 R_j. The charge exchange lifetimes will therefore be vertically more extended for radial displacements from Jupiter equal to or greater than the orbital position of Io. As the plasma torus oscillates about the satellite plane, charge exchange reactions may therefore introduce magnetic longitudinal effects in the plasma torus preferentially inside of Io's orbit. This longitudinal dependence could, however, be modified and even eliminated if a corotational lag of order 1% or more were present in the plasma torus. Corotational lags of order 6±4% have been attributed to the plasma torus at 5.9 R_j by Brown (1983), but may equally well be explained as strict corotational flow that is not azimuthally symmetric as noted by Barbosa and Kivelson (1983). Magnetic longitudinal variations in the ion emission brightnesses have however been measured by Morgan (1983) and may possibly be related to this longitudinal dependence of the ion source.

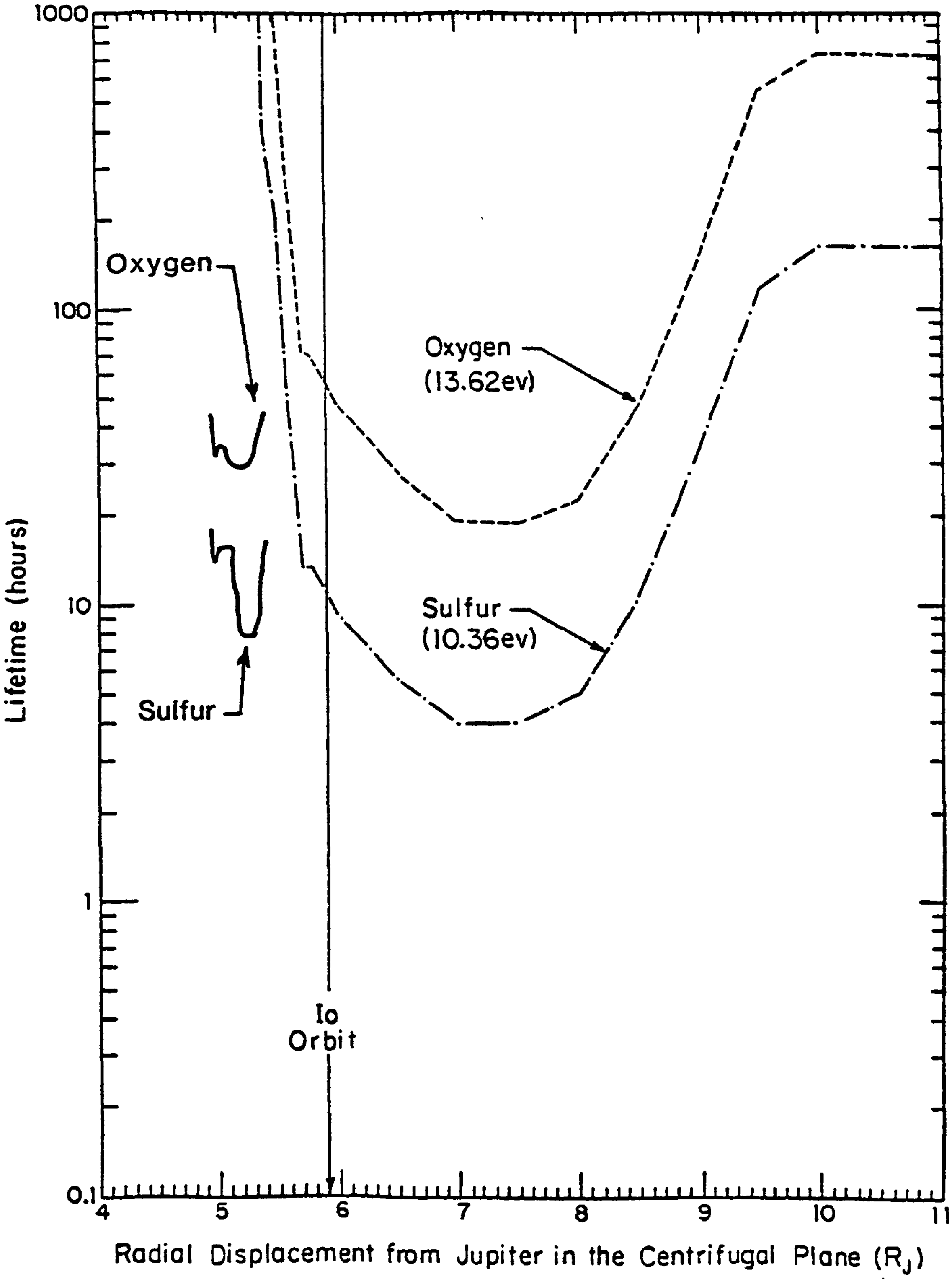

Figure 1. The lifetimes of OI and SI for electron impact ionization and charge exchange reactions of Table 1 are calculated in the centrifugal plane of the plasma torus as described in the text and shown separately. The solid contours between 4.9 and 5.4 R_J are for the charge exchange reactions.

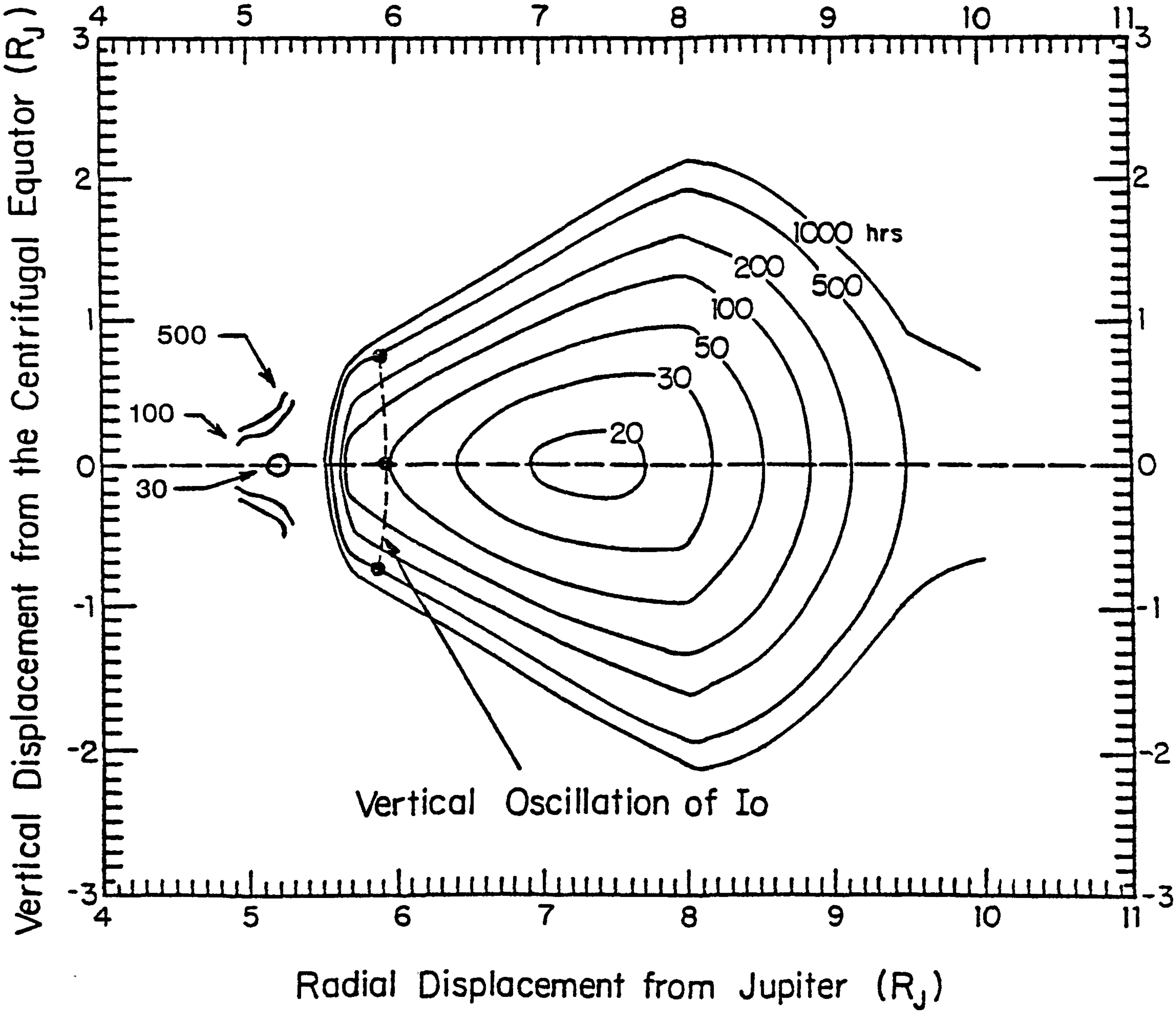

Figure 2. The lifetimes of OI for electron impact ionization and charge exchange reactions of Table 1 are calculated in the plasma torus as described in the text and shown separately. The heavier contours between 4.9 and 5.3 R_J are for the charge exchange reactions.

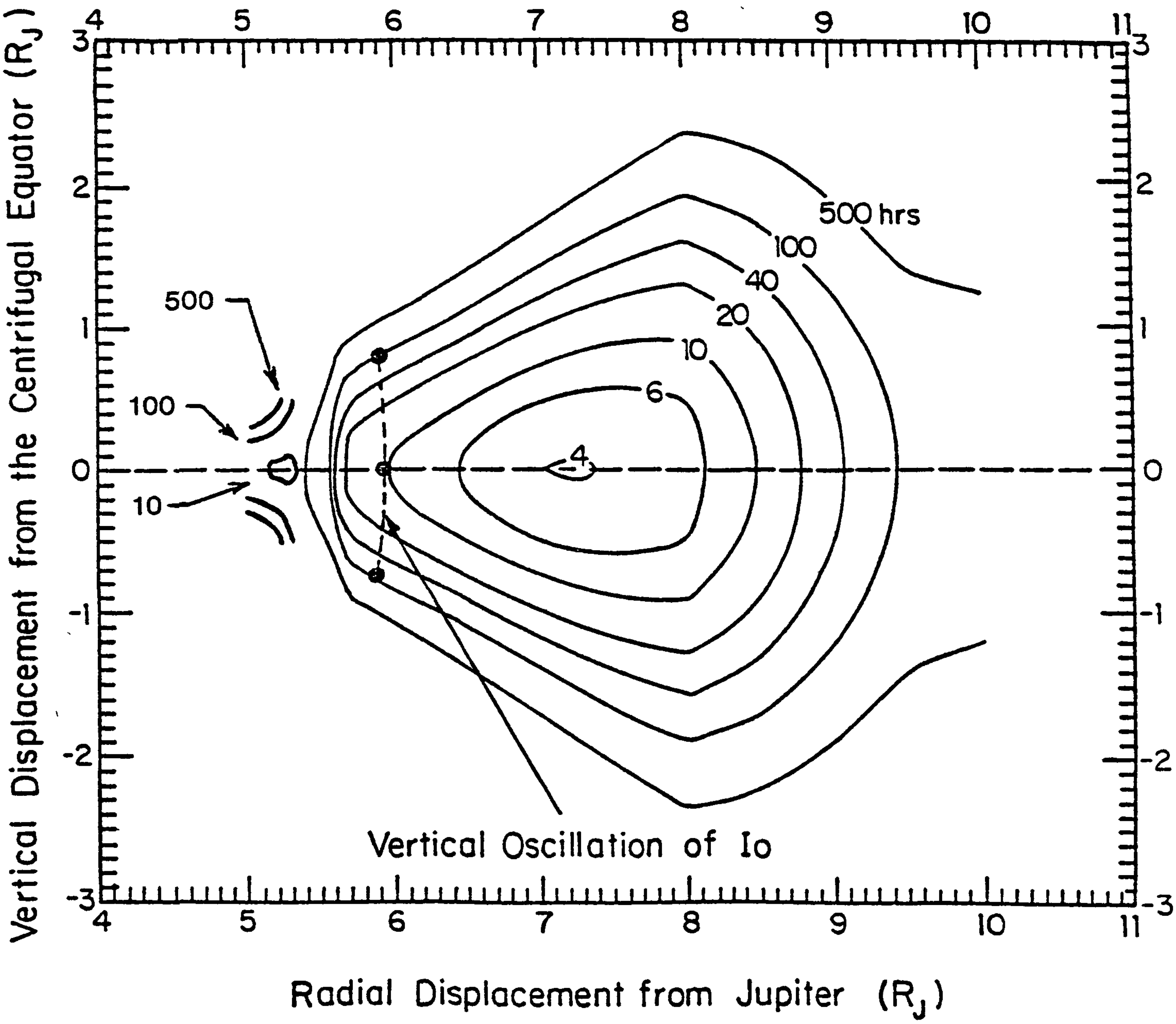

Figure 3. The lifetimes of SI for electron impact ionization and charge exchange reactions of Table 1 are calculated in the plasma torus as described in the text and shown separately. The heavier contours between 4.9 and 5.3 R_J are for the charge exchange reactions.

II. PROGRAM FOR THE NEXT TWO QUARTERS

Io Oxygen and Sulfur Cloud

Efforts in the last half of this project year will be directed toward (1) obtaining a distribution for the densities of the major ions in the plasma torus, (2) incorporating these ion densities in the model to calculate the lifetime of OI and SI and other relevant physical quantities describing ion input rates, and (3) performing model calculations to describe the spatial morphology of the neutral clouds and their impact on the plasma torus. As noted earlier, the ion densities will be sought from analyses of Bagenal (1983) and Shemansky (1983). Actions to improve the execution efficiency of our numerical models for OI and SI will also be undertaken.

Io Sodium Cloud

Model analysis for selected sodium D-line profile data will be performed in the last two quarters and consistency with atom ejection conditions appropriate to the directional features analyzed and explained by Pilcher et. al. (1983) will be investigated. A number of exploratory line profiles have been evaluated using the new sodium cloud model at AER that incorporates the oscillating plasma torus sink. These line profiles and others yet to be calculated will be used to select appropriate modeling basis functions for interpretation of the data. Limited model analysis will also be considered for selected slit intensity data as a second method of providing constraints for the modeling basis functions.

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