Monte Carlo Modeling of [O I] 630 nm Auroral Emission on Io. C. Moore, K. Miki, D. B. Goldstein, P. L. Varghese, L. Trafton, J. Zhang, *The University of Texas at Austin, TX 78712, (chris@cfdlab.ae.utexas.edu)*

Introduction: The interaction of Jupiter's plasma torus with Io's atmosphere produces an aurora with many distinct features. Unlike Earth's aurora which occurs mainly near the poles, Io's aurora is concentrated around the equator. Observations of Io's [O I] 630 nm aurora by Trauger *et al.* [1] and Retherford *et al.* [2] showed several distinct features including a limb glow, a bright spot in the wake, and the absence of appreciable emission on the upstream side of Io. Retherford *et al.* [2] offered an explanation for the brightness ratio observed for the north and south limb glows based on Io's position in the plasma torus which affected the electron column density above and below Io. Figure 1 shows Trauger's 1997 WFPC2 [O I] emission observation. In the present work a three-dimensional Monte Carlo model for the motion of electrons and excited oxygen atoms is used to simulate the electron flow around Io, electron-neutral collisions, and the resulting [O I] 630 nm emission. Electrons enter the domain across the polar boundaries with a thermal velocity parallel to the perturbed Jovian magnetic field; the bulk $\vec{E}\times\vec{B}$ drift velocity is neglected because the thermal velocity is almost two orders of magnitude greater. The simulation yielded a wake bright spot and no upstream spot.

Model: The computational domain of the simulation is a 6000 km cube with a 101x101x101 uniform Cartesian grid with Io at the center. The electrons are input randomly throughout both top and bottom polar planes and are given an initial Maxwellian energy distribution and a sine distribution for the velocity pitch angle with respect to the local magnetic field, as observed by Galileo. In general, Io's magnetic equator is inclined relative to Io's geodetic equator. This causes the wake feature to be inclined relative to the geodetic equator as seen in Figure 1. Figure 2 shows the 3-D domain of the simulation wherein the inclination of the magnetic field has been set to zero.

Since the time scale for electron motion is much smaller than the time scale of excited [O I] emission, the simulation proceeds in two distinct routines. The first is the excitation model in which the electrons move through the domain and possibly collide with SO_2 or O based on the energy dependent cross sections for the collision processes. The collisionally excited [O I] atoms are stored and then used as input for the second stage routine in which the excited O atoms are allowed to move in Io's gravitational field and either collide (and de-excite) with the atmosphere, or emit. Figure 3 shows a schematic of the model.

The simulation uses a stationary, pre-determined neutral atmosphere because the time scales for atmospheric changes are much longer than the time scales of the [O I] emission. Our model of Io's atmosphere takes into account the dependence of the SO_2 and O number density on longitude, latitude, and altitude. The altitude and longitude dependence are based on Wong and Johnson's models [3]. The latitude dependence is based on Strobel [4]. Io's volcanoes are accounted for by superimposing the flowfield properties of a pre-computed volcano from Zhang's existing model [5]. We distinguish between two different types of volcanoes: Pele-like and Prometheus-like. All 31 of the included volcanic plumes are treated as one or the other and all contain 95% SO_2 and 5% O.

In order to simplify the simulation, a pre-computed magnetic (and electric) field is used to dictate the movement of the electrons in the simulation. Combi's fields which include ion mass loading, ion neutral drag, and an intrinsic magnetic field for Io are used in the simulation [6]. Although this means the simulation is not entirely self-consistent, the simulation should still be reasonably accurate because Combi's model compares well with data from a Galileo flyby of Io.

Results: Figure 4 shows the energy deposition profile as seen from Earth, normalized by the peak value. Pele and Tvashtar are visible, as well as the wake. Figure 5 shows the [O I] emission profile from Earth. There is little upstream emission and the wake feature is present, but at a slightly lower altitude than observed by Trauger *et al.* [1]. The overall morphology of the emission was found to be relatively independent of the torus electron temperature. More detailed results can be found in Miki *et al.* [7]

It was found that virtually no 630 nm emission takes place where the neutral atmosphere is dense, despite the high number of excitation events and large amount of energy deposited by the electrons. This is because the molecular/atomic collision rate in the dense regions of the atmosphere is large compared to the Einstein-A coefficient and therefore an excited oxygen atom usually de-excites through collision before it has time to emit.

The absence of a 630 nm bright spot on the upstream side of Io can be partly explained by the magnetic mirror effect. The motion of Jupiter's magnetic field relative to Io perturbs the field in the vicinity of Io causing the field intensity to be higher upstream of Io and lower in the wake. The higher magnetic field upstream tends to deflect electrons, while the electrons tend to be trapped in the wake after a collision event. Figure 6 shows the fraction of electrons inserted along the top border that would reach a given location in the y=0 plane absent collisions. Note that only ~60% of electrons reach the upstream side of Io and that if an electron reaches Io's surface it is absorbed. Collisions would only tend to increase the number of electrons in the wake through trapping and ionization, and therefore would further decrease the upstream/downstream emission intensity ratio.

References: [1] Trauger, J.T., *et al.*, AAS-DPS abstract 1997DPS29.1802T. [2] Retherford *et al.* PhD dissertation, 2002, John Hopkins University. [3] Wong, M.C., and Johnson, R.E., JGR **101**, 23,243-23,254. [4] Strobel, D.F., and Wolven, B.C., Astrophys. Space Sci. **277**, 271-287. [5] Zhang, J., *et al.*, *Icarus* **163**, 182-197. [6] Combi, M.R., *et al.*, JGR **103**, 9071-9081. [7] Miki K., *et al*., Modeling of HST Observation of Auroral Emissions of Io in Eclipse, submitted to Icarus, 2004.

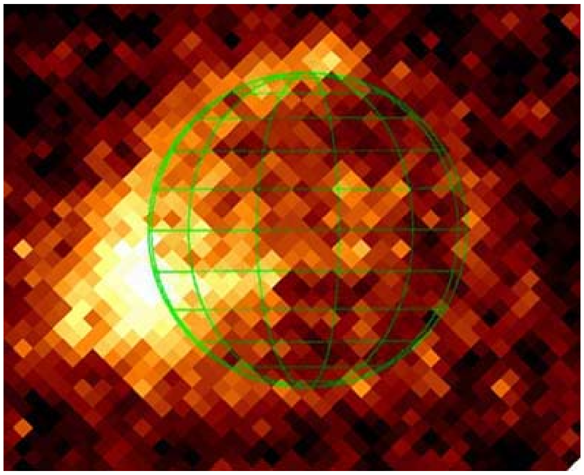

Figure 1: [OI] 630nm emission from Io in Eclipse by Trauger *et al*.(1997) with WFPC2 in May 1997.

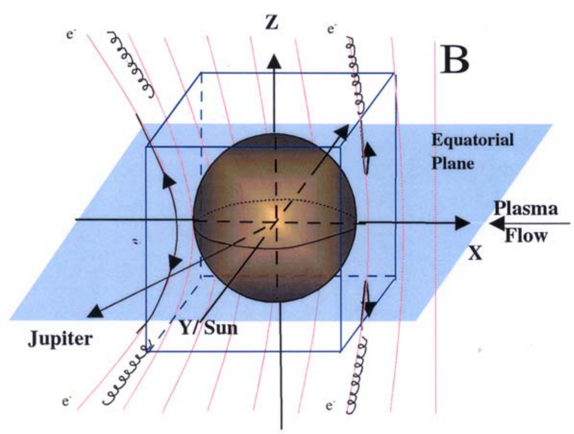

Figure 2: Schematic of computational domain.

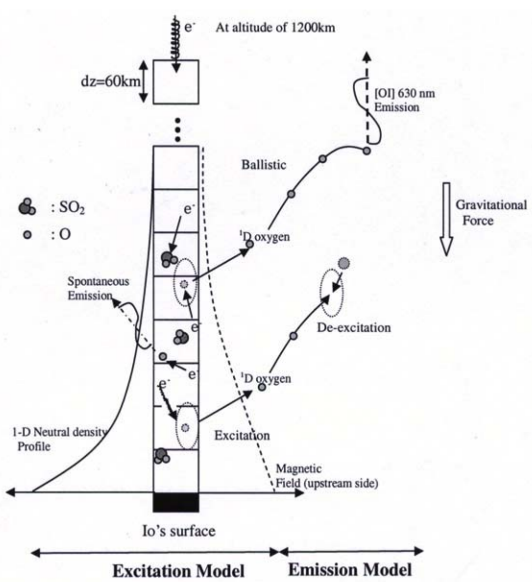

Figure 3: Schematic diagram of the excitation model and emission model (in 1-D).

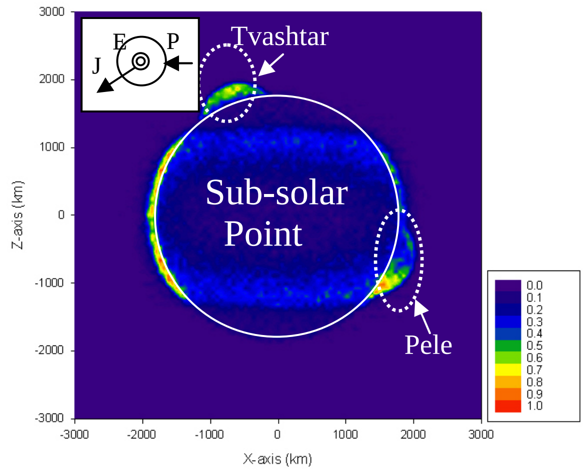

Figure 4: Normalized Energy deposition profile for electrons. Absorption in the largest volcanic plumes is apparent. The schematic insert is a perspective view suggesting Jupiter is to the left, the ion plasma comes from the right and the Earthward direction is perpendicular, out of the page.

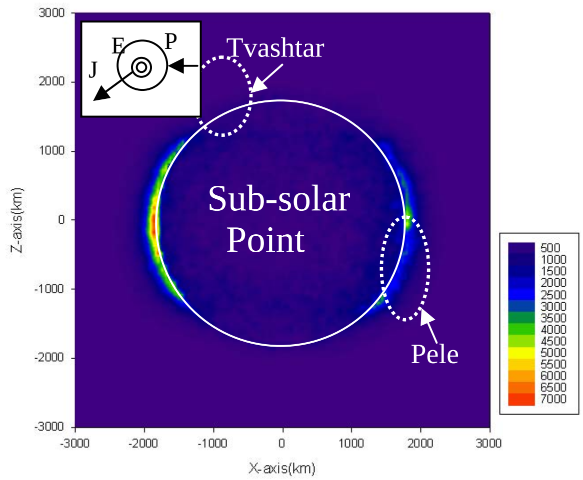

Figure 5: Line-of-sight integrated [OI] 630nm emission (in Rayleighs) viewed from Earth. The white dotted lines indicate the positions of Pele and Tavashtar, and the solid white line shows Io's surface.

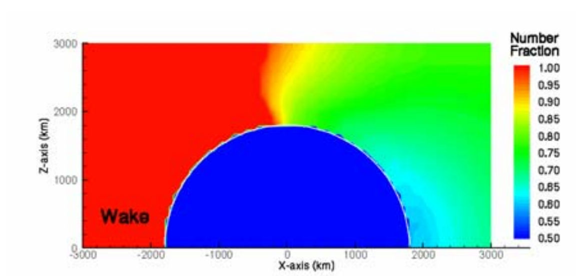

Figure 6: Number fraction of electrons reaching a given point in space. Note that the increased magnetic field upstream of Io results in a magnetic mirror effect which reflects ~40% of electrons. Collisions have been neglected and electrons are inserted only along the top boundary. Note that all electrons (inserted at the appropriate location) can travel through the wake and out the bottom boundary.