PLASMA SPUTTERING NEAR ENCELADUS AND THE SOURCE OF E-RING PARTICLES, P. K. Haff, Caltech, Pasadena, CA 91125, and A. Eviatar and G. L. Siscoe, Dept. of Atmospheric Sciences, UCLA, Los Angeles, CA 90024.

Both the Saturnian satellite Enceladus and the E-ring, which is associated with it, are subject to sputter erosion by virtue of the central plasma sheet identified by the Pioneer [1] and Voyager [2,3] spacecraft in the vicinity of that satellite. Heavy ion (oxygen) densities on the order of 50 cm^{-3} imply an impacting O flux of about 1.3×10^{-8} cm^{-2} s^{-1}. At the orbit of Enceladus, these co-rotating O ions impact the satellite and ring particles with an energy of ~60 eV. Sputtering experiments have yet to be performed on volatile targets such as frozen H_2O by ions of such low energy, but the sputtering yield Y (Y = average number of H_2O molecules removed per incident ion) can be estimated using a theory [4] which works reasonably well for other more refractory substances; the yield Y is found to be about 3 for a smooth, clean H_2O surface. A source of this strength, however, would have generated a hot plasma of Enceladian origin which would in turn have been detected by Voyager. Voyager data [R. L. McNutt and J. D. Sullivan, private communication] limits the sputtering yield to Y ~ 0.4, about an order of magnitude less than the calculated value. (Small scale surface roughness on Enceladus may depress the calculated yield, inasmuch as a particle sputtered at one point may strike a nearby protrusion and stick.)

If Y = 0.4 is taken as the actual sputtering yield, the lifetime of a 10^{-6} m ring particle against sputtering is then calculated to be rather short, on the order of 1000 y. If the adopted sputtering yield and incident flux values are correct, then one of two possibilities suggests itself: (1) the ring particles were created all at once in the recent past by some catastrophic event, such as a large meteoric impact on Enceladus, and the E-ring will thus vanish a few thousand years in the future (Baum, et al. [5] suggest that the E-ring may be in an early stage of evolution), or, (2) there is some steady source of particles which replaces losses due to sputtering (and due to other slower degradation and loss mechanisms, such as photosputtering [6], fast (MeV) proton sputtering [7], and convection and diffusion [8]). Here we examine the latter possibility.

Enceladus seems a likely particle source since the E-ring has a sharp density peak at the satellite orbit (while Mimas, for instance, lacks an associated ring). Two possible Enceladian sources are ejecta from numerous small meteoroid impacts, and active geysers. Because of the low escape velocity of Enceladus (~ 200 m s^{-1}), a meteoroid-driven source seems attractive. However, with an incident cumulative meteoroid flux comparable to that suggested by Cook and Franklin [9], even an optimistic estimate of the ratio of particulate ejecta mass to incident meteoroid mass (= 10^{-4}) fails to provide material fast enough to the ring to balance sputtering losses. Pang, et al. [10] have argued from Voyager 2 observations that the E-ring may be composed of spherical particles of fairly uniform size (~ 10^{-6} m), as might be formed by condensation processes. If such a geysering mechanism is to supply the E-ring, droplet material must be escaping Enceladus at a rate of ~ 6×10^{-17} g cm^{-2} s^{-1}.

To the extent that the lifetime of the E-ring is longer than the ~1000 y calculated above, the problem of material supply diminishes. A longer lifetime would be possible: (1) if the sputtering yield were smaller than 0.4; although no refined sputtering model has been given in the relevant energy range for frozen volatiles, it seems unlikely that our

estimates (which predict Y ~ 3) would be much more than an order of magnitude in error; (2) if the heavy ion density were much smaller than 50 cm^{-3} at the orbit if Enceladus; spacecraft evidence suggests otherwise; or, (3) if the E-ring were not composed of ice, but of a more refractory silicate material. A decrease in the sputtering yield by perhaps an order of magnitude might be expected in this case. However, the corresponding particle lifetime, 10^4 y, is still very short and implies a substantial supply rate.

Further analysis of Voyager data may provide additional information on plasma densities near Enceladus. Studies of small hypervelocity impacts in icy material of regolithic consistency will be needed to establish a better picture of particulate ejecta velocity spectra (and hence escape probabilities). Finally, very low energy heavy ion sputtering experiments on frozen H_2O targets (including targets with regolith-like surface roughness) will be of importance not only for the problem of the Enceladian ring, but also for studies of the stability of ice surfaces elsewhere in the solar system.

This work was supported in part by NASA [NAGW-202] and by NSF [PHY79-23638].

REFERENCES: [1] Frank, et al., JGR, 85, 5695, 1980; [2] Bridge, et al., Science, 212, 217, 1981; [3] Bridge, et al., Science, 215, 563, 1982; [4] Sigmund, Phys. Rev., 184, 383, 1969; [5] Baum, et al., Icarus, 47, 84, 1981; [6] Carlson, Nature, 283, 401, 1980; [7] Cheng, et al., JGR, 87, 4562, 1982; [7] Morfill, et al., JGR, in press; [9] Cook and Franklin, Astron. J., 75, 195, 1970; [10] Pang, et al., Abstract, Tucson Saturn Conf., p5, 1982.