# SATURN'S E-RING AND SATELLITE ENCELADUS

K. D. Pang*, C. C. Voge, J. W. Rhoads and J. M. Ajello

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

Spacecraft flybys of Saturn have returned a wealth of information on the planet, its satellites, rings and magnetosphere. Analysis of these data has led to major advances in understanding satellite-ring, ring-magnetosphere and satellite-magnetosphere interactions. However, many important problems remain unsolved. Among the major issues is the source and nature of geological activity on Enceladus, and its relationship to Saturn's outermost (E) ring [1].

Saturn's E-ring appears to be closely related to its satellite Enceladus. The densest part of the E-ring coincides with the orbit of Enceladus, suggesting the satellite as the source of ring particles [2]. The E-ring particles have a short life expectancy ($\lesssim 10^4$ years) due to their interactions with the ambient plasma [3]. The satellite's very clean ($p_b$ = 1.0 ± 0.1) and spectrophotometrically homogeneous surfaces also suggest that it is uniformly "powdered" as it sweeps back up the E-ring particles [4]. The E-ring material, therefore, must be constantly replenished.

Studies of the microphysical properties of the E-ring particles provide additional evidence linking the E-ring with Enceladus. The E-ring particles:

(1) Are very small, with effective diameters between 2 to 2.5 microns [5,6,7].

(2) Have a spherical shape [7].

(3) Have a narrow size distribution, with an effective variance between 0.1 and 0.15 [7]. See [8] for definitions of the "effective" parameters.

Mie scattering by such an ensemble of ice spheres can explain all observed visible and infrared properties of the E-ring [7]. See Figures 1 and 2. Particles in the gap between the G and E rings were studied in situ by Voyager PRA and PWS experiments, and were found to have properties (1) and (3) also [12,13]. These particles may have spiraled in from the E-ring due to Poynting-Robertson drag.

Particles with properties (2) and (3) are produced by atomization of a liquid or condensation from a gas. This suggests that the E-ring particles have a volcanic origin [7]. Since Enceladus is the only geologically active satellite found within the E-ring, it is reasonable to conclude that water droplets are ejected from Enceladus, quickly frozen by radiating to space, and reside within the E-ring until lost or destroyed.

The shape of the E-ring's phase curve, observed near the backscatter direction (see Fig. 2), constrains the composition of the E-ring particles. Spheres with refractive indices between $\sqrt{2}$ and 2 produce a noncentral ray after one internal reflection [8]. Liou and Hansen [14] showed that such particles give rise to an intense glory, with an innermost ring of only a few degrees angular diameter. The fact that such a glory has not been observed for Saturn's E-ring means that its particles have a refractive index outside the $\sqrt{2}$ to 2 range. Table 1 gives the refractive indices of possible E-ring materials. The first four substances satisfy the observational constraint, while the last two do not.

The presence of low melting point clathrates within Enceladus has been invoked to lower the energy cost of melting the satellite's interior [21]. The phase function of the E-ring particles seems to permit both $NH_3$ and $CH_4$ hydrates. The spectral data favors $CH_4$ hydrate over $NH_3$. Moreover, the nondetection of N ions by the Voyager LECP instrument within Saturn's magnetosphere

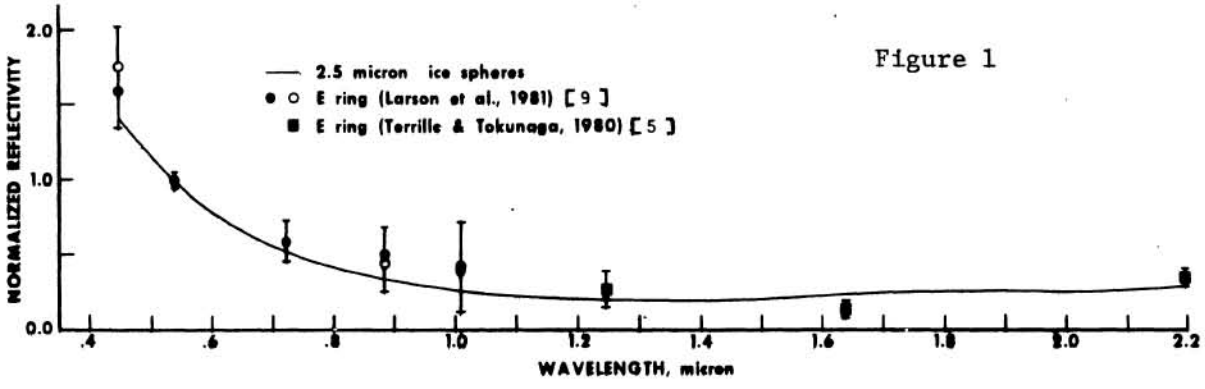



Figure 1

does not support a source of nitrogen compounds on Enceladus [22]. The detection of C and H ions by LECP fulfills a necessary but not sufficient condition for a methane source on Enceladus.

To summarize, water ice can explain available spectrophotometric observations of the E-ring (this work) and Enceladus [23]. If a clathrate is needed to lower the energy cost of melting Enceladus it is more likely to be methane and not ammonia hydrate. Continued data analysis and geodynamical studies, e.g., [24], are expected to resolve the question of the source and nature of geological activity on Enceladus soon.

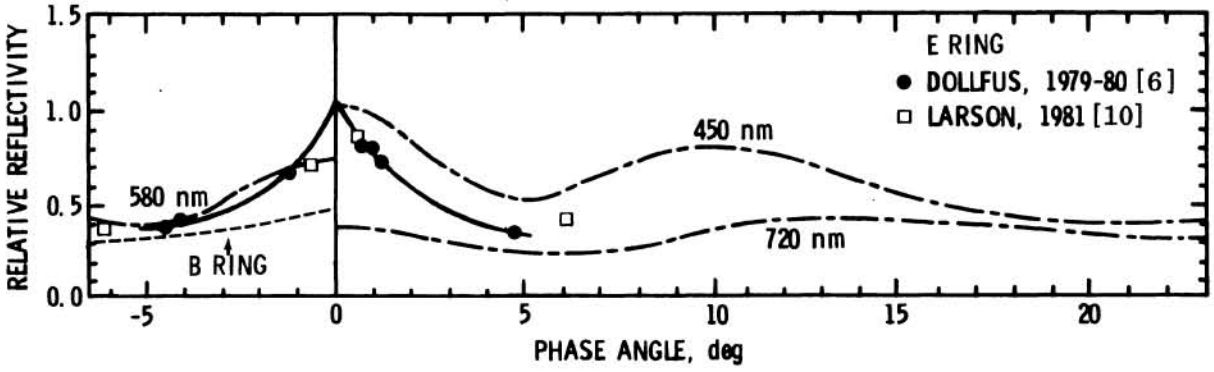
Table 1

| Substance | n | λ, nm | Temp. °K | Ref. |
|---|---|---|---|---|
| $H_2O$ ice | 1.31 | 550 | 266 | [15] |
| $CH_4$ ice | 1.33 | 589 | 91 | [16] |
| $CH_4 \cdot 5\frac{3}{4}H_2O$ | 1.35 | 488, 514 | 263 | [17] |
| $NH_3 \cdot H_2O$ | (1.36) | 589 | 253 | [18] |
| $NH_3$ ice | 1.43 | 589 | 20 | [19] |
| Silicates | $\geq 1.5$ | 589 | 300 | [20] |

Acknowledgement. Research at JPL/Caltech is sponsored by NASA.

References

1. Johnson, T. V. [1982] EOS 63, 1021-1022.
2. Baum, W. A., T. Kreidl, J. A. Westphal, G. E. Danielson, P. K. Seidelmann, D. Pascu and D. G. Currie [1981] Icarus 47, 84-96.
3. Cheng, A. F., L. J. Lanzerotti and V. Pirronello [1982] J. Geophys. Res. 87, 4567-4570.
4. Buratti, B., J. Veverka and P. Thomas [1982] Bull. Amer. Astron. Soc. 14, 737-738.
5. Terrill, R. J. and A. Tokunaga [1980] Bull. Amer. Astron. Soc. 12, 701.
6. Dollfus, A. and S. Brunier [1981] Bull. Amer. Astron. Soc. 13, 727.
7. Pang, K. D., C. C. Voge and J. W. Rhoads [1982] In Planetary Rings, edited by A. Brahic, CNES, Toulouse, France.
8. Hansen, J. E. and L. D. Travis [1974] Space Sci. Rev. 16, 527-610.
9. Larson, S. M., H. J. Reitsema and B. A. Smith [1981a] Bull. Amer. Astron. Soc. 13, 726-727.
10. Larson, S. M., J. W. Fountain, B. A. Smith and H. J. Reitsema [1981b] Icarus 47, 288-290.
11. Franklin, F. A. and A. F. Cook [1965] Astron. J. 20, 704-720.
12. Aubier, M. G., N. Meyer-Vernet and B. M. Pederson [1982] In Planetary Rings, edited by A. Brahic, CNES, Toulouse, France.
13. Gurnett, D. A., E. Grun, D. Gallagher, W. S. Kurth and F. L. Scarf [1983] Submitted to Icarus.
14. Liou, K.-N. and J. E. Hansen [1971] J. Atmos. Sci. 28, 995-1004.
15. Hobbs, P. V. [1974] Ice Physics, Clarendon Press, Oxford, England.
16. Marcoux, J. E. [1969] J. Opt. Soc. Amer. 59, 998.
17. Whiffen, B. L., H. Kiefte and M. J. Clouter [1982] Geophys. Res. Lett. 9, 645-648.
18. Estimated from the refractive index of an aqueous solution of ammonium hydroxide with the same mole fraction of ammonia [20].
19. Arnold, F., R. B. Sanderson, A. W. Mantz and S. B. Thompson [1973] AFRPL-TR-73-52, Rocket Propulsion Laboratory, U.S. Air Force, Edwards, California.
20. Handbook of Chemistry and Physics [1982] CRC Press, Boca Raton, Florida.
21. Stevenson, D. J. [1982] Nature 298, 142-144.
22. Bridge, H. S. et al. [1982] Science 215, 563-570.
23. McCord, T. B. and D. P. Cruikshank [1981] In Infrared Astronomy, edited by C. G. Wynn-Williams and D. P. Cruikshank, pp. 57-87, Reidel, Boston.
24. Lissauer, J. J., S. J. Peale, J. N. Cuzzi and S. W. Squyres [1982] EOS 63, 1022.




E RING —— INTERPRETED AS AN OPPOSITION EFFECT (DOLLFUS, 1981) [6]

B RING ––– (FRANKLIN & COOK 1965) [11]

– – – INTERPRETED AS SCATTERING BY 2.1 MICRON ICE SPHERES (THIS WORK)

Figure 2