various sulphur and other compounds and the physical and optical effects of adsorbed gases such as H_2S and SO_2 thereon need to be studied as possible strong contributors to Io's spectral reflectance and other surface properties.

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1. Fanale, F. P., Johnson, T. V. & Matson, D. L. *Science* **186**, 922–925 (1974).
2. Nash, D. B. & Fanale, F. P. *Icarus* **31**, 40–80 (1977).
3. Wamsteker, W., Kroes, R. L. & Fountain, J. A. *Icarus* **23**, 417–424 (1974).
4. Nelson, R. M. & Hapke, B. W. *Icarus* **36**, 304–329 (1978).
5. Harris, D. L. in *The Solar System Vol. III. Planets and Satellites* (eds Kuiper, G. P. & Middlehurst, B. W.) 272–342 (University of Chicago Press, 1961).
6. Johnson, T. V. *Icarus* **14**, 94–111 (1971).
7. Johnson, T. V. & McCord, T. B. *Astrophys. J.* **169**, 589–593 (1971).
8. Pollack, J. B. *et al. Icarus* **36**, 271–303 (1978).
9. Cruikshank, D. P. *Icarus* (in the press).
10. Morrison, D., Cruikshank, D. P. & Burns, J. A. in *Planetary Satellites* (ed. Burns, J. A.) 3–17 (University of Arizona Press, 1977).
11. Johnson, T. V. & Pilcher, C. B. in *Planetary Satellites* (ed. Burns, J. A.) 232–268 (University of Arizona Press, 1977).
12. Morrison, D. & Morrison, N. D. in *Planetary Satellites* (ed. Burns, J. A.) 363–378 (University of Arizona Press, 1977).
13. Caldwell, J. *Icarus* **25**, 384–396 (1975).
14. Matson, D. L., Johnson, T. V. & Fanale, F. P. *Astrophys. J. Lett.* **192**, L43–L46 (1974).
15. Herzberg, G. *Infrared and Raman Spectroscopy of Polyatomic Molecules* (Van Nostrand, New York, 1945).
16. Nakamoto, K. *Infrared Spectra of Inorganic and Coordination Compounds* (Wiley, New York, 1963).
17. Eischen, R. & Pliskin, W. *Advances in Catalysis* Vol. 10, 1–56 (Academic, New York, 1958).
18. Lebofsky, L. *Icarus* **25**, 205–217 (1975).
19. Nash, D. B. *J. geophys. Res.* **71**, 2517–2534 (1966).

Spectral evidence for SO_2 frost or adsorbate on Io's surface

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The infrared reflection spectrum of Io matches that from an SO_2 frost grown in the laboratory.

IT has been recently suggested that adsorbed SO_2 and/or H_2S on the surface of a spectroscopically benign substrate can explain the IR spectrum of Jupiter's satellite, Io[1]. SO_2 gas has been identified as a major constituent of the volcanic gas plumes recently discovered by the Voyager 1 spacecraft[2]. We have measured the reflection spectrum of SO_2 frost grown under low pressure at 140 K in the laboratory and find that it provides an excellent match to Io's spectrum in the 1.0–4.5 μm range.

The apparatus used and experimental methods have been described by Kieffer[3] and Smythe[4] respectively. Figure 1 compares the spectral geometric albedo of Io[5,6] and our laboratory spectrum. Clearly SO_2 frost can explain the Io absorption bands at 1.35, 2.55, 2.80, 3.80, 3.90, 3.95, and 4.08 μm. Other candidate materials such as sulphates, nitrates and carbonates[5] do not provide such a unique match to these bands.

Although SO_2 frost may be unstable on Io, except at the poles or nightside (see ref. 7), adsorbed SO_2 should be present on the surface particulates due to the extensive volcanic outgassing. The absorption bands of adsorbed and condensed species are known to be similar in wavelength[8]. Slight shifts in band positions and depths may reflect areal or temporal variation in frost/adsorbate or condensate/substrate contribution ratios to a multicomponent spectrum. Mixtures of alkali sulphides, free sulphur and adsorbates of SO_2 or H_2S have been suggested to explain Io's overall UV-VIS-IR reflectance[1]. We conclude here that SO_2 as a frost or an adsorbate is the primary contributor to Io's IR spectral reflectance.

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1. Nash, D. B. & Nelson, R. M. *Nature* **280**, 763–766 (1979).
2. Hanel, R. *et al.* Press Release (American Geophysical Union meeting, Washington, D.C., 5 May 1979).
3. Kieffer, H. H. *Appl. Opt.* **8**, 2497–2500 (1969).
4. Smythe, W. D. thesis, Univ. California, Los Angeles (1979).
5. Pollack, J. B. *et al. Icarus* **36**, 271–303 (1978).
6. Cruikshank, D. P. *Icarus* (in the press).
7. Lebofsky, L. A. *Icarus* **25**, 205–217 (1975).
8. Eischens, R. P. & Pliskin, W. A. *Adv. Catalysis* **10**, 1–56 (1958).

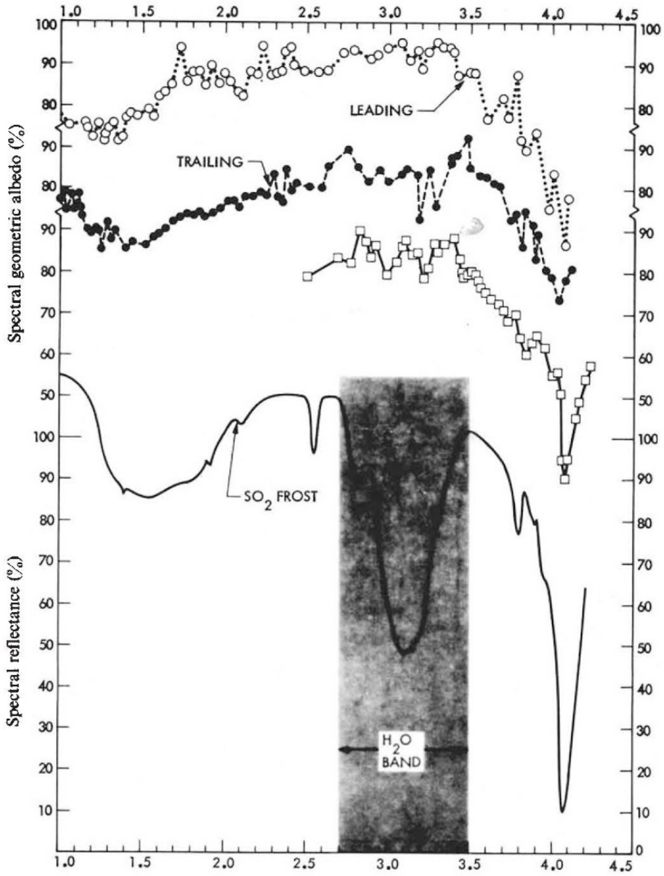

Fig. 1 *a*, Spectral geometric albedo of Jupiter's satellite Io, 1.0–4.5 μm based on previous studies[5,6], normalised as in ref. 1. ○, ●, Data from ref. 5; □, data from ref. 6. *b*, Spectral reflectance of SO_2 frost grown in the laboratory. The 3.1 μm H_2O band (stippled area) is due to contaminant water.