

IO SPECTRA FROM HUBBLE: VOLATILE DISTRIBUTION, COMPOSITION, AND PROCESSES. J.S.

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Introduction: Analysis of Hubble WF/PC2 spectra of Io (12 bands, 255-1,000 nm, spatial resolution 160 km/pixel; obtained from J. Spencer) confirms that elemental S_x is a major, widespread constituent in dark regions, yellow and yellow-green plains, and Pele's aureole, but S_x probably is a minor constituent in bright plains, consistent with prior studies [1-6]. Io's sulfur is inhomogeneous—either it contains varying amounts of impurities, or it occurs with varying S chain lengths, or both. Pele's deposits exhibit concentric zonation of S-rich materials consistent with either or both of two explanations: (a) Zonation of sulfur polymorphs related to the temperature and vigor of volatile-silicate interactions in the vent—quasi-ballistic deposition of S₁ and S₂ (and annealing to S₃ and S₄) during highest temperature silicate interactions and most expansive plume activity, and deposition of long-chain polymers by cooler interactions and less vigorous eruptions; or (b) zonation of impurities related to condensation temperature. Galileo NIMS spectra (408 bands, similar spatial resolution to Hubble, de jittered by L. Soderblom) and Hubble data have been merged but not yet analyzed.

Io spectra indicate widespread S_x: Figure 1 shows Hubble band 7 (center at 502 nm) with colored overlays of areas of interest. Pele's multi-zoned concentric structure is resolved, although details of smaller plumes are not. Average spectra of nine regions were obtained, including three zones of Pele, four dark regions, and two bright regions. Figures 2, 3, and 4 compare these spectra with those of several specimens of natural terrestrial sulfur (data from [7]). The terrestrial sulfur spectra were obtained at room temperature, so the representations of these materials shown here have been shifted by -30 nm in a first-order correction to simulate Io's surface temperature [7]. The bright regions are not similar to sulfur but closely resemble SO₂ frost (not shown), as reported by others. The other Io spectra are similar to sulfur, especially impure sulfur specimens from Yellowstone National Park. Relatively pure sulfur, represented by sample Kawah Ijen-Opp-1 (donated by Clive Oppenheimer), has a steeper absorption edge than any of the Io spectra. Some impure sulfur specimens from Kusatsu Shirane volcano (donated by Pierre Delmelle) and elsewhere have spectra that are much flatter from 500 to 1,000 nm than Io spectra. However, all the sulfur specimens have an upturn in reflectance near 400 nm at virtually the same wavelength as shown by all of the Io spectra other than

the bright SO₂ regions. There is little doubt that sulfur polymorphs are mainly responsible for this absorption edge, but there is severe distortion of this edge when compared to pure, well-crystallized orthorhombic sulfur. Distortion mechanisms were reviewed and new data regarding the powerful effects of certain impurities were recently discussed by [7].

Process implications: Spectra of impure sulfur from Yellowstone (S_x containing minor amounts of Fe, C, As, Se, and others) provide excellent matches to spectra of Io's dark regions, yellow-greenish plains, and Pele. These regions may consist of similar impure sulfur. Around Pele, the data are consistent with increasing impurities near the vent, as though less-volatile impurities are preferentially cold-trapped there; this explanation requires that the ground temperature is somewhat elevated near the vent. Alternatively, spectra of these regions may be explained by relatively pure sulfur of different chain lengths. The outer red ring of Pele could be explained by S₃ and S₄ annealed from the condensates of S₁ and S₂ sulfur gases produced by extremely hot sulfur-silicate magma interactions in Pele's vent; the interior zones could represent other sulfur polymorphs with or without impurities condensed from gases that had experienced cooler interactions. Support for the latter interpretation comes from the recent discoveries of S₂ and S₁ in Pele's plume (J. Spencer, personal communication).

The activity and spectrally zoned deposits of Pele and other plumes may be part of regional volatile cycles (Figure 5). Erupted volatiles accumulate in a thick annular pile, which then may melt at depth [8]; liquid SO₂, molten sulfur, and other volatiles then flow laterally and may be recycled into the vent area, where violent thermophysical interactions with high-temperature silicate magmas occur [9]. Volatiles are erupted, recondense and are redeposited in concentric zones, completing the cycle, as a result of either mechanism described above (or both of them). The poorly known topography of Io [10] may determine whether such a cycle could function.

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Figure 1 (upper right). Regions of interest on Io.
 Figure 2 (below). Pele spectra compared to terrestrial S.
 Figure 3 (lower left). Dark region spectra compared to terrestrial sulfur.
 Figure 4 (right center). Bright region spectra compared to terrestrial sulfur.
 Figure 5 (bottom right). Preliminary conceptual model of a plume-driven sulfur cycle.

