GALILEO OBSERVATIONS OF VOLCANIC PLUMES ON IO.

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Summary: Co-analysis of Galileo imaging observations of the gas and dust components of Io's plumes suggests that the deposits produced by Prometheus-type plumes are made up of pyroclastic particles that are entrained with the gas flow. Pele-type plumes, in contrast, deposit material that could be condensed from the gas phase.

Introduction: Many outstanding questions remain to be answered about Io's spectacular volcanic plumes [1]. Voyager and Galileo imaging observations have established that there are two distinct classes of plumes on Io [2]: giant plumes like Pele that vent sulfur-rich gases from the interior of the moon and spray-paint the surface with enormous red rings, and more numerous smaller plumes like Prometheus that are produced when hot flows of silicate lava impinge on volatile surface ices of SO_2. Both classes of plumes possess gas and dust components, although the density of dust and gas varies from one plume to another. The fallout from plumes contributes significantly to Io's resurfacing.

Still poorly known are the temporal and spatial variability of plumes, the relationship between the plumes and the surface changes they produce, and the nature and source of the particulates present in plumes of both classes (in particular, whether the dust is condensed from the gas or simply entrained by the flow). Here we begin to address these questions through a systematic study of the dimensions and opacities of dust plumes in the complete set of Galileo images, together with comparisons of the dust plumes seen in daylight to the auroral glows seen in eclipse and the record of surface changes.

Sunlit Observations: Galileo acquired many low-resolution imaging observations of the dust component of the plumes as seen in reflected sunlight during daytime observations. All but one of these depict the small, Prometheus-type plumes; Pele was barely discernable to Galileo's imaging system, which lacked sensitivity at ultraviolet wavelengths. These 66 distinct measurements (corrected for foreshortening) yield a mean height for the Prometheus-type plumes of 82 +/- 15 km. Pillan, Ra and Thor reached over 100 km in height, but none of the smaller plumes exceeded 118 km. Repeated observations showed no temporal variability in dust column height outside of measurement uncertainty. The dust load varied considerably from plume to plume: no dust columns were seen at Acala and Culann, and the opacity of stealthy Marduk is an order of magnitude less than that of similarly sized Zamama (Figure 1).

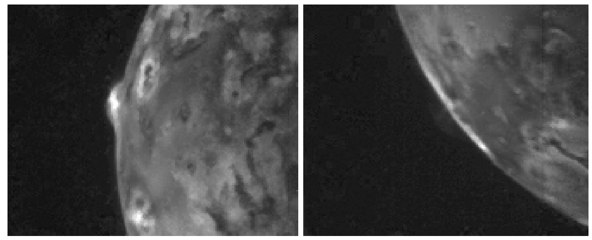

Figure 1: Comparison of dust columns from Zamama (left) and Marduk (right) under nearly identical illumination and viewing conditions.

Eclipse Observations: Galileo observed auroral emissions from several favorably located plumes while Io was eclipsed in Jupiter's shadow. Because of their distinctive morphology, these plume glows can be distinguished from the variety of auroral emissions that are visible even when no plumes are present. The plume glows are stimulated by electrical currents near the sub- and anti-Jupiter points, and show the extent of the gas component of the plumes. Using 15 measurements from 7 diverse plumes, we find the mean height of the gas columns of Prometheus-type plumes to be 250 +/- 71 km, considerably larger than the dust columns. Significantly, we find no consistent difference between the gas plume heights of dusty plumes (such as Zamama or Prometheus) and stealth plumes (Acala and Culann). Acala is much brighter than other Prometheus-type plumes in eclipse, perhaps suggesting a higher gas density from this plume.

Contemporaneous Gas and Dust Plume Observations: A few plumes were seen in both daylight and eclipse observations during the same Galileo orbit, giving us a means to double check the result that the gas plumes are larger than their dusty counterparts. Ra was seen in both daylight and eclipse during orbit G1; Kanehekili was seen during orbit E11; and Prometheus was seen twice, during orbits E8 and E11. These near-contemporaneous observations suggest that the Prometheus-type gas plumes are nearly 3 times larger than the dust plumes, consistent with the numbers given above.

The most compelling indication that the gas plumes exceed the dust columns in stature comes from a pair of high phase angle, long exposure observations of Thor's eruption during orbit I31 (Figure 2). Initially reported as the largest plume ever seen on Io, the surface changes produced by the plume were only slightly broader than typical for Prometheus-type plumes. We suggest instead that the faint outer plume (pale blue in Figure 2) is actually gas seen in scattered sunlight, while the dust column is limited to the bright (red) core close to the surface.

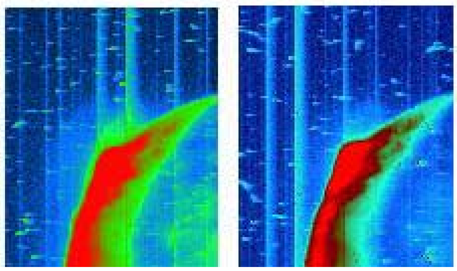

Figure 2: Simultaneous gas and dust column observations of Thor. The faint gas plume (pseudocolored pale blue) is ~2.5 times taller than the dense dust column (red).

Comparison With Surface Changes: The dimensions of the gas and dust plume components can be compared to the sizes of surface changes that are caused by deposition from the plumes to tell us more about the mechanisms by which Io repaints herself. Figure 3 shows the maximum extents of surface changes observed during the Galileo mission [3]. The distribution is bimodal, corresponding to the two classes of Ionian plumes. Asterisks mark the maximum ranges of deposits expected from Prometheus-type gas and dust components (twice the heights of the dust and gas columns, since the maximum radial extent of ballistic deposition is expected to be double the maximum height). The surface changes caused by Prometheus-type plumes appear to be produced by dust deposition rather than condensation of gas on the surface.

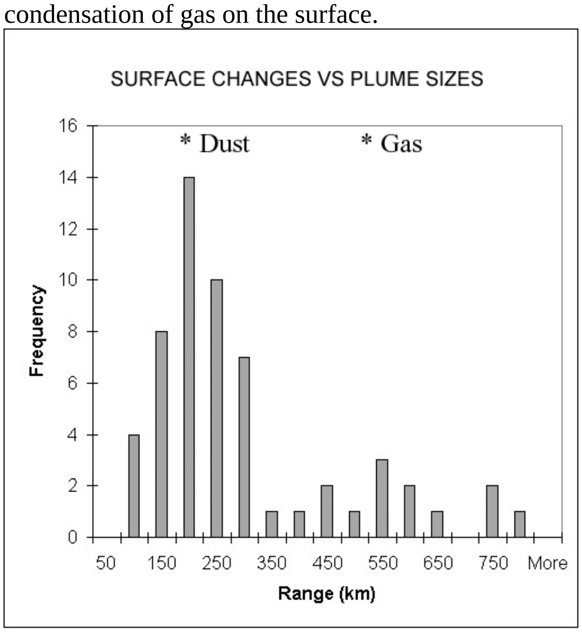

Figure 3: Dimensions of surface changes seen during the 5 year Galileo Mission compared to the mean sizes of Prometheus-type dust columns and gas plumes. The expected mean extent of dust deposition (twice the height of the dust column) closely matches the mean range of Prometheus-type surface changes.

Giant Plumes: Galileo images of giant plumes are limited to a single detection of Pele in sunlight and a possible detection of a giant plume south of Karei in eclipse. Pele's faint outline was seen during daytime on orbit E4, more than 400 km high and at least 800 km across. Higher resolution Voyager images of Pele in sunlight show a shield-shaped structure more than 1100 km across with only a faint central column [4]. The eclipse observation taken during orbit C21 shows a faint glow from a region near the Jupiter-facing point where a giant red ring was briefly deposited by an eruption centered at 12 S, 13 W [3]. The gas plume here is ~500 km high and 1100 km across, matching the breadth of the red ring.

Other Plumes: Diffuse glows were spotted in the vicinity of a poorly resolved field of hot spots near the sub-Jupiter point, especially during the eclipse observation of orbit C10. These emissions could indicate venting of gas from extended sources or from several volcanic centers too weak to be detected as individual plumes.

Discussion: Together, these observations fill in some of the missing pieces of the plume puzzle. The dust and gas components of giant Pele-type plumes are similar in size to each other and to the dimensions of their bright red deposits, indicating that the deposits could be directly condensed from the gas phase or made up of particles small enough (<10 nm in radius [5]) to be carried along with the gas flow. On the other hand, the dust erupted in Prometheus-type plumes is coarse enough to decouple from the gas and fall short, forming the visible surface changes. The sizes of these smaller plumes does not appear to depend on their dust content; the gas and dust columns of stealthy and dust choked extremes of Prometheus-type plumes are similarly sized, and thus can not be very different in gas temperature (which controls the size of the plumes). Put another way, the presence or absence of dust does not depend upon the temperature of the gas. This argues that the particulates in Prometheus-type plumes are entrained in the liquid or solid phase upon eruption, and not condensed from the gas as it expands and cools.

References: [1] Geissler, P. and D. Goldstein (2006) in *Io After Galileo*. [2] McEwen, A. S. and L. Soderblom (1983) *Icarus* 58, 197-226. [3] Geissler, P., et al. (2004) *Icarus* 169, 29-64. [4] Strom, R., et al. (1981) *JGR* 86, 8593-8620. [5] Zhang, J., et al. (2004) *Icarus*, 172, 479-502.