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Io' Active Eruption Plumes: Insights from HST

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1. Introduction

Io is the most volcanically active body in the Solar System. Volcanism on Io has been studied extensively over the last 30 years thru imaging and spectroscopy using instrumentation aboard the earth orbiting Hubble Space Telescope (HST), at ground based observatories and using the payloads of spacecraft travelling in and thru the jovian system such as: Voyager, Galileo, Cassini and most recently the New Horizons (NH) spacecraft. From the first Voyager observations of Io it was established that all of the SO_2 gas on Io ultimately originates from Io's active volcanism [1]. Although Io's volcanism styles are varied, Io's gaseous plumes have been segregated solely into two classes, namely: Pele- and Prometheus-type plumes [2, 3, 4]. Pele-type plumes are rich in diatomic sulfur (S_2) gas [5] and produce large pyroclastic deposits of average maximum radius ~ 600 km, that are dominantly red in color, due to the probable presence of S_3 and S_4 [3,6]. Prometheus type plumes are produced from the interaction of hot silicate lava with SO_2 surface frost [6, 7, 8]; these plumes form small ($\leq$ 350 km) dominantly white pyroclastic deposits [3,6], are rich in SO_2 gas and do not have a significant abundance of S_2 gas [9]. Although the dimensions of the two plume types are well established, the relative significance of the two plume types in maintaining Io's tenuous atmosphere or in maintaining Io's resurfacing rate is not. Consequently, a detailed study of the composition and density of the gas and dust density species within each of Io's active plume types is needed.

2. Data Overview

Taking advantage of the available data, we recently [10] completed a detailed analysis of the spectral signature of Io's Pele-type Tvashtar plume as imaged by the HST Wide Field and Planetary Camera 2 (HST/WFPC2) via absorption during Jupiter transit and via reflected sunlight in 2007, as well as HST/WFPC2 observations of the 1997 eruption of Io's Prometheus-type Pillan plume (Fig. 1). These observations were obtained in the 0.24-0.42 μm range, where the plumes gas absorption and aerosol scattering properties are most conspicuous. By completing a detailed analysis of these observations, several key aspects of the reflectance and the absorption properties of the two plumes have been revealed. Additionally, by considering the analysis of the HST imaging data in light of previously published spectral analysis of Io's Prometheus and Pele-type plumes several trends in the plume properties have been determined, allowing us to define the relative significance of each plume on the rate of re-surfacing occurring on Io and providing the measurements needed to better assess the role the volcanoes play in the stability of Io's tenuous atmosphere.

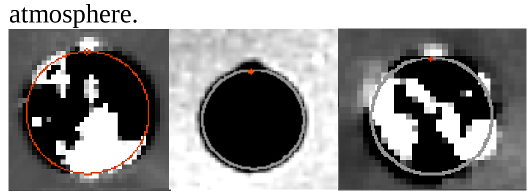

Fig. 1: Io's 1997 Pillan (left) eruption plume at 0.33 μm; Io's Tvashtar eruption plume in reflected sunlight at 0.33 μm (right) and during Jupiter transit (middle) at 0.26 μm, plume at top of disk.

3. Summary and Conclusions

Previously published spectral observations indicate that the SO_2 gas density in the Pele plume can range from ~ 0.5-5x10^{16} cm^{-2}, the resulting SO_2 resurfacing rate can range from ~ 0.12-0.57 cm yr^{-1}, and the S_2/SO_2 gas density ratio is ~ 0.05-0.3 [5,11]. Presuming that the S_2/SO_2 for both the Pele and Tvashtar plumes is ~ 0.05-0.3, analysis of the HST Tvashtar plume transit data indicates that the plume SO_2 and S_2 gas densities are ~ 2-8x10^{16} cm^{-2} and 3-6x10^{15} cm^{-2}, respectively, potentially producing SO_2 and S_2 gas resurfacing rates ~ 0.3-1.3 cm yr^{-1} and 0.07-0.12 cm yr^{-1}, respectively. Thus, we find that the gas density in the Tvashtar plume overlaps that derived from the Pele observations. Additionally, the Tvashtar SO_2 gas mass resurfacing rates are comparable to or less than the 1.7-2.4 cm yr^{-1} rates derived from previous observations of the Prometheus plume [9, 7]. At the same time, from the color of Tvashtar in reflected sunlight we estimate that the 2007 Tvashtar eruption released ~ 10^9 g of sulfur dust, and the inferred SO_2 gas column density corresponds to an SO_2 gas mass ~ 10^{13} g, thus the dust/gas ratio is ~ 10^{-4}, and the SO_2 gas released in the eruption is the primary resurfacing source.

Additionally, the highest SO_2 gas densities (~0.2-6.0 x 10^{18} cm^{-2}) and resurfacing rates (~1.7-100 cm yr^{-1}) inferred from amongst all the available HST spectral and imaging data taken between 1995 and 2007, were for the 1997 Pillan and 2001 Prometheus plume eruptions. The dust mass of the 1997 Pillan plume was ~ 10^{10} g, and so again the inferred dust/gas ratio is significantly less than 1, making the SO_2 gas released in the eruption the primary resurfacing source. Each of these eruptions were driven by lava-frost interactions [7, 4] and formed in fields enriched in SO_2 frost/slush [12, 3, 13]. Yet in 2003 when all known SO_2 seepage had ceased, Pillan's ~ 2x10^{16} cm^{-2} SO_2 gas density was ~300x lower than in 1997, potentially producing ~0.33 cm-yr^{-1} of SO_2 surface mass; thus, releasing gas mass comparable to that inferred from the Pele-type plume observations. This dramatic variability may indicate that the density of SO_2 gas released in the detected Pillan eruptions is directly correlated with the presence/absence of SO_2 slush seepage into the Pillan Paterae floor. This suggests that the mobilization of buried/trapped SO_2 frost into regions of high volcanic (magma/lava) activity can significantly impact the SO_2 gas density released during the resultant violent volatile driven plume eruptions. If so, this would also imply that the overall impact of the lava-frost interaction driven plumes on Io's resurfacing rate will be function of the local SO_2 frost abundance at the time of eruption.

Finally, we note that these results provide important insights into the older Voyager spectral observations as it relates to the HST observations obtained during the Galileo era. In particular, the derived 1997 Pillan eruption SO_2 gas density is comparable to the ~5.4x 10^{18} cm^{-2} derived from the 0.7 μm detections of SO_2 gas absorption in the vicinity of the 1979 Loki plume (Pearl et al. 1979); thus these results validate the occurrence of high density (>10^{17} cm^{-2}) SO_2 gas eruptions on Io. Additionally, each of the plumes with high (>10^{17} cm^{-2}) SO_2 gas content are known to scatter strongly at nearly blue (~0.33-0.4 μm) wavelengths. In fact, the average I/F brightness level inferred for both 1979 Loki eruption and the 1997 Pillan plumes was significantly higher in the NUV to blue (~ 0.33-0.34 μm) than at longer wavelengths; and, the 1997 Pillan 0.33 μm I/F level was 10x brighter than that of previous detections of Io's Pele-type plumes, while Loki's 0.34 μm brightness was 3x brighter than the Pele-type plumes. Thus, these results further establish the long suspected connection between the abundance of SO_2 gas released during the eruptions and the magnitude of the plumes 0.34 μm brightness level.

Acknowledgements

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