A CLOSE-UP VIEW OF IO IN THE INFRARED: NIMS RESULTS FROM THE GALILEO FLY-BYS

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A major objective of the Galileo mission was to obtain high spatial resolution views of Io, in both the visible and in the infrared regions. These long-awaited observations were obtained in October 1999 (orbit I24) and November 1999 (orbit I25). A third fly-by is planned for February 2000 (orbit I27). Here we report the initial results obtained by Galileo's Near-Infrared Mapping Spectrometer (NIMS) during these fly-bys. Our data reveals, for the first time, the detailed thermal structure of hot spots and the local distribution of SO_2 frost on the surface.

Io's volcanic activity and SO_2 distribution have been studied by NIMS since June 1996 but, prior to the fly-bys, the observations were obtained with spatial resolutions ranging from 65 km/NIMS pixel (for one observation in orbit C21) to over 500 km/NIMS pixel. These distant observations (111 in total) allowed us to make global studies of the distribution and temporal variations of volcanic activity (1,2) and of the distribution of SO_2 (3,4). Joint studies with Galileo's Solid State Imaging system were used to correlate thermal emission detected by NIMS with surface colors and plumes (2,5,6), and to detect very high temperature volcanism (7,8).

NIMS obtained 17 high-spatial resolution observations during orbit I24 and 4 observations during I25. Most of these observations had spatial resolutions from 0.5 to 25 km/NIMS pixel, allowing studies of the detailed thermal structure of hot spots and of the local distribution of SO_2 frost. NIMS observations, combined with the visible images obtained by Galileo's Solid State Imaging system (SSI), give new insights into the interaction between thermal output, SO_2 frost, volcanic plumes, and surface colors.

Our observing strategy during the fly-bys was to obtain NIMS spectra over the same regions that were being imaged by SSI, to allow correlation between the visible and the infrared data. Differences in the data-taking mode of the two instruments give NIMS less spatial coverage than the SSI images, as SSI can obtain data faster than NIMS. We thus chose specific areas within SSI frames for NIMS to observe. The major targets were areas known to have active hot spots, and areas showing different colors in the visible that may represent different surface compounds.

The NIMS observations in I24 and I25 obtained only 14 wavelengths, because the instrument grating did not move. While this has compromised our search for yet unknown surface compounds, a benefit of this mode has been to acquire more samples (24 instead of 1) at each wavelength, thus increasing the signal/noise ratio and providing a very robust data set. The reduced number of wavelengths is suitable for thermal analysis. SO_2 mapping can also be done using a wavelength channel within the deep absorption band centered at 4.1 microns.

Our observations during the fly-bys targeted a variety of different regions. Orbit I24 included nightside observations of Loki and Pele. Because of the lack of reflected sunlight, these observations are particularly suited for detailed thermal mapping (9, 10). Other observations in I24 and I25 were taken in reflected sunlight. These observations are particularly well suited for SO_2 mapping, though thermal mapping was also done using a surface albedo model for wavelengths greater than 4 microns.

Our major results can be summarized as follows:

1. Local distribution of thermal output in volcanic centers: Temperatures (both color and brightness) of individual hot spots were obtained for a variety of different volcanic regions. The thermal maps of Loki and Prometheus are particularly revealing of the local volcanic processes. The detailed map of Loki, made from a nightside observation [9], shows that the dark area that forms the floor of the caldera is largely uniform in temperature. The lighter-colored area that forms an island-like feature in the center of the caldera has a lower thermal output than the surrounding dark material. It is likely that the dark floor of Loki is made up of extensive, cooling lava flows, which were emplaced close together in time. The structure of Loki is further discussed in [9]. The thermal map of the Prometheus region, described in (4) below, shows two major hot spots rather than one as previously thought, and implies a possible new mechanism for plume formation.

2. Detection of smaller, fainter hot spots not seen in the global-scale observations. Prior to the fly-bys, analysis of thermal emission detected from observations by NIMS, SSI, Voyager, HST [10], and from ground-based observations [11, 12] showed 81 confirmed and 23 unconfirmed active volcanic centers on Io's surface. The fly-by observations showed that several hot spots, such as Prometheus, Culann, and Camaxtli, have a significantly more complex structure than previously thought, and that several vent areas can be distinguished within a single volcanic region. A striking correlation between low-albedo deposits and thermal emission is also apparent. Although this general correlation had been noted in previous studies [e.g. 2, 5], regional observations by NIMS at scales of about 20-25 km/pixel show that most dark deposits seen in visible images are sites of thermal emission. This result shows that a larger amount of Io's heat flow than previously thought is being produced by active volcanic centers.

3. Local distribution of SO_2 and correlation with surface colors shown by SSI. The SO_2 ratio maps obtained from NIMS observations show variations that can be interpreted as differences in SO_2 abundance and grain size. We have used the ratio of two wavelengths obtained by NIMS, 4.32 microns (within the deep absorption band centered at 4.1 microns) to 1.19 microns (in the continuum). Comparison of the ratio maps obtained from a global and a regional observation, both taken in I24, with maps obtained from previous orbits by Doute' et al. [4] show that the ratio primarily describes the SO_2 abundance. A particularly striking map is that of the Prometheus regional observation taken in I24. The fallout from the Prometheus plume is readily apparent in the NIMS SO_2 map, giving the first direct measurement of SO2 condensing from this plume. The ring is asymmetrical. The highest SO_2 concentration is located on the outside of the ring that appears white in the visible images. Detailed comparison of the visible images with the NIMS SO_2 map shows a general lack of correlation between SO_2 concentration and high albedo areas. S_8 may contribute to the visible white areas. Higher resolution observations of the Tohil, Amirani, and Culann regions show local higher concentrations of SO_2 coinciding with deposits that appear red at visible wavelengths. Red deposits are thought to be short-chain sulfur compounds [13] and are generally associated with hot spots [2, 5]. It is possible that sulfur and SO_2 are being deposited on the same locations by plumes, and that the correlation detected by NIMS reflects deposition conditions.

4. Correlation between local thermal output, SO_2 distribution, and SO_2 distribution at Prometheus. Observations by SSI during Galileo's first orbit showed that the Prometheus plume site had moved about 100 km west since the Voyager observations in 1979 [14]. Observations by SSI during I24 showed a new caldera just to the north of the Voyager plume site [15], and a long lava flow running between the Voyager and Galileo plume sites. The NIMS observation of the same region showed 2 main hot spots, though thermal emission can be detected by NIMS along the length of the lava flow. The eastern hot spot coincides with the location of the Voyager-era active plume, while the western hot spot is at the same location as the currently active plume. Thermal mapping reveals that the eastern hot spot has a higher temperature than the western hot spot, consistent with the lava flow vent being at the same location as the Voyager plume site. It is possible that the present plume results from the interaction between hot lava and the underlying SO_2 snowfield, emerging either from the margins or through conduits created within the lava flow. Images of other plume sites obtained by SSI [15] suggest that this plume generation mechanism may be happening at other locations. Theoretical work [16] is currently underway to understand the thermodynamics of this proposed mechanism.

These initial results provide new insights into Io's surface processes and allow us to better understand our previous global-scale observations. Attempts are currently underway to correct the NIMS grating anomaly so that observations from the I27 flyby will obtain the full NIMS wavelength coverage. Observations in I27 will include the persistent hot spots Prometheus and Pele, the new fire fountain hot spot Tvashtar, and Chaac, an area rich in green deposits that was found to be volcanically active from NIMS observations in I25.

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