GLOBAL DISTRIBUTION OF ACTIVE VOLCANISM ON IO AS KNOWN AT THE END OF THE GALILEO MISSION.

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Introduction: Hot spots are manifestations of Io's mechanism of internal heating and heat transfer. Therefore, the global distribution of hot spots and their power output has important implications for how Io is losing heat [1-4]. The end of the Galileo mission is an opportune time to revist studies of the distribution of hot spots on Io, and to investigate the distribution of their power output.

Global Distribution of Hot Spots: Observations performed by Galileo's Near-Infrared Mapping Spectrometer (NIMS), Solid State Imaging System (SSI) and Photopolarimeter Radiometer (PPR) have revealed numerous hot spots not previously known from Voyager, HST, or ground-based observations. The latest compilations of locations of known hot spots on Io are given by Lopes et al. [5] and Rathbun et al. [6], totaling 166 hot spots. The key point about the new data, particularly in the case of NIMS, is that high-spatial resolution, global-scale observations were made in the last two Io fly-bys (I31 in August 2001 and I32 in October 2001) specifically to investigate the distribution of hot spots, many of which could not be detected from previous observations at lower spatial resolution. We compare this distribution with those of active and inactive (or dormant) volcanic centers and calderas, and with previous results from NIMS.

Summary of previous results: The global distribution of hot spots on Io using all data available during the first 10 orbits of Galileo (61 hot spots total, Lopes-Gautier et al. [7]) showed that hot spots were distributed fairly evenly with latitude and longitude, with no significant variations apparent. However, the most persistent hot spots (e.g. Pele, Prometheus) were concentrated towards the lower latitudes. This work also showed that NIMS was able to detect bright hot spots at high emission angles, thus making it unlikely that hot spots of similar brightness to Pele, Prometheus, Malik and other persistent hot spots were "hidden" at high latitudes.

Other studies have focused on the distribution of all volcanic centers, whether they had been observed to be active or not. Carr et al. [8] concluded that the large-scale distribution was uniform with longitude, but appeared to exhibit a lower density at high latitudes. Results from Schenk et al. 2001 [9] confirmed the suggestion that there are relatively fewer volcanic centers at high latitudes. Their data indicated a 30-40% greater than expected abundance of volcanic centers in the equatorial region. Schenk et al's investigation with longitude revealed that the highest areal densities of volcanic centers are near the sub- and anti-Jovian regions, a bimodal distribution that is consistent with models of asthenospheric tidal heating [e.g. 4].

Radebaugh et al. [10] examined the distribution of paterae taking their sizes into account and concluded that there are fewer and larger paterae at high latitudes, suggesting that the character of the eruptions may be different nearer the poles than at the equator. The distribution with longitude showed definite peaks at 330^0W and 150^0W, near the sub-Jovian and anti-Jovian points. (More recent work by Radebaugh et al. is reported in this volume).

Current investigation: We have used the locations of the 166 hot spots currently known to investigate how their distribution compares with the above results. We have examined our data in two different ways. First we considered all known hot spots, not taking into account that Galileo observations favored the anti-Jovian hemisphere and that hot spots were detected from observations at various spatial resolutions. As pointed out in previous studies [5,7,11], for NIMS observations the detection of hot spots is largely dependent on the spatial resolution of the observation.

In order to eliminate the bias of the data set with respect to spatial resolution, our second analysis was made using only hot spots detected from the I31 and I32 NIMS global-scale observations, at spatial resolutions from 34 to 88 km/NIMS pixel.

The results of the first method, including all known hot spots, largely agree with those from Radebaugh et al. [10] and Schenk et al. [9]. However, with respect to longitudinal distribution, only the peak at the anti-Jovian hemisphere, near 150^0 W, was apparent in our data set. This is probably due to Galileo observations (which comprised the bulk of the data set) favoring that hemisphere. With respect to latitude, the excess at the lower latitudes reported by the previous studies [8.9] was not found to be significant in the distribution of hot spots, though we have found a decline at latitudes > 60^0S. Such a decline would also be apparent for the northern latitudes if Galileo had not obtained high spatial resolution observations of the Tvashtar region [5].

The results of the second method, using only 78 hot spots detected from the highest spatial resolution global-scale observations, showed no significant departure from an uniform distribution with latitude, though at these spatial resolutions no hot spots at latitudes higher than 70^0 were detected. The total longitude range covered by these observations was from 70^0 W to 250^0 W. More than 50% of the hot spots detected were between 100^0 W and 160^0W, thus slightly offset from the 150^0 W peak found for the paterae by Radebaugh et al. [10].

The distribution of hot spots on the surface is useful for constraining models of internal heating, if we assume that the hot spots represent the major pathways of magma to the surface and can therefore reflect the distrubution of total heat flow. However, hot spots differ significantly in their power output (e.g. [5]) so it is important to compare the results of the distribution of hot spots with those obtained from measurements of power output.

Distribution of Power Output: Most of Io's heat flow is radiated at wavelengths longer than 10 microns [12], beyond the 1 to 5 micron range that NIMS can observe. However, NIMS can detect the power output from active volcanic regions, down to the lower limit of 180 K for a filled pixel. Therefore, we can use NIMS data to measure the relative power output from different hot spots and to compare these results with those from the global distribution of hot spots and volcanic centers. Previous results obtained from NIMS low spatial resolution observations [13] showed that the power output (for the anti-Jovian hemisphere) was mostly from the equatorial regions (latitudes $<45^0$).

In order to extend these analyses to higher spatial resolutions, we used the three highest spatial resolution global–scale observations obtained by NIMS in orbits I31 and I32 as mentioned above. Because these observations were taken in reflected sunlight, we have not used the shortest NIMS wavelengths and have calculated power at the single wavelength of 4.7 microns.

The results show that the power output at 4.7 microns in equatorial regions ($\pm 30^0$) is about twice that of the higher latitudes. This agrees with the earlier conclusion by Lopes-Gautier et al. [7] that the most persistent and brightest hot spots are located near the equator, even though the hot spots appear to be uniformly distributed on Io.

We have also examined the variations in power output of the hot spots in these 3 observations, but they were not found to be sufficiently high to invalidate the conclusions. The major variation detected was in Gish Bar, which brightened considerably at NIMS wavelengths between I31 and I32 [5, 14].

Eruption styles and latitude: Previous work [7] addressed the lack of detection of hot spots at high latitudes by NIMS and concluded that it was not simply due to the spacecraft viewing angle. The sub-spacecraft point for all Galileo global-scale observations was close to equatorial, therefore, hot spots at high latitudes were viewed at lower spatial resolutions than those at the equatorial regions. However, the global-scale observations at high spatial resolution obtained in I31 and I32, taken with the purpose of detecting hot spots at all latitudes, failed to reveal previously unknown hot spots at high latitudes, although they detected numerous at lower latitudes.

Our conclusions here confirm that the lack of detection of high latitude hot spots is not simply due to viewing geometry. The brightest hot spots are located at lower latitudes and many of these have been detected near the limb (thus at high viewing angle) in other NIMS observations.

The nature of high latitude volcanism still remains a puzzle. Only two hot spots have ever been detected at latitudes higher than 70^0. Although it is possible that topography plays a role in hiding high-latitude hot spots from view, if these locations erupted extensive flows or fire fountains, they would have been detected by NIMS. It is likely that the style of volcanism is significantly different at higher latitudes, a suggestion already put forward by others. Radebaugh et al. [10] reported that there are fewer but larger paterae at high latitudes. Either these paterae house eruptions that are too faint to be detected by NIMS, or else eruptions at high latitudes may be more sporadic but more violent [15], perhaps predominantly of Pillanian type. This last suggestion is consistent with the findings of Geissler et al. [16] who suggested that explosive polar eruptions tended to be episodic, while those at lower latitudes are usually persistent and smaller.

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