GALILEO'S LAST FLY-BYS OF IO: NIMS OBSERVATIONS OF LOKI, TUPAN, AND EMAKONG CALDERAS. Rosaly M. C. Lopes[1], L.W. Kamp[1], A.G. Davies[1], W.D.Smythe[1], R.W. Carlson[1], S. Doute'[2], A. McEwen[3], E. P.Turtle[3], F. Leader[4], R. Mehlman[4], J. Shirley[1], M. Segura[5]. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109 (rlopes@lively.jpl.nasa.gov), [2]Observatorie de Planetologie de Grenoble, France, [3]Planetary Imaging Research Laboratory, University of Arizona, [4]IGPP, University of California at Los Angeles, [5]Goddard Space Flight Center.

Introduction: The last two fly-bys of Io by Galileo (I31 in August 2001 and I32 in October 2001) have obtained spectacular observations of some of Io's most intriguing volcanic centers. This paper will discuss observations from the 2001 fly-bys of Io and present preliminary results from the last Galileo Io fly-by (I33, January 2002). The I33 encounter will view Io's Jupiter-facing hemisphere at high spatial resolution, a "first" for Galileo.

We focus our analysis of I31 and I32 observations on three calderas: Loki, Tupan, and Emakong. Our results suggest that all three may contain lava lakes, but their levels of activity are quite different. Loki's caldera size and power output at 4.7 microns are considerably larger than those from the other two. Previous studies have shown that Loki's power output shows significant changes with time, perhaps in a periodic way. The Tupan caldera may contain lava lake. NIMS observations show that Tupan's activity is fairly steady, unlike Loki's. Emakong is very faint at NIMS wavelengths, but a high resolution observation shows that the distribution of thermal emission may also be indicative of a lava lake. The NIMS observations of Pele, a caldera also thought to contain a lava lake, are discussed by Davies et al. (this volume). The new observations presented here suggest that lava lakes may be common on Io, perhaps much more than on Earth, possibly reflecting differences in magma composition.

Loki: This is the most powerful volcano on Io, and the one most frequently observed from Earth. It is known that Loki has been continuously active for at least a decade [e.g. 1, 2] and probably for considerably longer. Despite a wealth of observations, the mechanism of eruption remains unclear and it has not been possible to distinguish between two explanations: is Loki a caldera that is continuously flooded by lava flows or is it a lava lake? A NIMS observation obtained earlier during I24 suggested a lava lake [3] but the results were not conclusive.

The NIMS observation obtained during I32 strongly suggests a lava lake and initial results support the model proposed by Rathbun et al. [2]: Loki is a lava lake that periodically overturns, leading to the observed patterns of brightening and fading. In this model, a wave of resurfacing by silicate magma propagates around the caldera starting in the southwest corner. The wave starts when the crust on the lake founders, exposing hot material. PPR observations of Loki obtained during October 1999 and February 2000 [4] were interpreted as the movement of the foundering front across the floor of the caldera at a rate of approximately 1-2 km/day [2].

NIMS observed Loki during I32, with a resolution of ~2-3 km/pixel. The caldera was in darkness, allowing temperature determinations to be made from the data without the need to extract the reflected sunlight component. This large observation, targeting the southern portion of the caldera, was intended to test whether the temperature distribution on the caldera floor was more consistent with that of a lava lake or multiple lava flows. Two-temperature fits were made to each NIMS pixel (Figure 1). The high temperature component map shows a hot region adjacent to the southwest margin of the caldera, where the model of Rathbun et al. [2] suggest the resurfacing wave starts. A colder region is seen immediately to the east of this area that likely represents the oldest crust resulting from the previous resurfacing wave.

The lower temperature component (which occupies most of the area of each pixel) was used to determine the age distribution of the pixels across the caldera. Each temperature was assigned an age, based on the cooling of silicates on Io [5]. An initial profile of ages across the floor of the Loki caldera shows the youngest area of the flow is at the western margin of the caldera. Surface age then decreases towards the east, with one west-east profile (covering about 110 km) producing an age differential in excess of 100 days. This age distribution is consistent with the lava lake overturn model of Rathbun et al: the oldest crust is closest to the active margin, and decreases in the direction of the foundering wave.

Tupan: This caldera has been active since at least June 1996, when its thermal activity was first detected by NIMS [6]. During the I32 fly-by, both SSI and NIMS obtained high resolution observations of Tupan [7, 8]. The SSI image revealed dark material covering the eastern part of the caldera, an "island" in the center, and patches of dark material on the western side, which may represent flows over a crusted lava lake surface [Keszthelyi et al., this volume]. The NIMS observation, at about 8 km/pixel, shows that most of the thermal emission is located on the eastern side of the caldera, coinciding with the larger area of dark material seen in the SSI images. The "island" is sufficiently cold in its center for SO_2 frost to form. The distribution of SO_2 frost around Tupan is asymmetric: considerably more SO_2 is seen to the east of the caldera than to the west. It is possible that more degassing of SO_2 is happening from the eastern side, or else the area to the west of the caldera may be warm (but below the detection limit of NIMS), preventing SO_2 from condensing.

Tupan appears similar to Loki in its thermal structure: both calderas contain large areas of dark, hot materials surrounding a cold "island" (or topographically high area). The SSI image is suggestive of a lava lake [8]. However, there are significant differences in the level of activity of the two hot spots: the power output from Tupan obtained from NIMS observations (at 4.7 microns) is considerably lower than from Loki, and has not shown variations greater than 30%. The power output at 4.7 microns from Tupan obtained from observations during the fly-bys has ranged from $(45.3\pm4.5) \times 10^8$ Wμ-1 to $(64.0\pm6.4) \times 10^8$ Wμ-1. Power output obtained from earlier, distant NIMS observations [e.g. 6] has also remained similarly steady. If Tupan is a lava lake, it has not been observed to have the violent crust-foundering/resurfacing events discussed for Loki.

Emakong: This dark caldera, located in the center of Bosphorus Regio, was first detected as a hot spot from a NIMS observation obtained during November 1999 [3]. Emakong is orders-of-magnitude fainter at NIMS wavelengths than either Tupan or Loki and had not been detected as a hot spot from distant NIMS observations of Io. The power output from Emakong (at 4.7 microns) was measured to range from $(0.2\pm0.1) \times 10^8$ Wμ-1 to $(0.4\pm0.2) \times 10^8$ Wμ-1. SSI observations show that Emakong's dark caldera floor has a uniform appearance. No "island" or topographic differences can be seen in the available data. NIMS observations obtained during I25 and I27 showed a peculiar spectrum of the caldera floor, with thermal emission and SO2 absorption indicating that pixels of about 25 km2 contained both warm regions (at about 300K) and areas cold enough for SO_2 to condense [3]. An observation of Emakong obtained during I32 (at about 5 km/pixel) revealed the thermal structure within the caldera: warmer regions are concentrated around the edges of the caldera. This is more consistent with a lava lake rather than a flooded caldera, as the crust of a lava lake tends to break up as it abuts against the caldera walls. However, if Emakong is a lava lake, its activity has been at very low levels since Galileo has started observing this region in June 1996. An alternative possibility, raised by analysis of the flows surrounding Emakong [9], is that the caldera floor may contain a sulfur lake.

Since the temperatures obtained from NIMS observations are minimum temperatures [3], the possibility that the Emakong caldera contains cooling silicate flows cannot be excluded. Temperatures detected by NIMS at Tupan and Loki are consistent with those of silicate lavas [e.g. 3, 10, 11]. Temperatures consistent with ultramafic compositions have been detected at Pele [3]. Temperatures in the ultramafic range have never been detected at Loki, despite the proposed model of crust foundering which would presumably expose large areas of hot materials.

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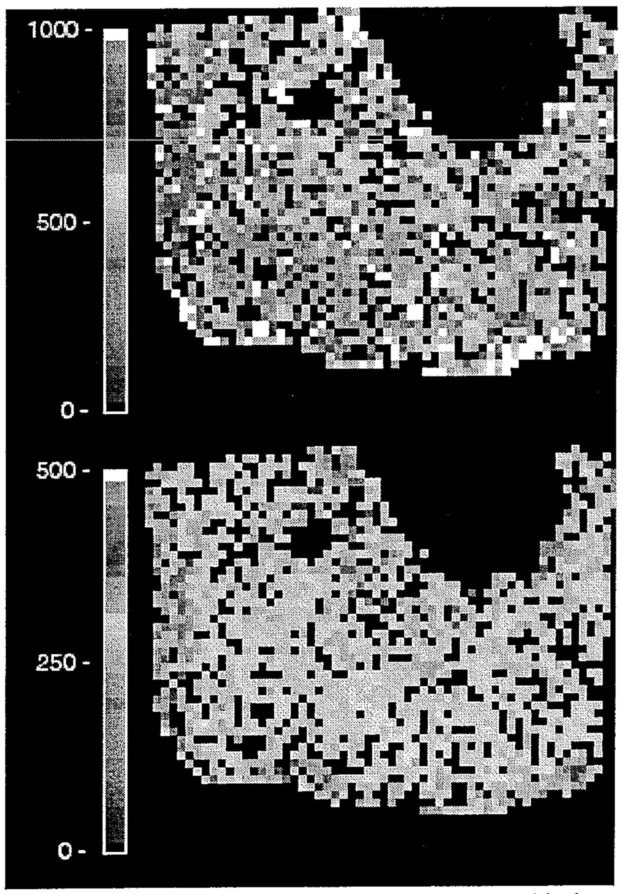

Fig. 1: Two-temperature fits to the NIMS Loki observation from I32. Top: high temperature component. Bottom: low-temperature component. Note the hot margins along the caldera wall in the top map.