ACTIVE VOLCANOES ON IO: RESULTS OF GROUND-BASED OBSERVATIONS FROM IRTF 2017-2020. J. A. Rathbun[1], C. D. Tate[2], A. G. Hayes[2], and J. R. Spencer[3], [1]Planetary Science Institute (rathbun@psi.edu), [2]Cornell University, [3]Southwest Research Institute.

Introduction: We have continued our two-decade long campaign to observe Io's active volcanoes from the InfraRed Telescope Facility (IRTF) on Mauna Kea in Hawaii. Our observations can be divided into two types. The first is observing Io while it is in eclipse and being occulted by Jupiter. This enables the elimination of reflected sunlight so that all observed emission is from active volcanoes on Io's surface. The timing of emission appearing (or disappearing) behind Jupiter's limb also gives its one dimensional location on Io. However, only the sub-Jovian hemisphere can be observed using this method. In order to detect volcanoes in other areas on Io, we also observe Io at random times when it is visible. Of course, these observations also include reflected sunlight, so only very bright volcanoes can be detected.

Both types of observations include obtaining images in K-, L-, and M-bands. But the occultation lightcurves themselves can only be observed in a single band, generally L-band.

Our observations have been used to understand the behavior of Loki, the most powerful volcano on Io [1-2], monitor sporadic eruptions [3], put spacecraft observations into long-term context [4-5], and search for possible correlations with phenomena in the Jovian magnetosphere [6].

Loki: The dominant volcano in most occultation lightcurves is Loki, which can generally be observed at an occultation phase of ~0.8. It is the most powerful volcano on Io and, when active accounts for nearly 15% of the moon's total heat output [7]. As such, it is also the best-studied volcano on Io. From 1988 through 2000, Loki erupted periodically with approximately 540 days between events, which we interpreted as overturning of the lava lake [1]. After a hiatus with few observations and no apparent pattern to its brightness, Loki began erupting periodically again in 2013, this time with a period of ~475 days [8-9]. Based on that period, Loki's most recent eruption would have started in September 2019. However, based on our observations, it began erupting between 29-Oct-2019 and 15-Feb-2020, during a gap in our coverage due to solar conjunction (Figure 1). The eruption ended between 4-Jul-2020 and 7-Aug-2020. Loki was still in a quiescent state during our last observation on 9-Dec-2020. Based on the 475-day period, and assuming that the previous eruption began in November 2019, the next eruption should begin in February/March 2021, which will unfortunately be difficult to observe.

Janus, Uta, and Kanehekili: Another volcano, which is located at an occultation phase of ~0.3, has

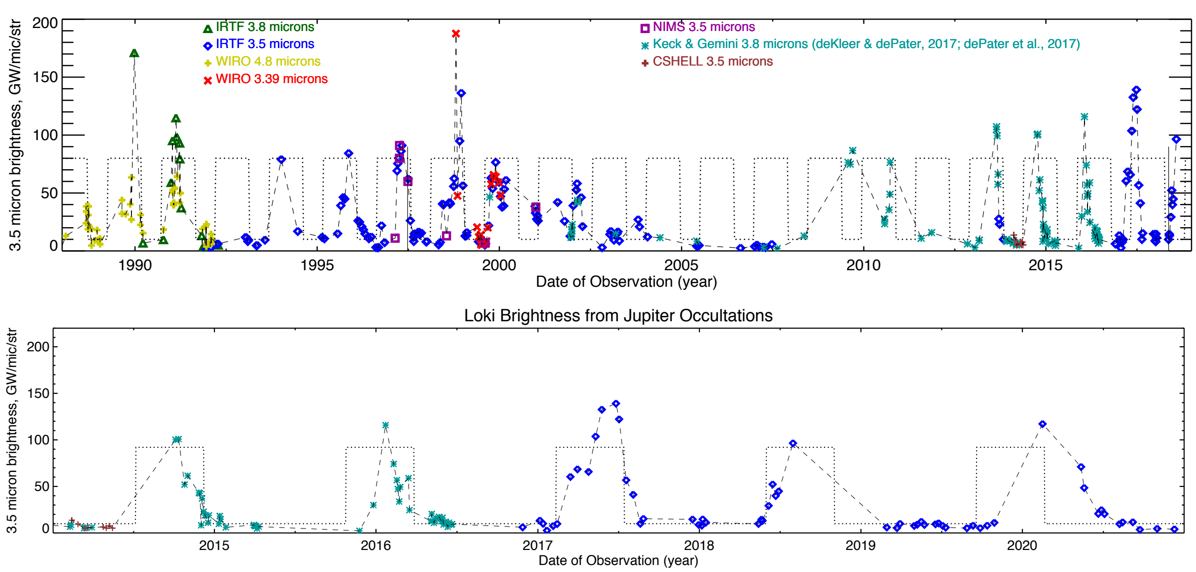

Figure 1: The brightness of Loki as a function of time from various sources. The upper panel shows the total available time history while the bottom is only the past 5 years. The square wave in the background is the original 540-day period.

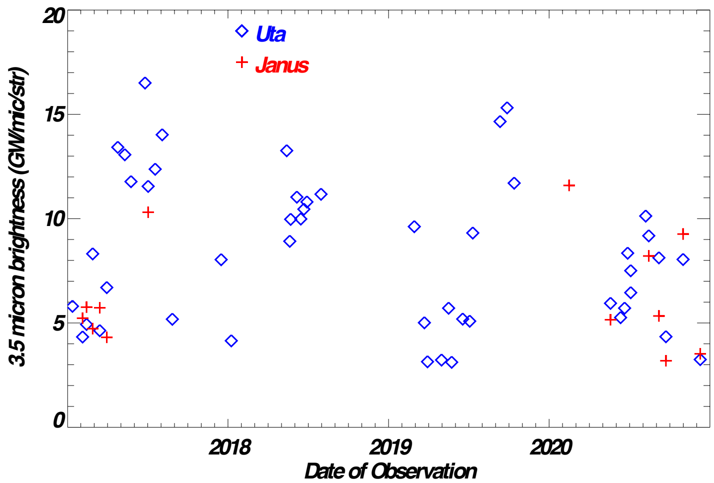

Figure 2: The brightness of Uta and Janus from Jupiter occultations.

been obvious in lightcurves acquired over the last two decades. We have previously interpreted this as the sum of Janus and Kanehekili since they cannot be resolved in our data [3]. However, based on recent observations from Keck and Gemini (which have better spatial resolution than our observations [10]), Uta and Janus were dominant during our 2017-2020 observations. Examination of Jupiter's limb at the times of the occultation of this volcano also suggest activity at both Uta and Janus. Figure 2 shows the brightness of these two volcanoes as determined from occultation lightcurves. Uta was detected more often than Janus, which isn't surprising since Janus is closer to Jupiter's limb. With the exception of the January 2020 observation of Janus, every time Janus was observed Uta was also observed.

Outbursts: Between 2017 and 2020, we detected 4 outbursts on Io [11], which are defined as eruptions that more than double Io's 5-micron intensity. Three of these outbursts were detected in occultation lightcurves, so their one-dimensional location can be determined. Because the observations were obtained in 3 wavelengths and while Io was in eclipse, we can also estimate temperatures for these volcanoes. The other outburst (observed in 2018) was observed only in 3.5-micron images of a sunlit Io, so a temperature cannot be determined and the location is not precisely known (table 1).

Two of the outbursts observed were also detected at 3.8-microns within 10 days after the original observation and each was observed to decay by more than an order of magnitude before the next observation. This suggests that frequent observations are necessary to detect outbursts [11].

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References: [1] Rathbun, J. A. et al. (2002) *Geophys. Res. Lett., 29(10)*, doi:10.1029/2002GL014747. [2] Rathbun, J. A. and Spencer, J. R. (2006) *Geophys. Res. Lett., 33*, doi:10.1029/2006GL026844 [3] Rathbun, J. A. and Spencer, J. R. (2010) *Icarus 209*, 763-769. [4] Howell R. R. et al. (2001) *J. Geophys. Res. 106*, 33129-22139. [5] Rathbun J. A. and Spencer J. R. (2007) *LPS XXXIII,* Abstract #2162. [6] Rathbun J. A. et al. (2014) *LPS XLV,* Abstract #1180. [7] Spencer J. R., et al. (2000) *Science 288,* 1198-1201. [8] Rathbun, J. A. et al. (2018) *LPSC 49,* abs. no. 2209. [9] deKleer, K. et al. (2019) *Geophys. Res. Lett., 46*, doi:10.1029/ 2019GL082691. [10] deKleer K. et al. (2019) *AJ 158*, 29. [11] Tate, C. D. et al. (2020) *DPS abs. 315.04.*

Table 1: Locations and other derived quantities for the 4 outbursts detected in the IRTF data [11].

Date UT	Location Name	Longitude	Latitude	Wavelength range (microns)	Temperature (K)	Radius (km)
10-May-2018	UP 254W	255 ± 5	-37 ± 2	3.8	960 ± 100	-
8-May-2019	1905A	320 ± 20	40 ± 40	2.3-4.8	1200 ± 110	4 ± 1
25-Jun-2019	1906A, Surt?	330 ± 20	45 ± 30	2.3-4.8	1170 ± 80	3.1 ± 0.5
15-Oct-2020	2010A	25 ± 20	-5 ± 70	2.3-4.8	1260 ± 70	3.6 ± 0.6