LARGE VOLCANIC OUTBURSTS ON IO MEASURED FROM GROUND-BASED OBSERVING

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Introduction: Io's radiative output is dominated by a few large volcanoes like Loki, which has a semi-predictable eruption cycle with a 1 to 1.5-year period throughout the last thirty years of ground-based observations [1-5]. This study updates that long-term observation campaign and extends it to exploring the total volcanic output in multiple infrared bands. In the IRTF time-series dataset of Io's activity, the largest to date total 3.5-micron brightness was observed on May 8th, 2019 when Loki was not in an eruption phase. This event is a case study of large outbursts that could influence particle-count Io's atmosphere and the Jovian magnetosphere.

Our IRTF observing campaign includes measuring the total brightness, in multiple infrared wavelengths, of an eclipsed Io as Jupiter occults it. Because Io is tidally locked in its orbit, these observations include only the sub-Jovian hemisphere. Here, we report on results of those observations

Loki Eruption Prediction Update: Loki is Io's largest, most powerful, and best-studied active volcano. When erupting, it accounts for nearly 15% of the total heat output from Io [6]. It is generally bright enough that it can easily be observed using ground-based telescopes, and its brightness has been measured hundreds of times over the past 30 years [1-5]. Early work based on both spacecraft and ground-based data determined that Loki erupted periodically and suggested that Loki is a large overturning lava lake [1]. More recent work has built on that original model [3,7-9]. Our collection of all available data from 1998 –2018 includes more than 300 data points from 3 different telescopes over 30 years (Figure 1). [10-11]. These data show that Loki erupted with a 540-day period between 1989 and 2001 and a 475-day period between 2013 and 2019. Between these intervals, Loki exhibited no measurable periodicity.

Last year, we predicted that the next Loki eruption would occur in the Fall of 2019 [10-11]. Our most recent IRTF observation was on October 29th, 2019; since then, the Jupiter system has been too close to the Sun to make observations. As of that date, Loki has not begun its next eruption. This suggests that either Loki's periodicity has changed, perhaps lengthening, or that it has again entered a phase without periodicity. We have applied for IRTF telescope time beginning in February and will report further on Loki's behavior.

Table 1. Table of Io brightness events greater than 100 GW/μm/sr from Io's sub-Jovian hemisphere in eclipse.

Date	**Io Brightness** [GW/μm/sr]	**Loki Brightness** [GW/μm/sr]
6/25/2019	106	5.2
5/8/2019	**270**	**6.8**
11/6/2003	216	20.9
2/20/2000	169	12.7
6/22/1999	205	6.3
10/6/1996	150	8.8

Bright Outbursts: The 2019 Io observing campaign witnessed two of the highest half-dozen outburst events seen to-date. Figure 2 shows the total brightness of the sub-Jovian hemisphere of Io while in

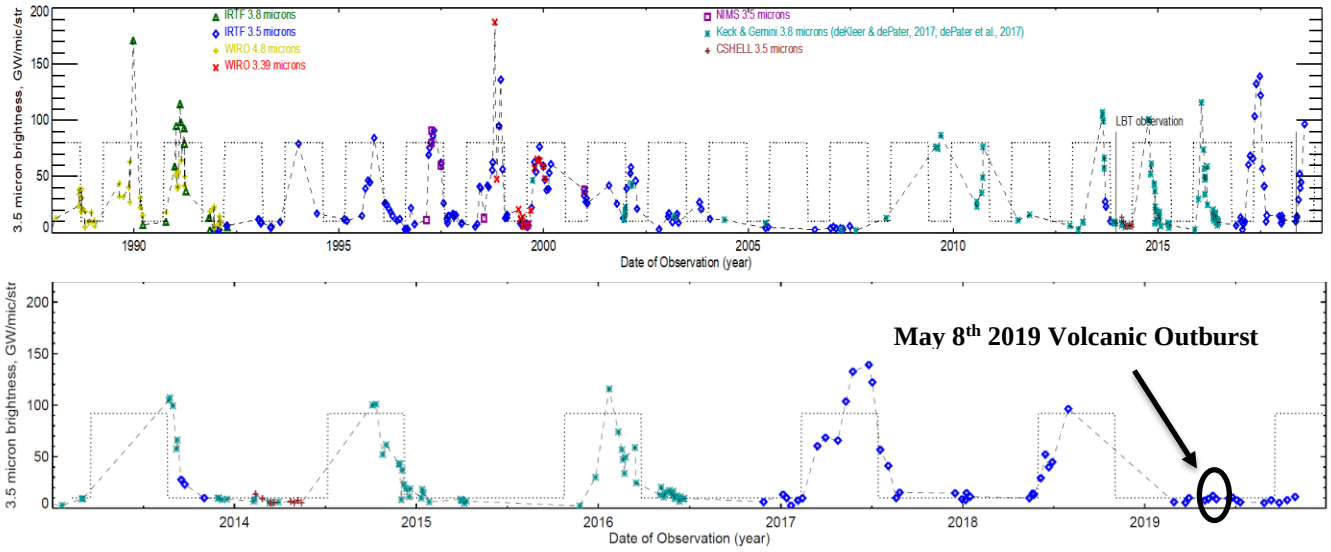

Figure 1. The time-series of Loki's brightness from various datasets. The upper panel shows the total available time history (the square wave is the original 540-day period) and the bottom is only the past 5 years (the square wave is the more recent 475-day period).

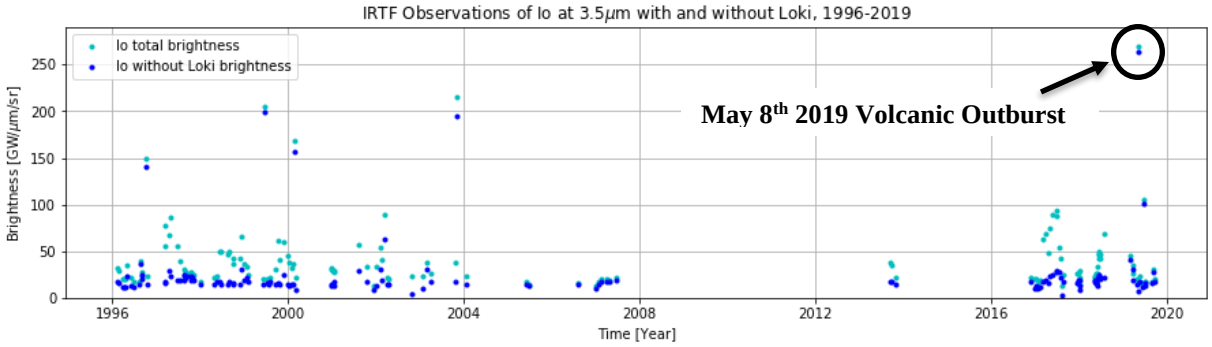

Figure 2: The time-series for Io's sub-Jovian brightness in eclipse with and without Loki's contribution at 3.5 microns. This is a proxy for the activity of Io's other volcanoes. The lack of a dominant periodicity shows that the aggregate volcanic activity is not as regular as Loki.

eclipse both before and after the corrected brightness of Loki is removed. The typical background brightness of Io hovers around 20 GW/μm/sr and does not exhibit any regular periodicity over this time frame. Six outburst events, where Io's total brightness (minus Loki) is greater than 100 GW/micron/str were observed (table 1). Two were in 2019 and the others were all before 2004. We measured the periodicity of these events with the Lomb-Scargle Periodogram and Phase Dispersion Minimization methods and found no dominate frequency. This finding supports the conclusion that these outbursts are semi-random events within this dataset.

On May 8th, 2019, we measured Io to at a higher brightness than ever before observed. Since Loki is not active during this event (Figure 1), the observed activity must be due to the eruption of another volcano(s). This study will present the location(s) of the outburst events(s) and use the brightness measured at other wavelengths to constrain the nature of these outbursts.

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