EPSC Abstracts
Vol. 6, EPSC-DPS2011-1645, 2011
EPSC-DPS Joint Meeting 2011

Tidally-controlled volcanism at Loki Patera, Io?

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Abstract

We compare the time-varying thermal emission from Io's Loki Patera to calculations of tidal stress caused by Io's orbital eccentricity. Our preliminary analysis supports the hypothesis that tidal stresses influence the timing of Loki emission.

1. Introduction

Three of Jupiter's large satellites – Io, Europa, and Ganymede – participate in an orbital resonance that forces their eccentricities to be non-zero [8]. Astrometry indicates that Io's extensive volcanic activity and Europa's probable liquid water ocean are sustained by the tidal heating generated as the moons deform throughout each orbit [7]. The daily changes in stress due to Europa's eccentricity (and obliquity) have been shown to correlate well with the shapes of tectonic features called cycloids [11] and the distribution of strike-slip faults [e.g. 12]. Ridges observed in high-resolution images of Io have also been linked to eccentricity-driven tidal stress [1].

Loki Patera is a presumed lava lake measuring 200 km in diameter [3]. Volcanic thermal emission at Loki was observed by Voyager 1, and Earth-based observing has shown that Loki exhibits temporal variation in its thermal emission [9][14]. This emission sets Loki apart as the most powerful volcanic feature in the solar system. We investigate the possibility that tidal stresses influence activity at Loki Patera. We hypothesize that cracks in Loki's cooling lid are either formed or widened due to tidal stresses, leading to increased emission.

To investigate the influence of tidal stress, we first phase-wrap observations of Loki's thermal emission at the tidal period of 1.7627 days. This value is 0.4% less than the orbital period due to Io's negative rate of perihelion precession. We also compute the maximum tensile tidal stress at Loki's location throughout an orbit. Our preliminary results show that the peak observed flux occurs at the same time in the orbit as the peak tensile tidal stress, but with considerable scatter in the flux values.

2. Observations of Loki Patera

We obtained a compilation of measurements of Loki flux compiled by Julie Rathbun [9][10], mostly at 3.8 μm. We excluded observations for which Loki was disappearing behind Io's limb (emission angle > 66°). To extend the dataset, we added observations at 4.8 μm from the Wyoming IR Observatory [4]. Note that the full-disk sunlit photometry from the WIRO dataset is considered questionable [5] and was thus excluded from our analysis. We included additional published data (Galileo NIMS [2], Voyager 1 IRIS [15], and other ground-based observatories), but these observations were few in number compared to the Rathbun and WIRO compilations.

3. Tidal stresses at Loki

Galileo magnetometer data along with interior models strongly suggest that Io has a magma ocean layer beneath its lithosphere [6]. Hence, the thin shell approximation often applied to Europa [e.g. 11] may also be reasonable for Io. The equations for tidal stress in a thin shell are well known and have been modified to account for orbital eccentricity [e.g. 11].

Our preliminary results are shown in Figure 1. The observed data, with different symbols representing different data sets, are phase-wrapped at the tidal frequency. We have overlain this data with the calculated maximum tensile tidal stress over the same time period, shown by the red line near the top of the figure (the vertical position of this curve is arbitrary). The stress includes only the effects of Io's eccentricity, and is given in bars. Here, positive is tension. The overall structure of the tidal stress curve agrees well with the observations. Emission is enhanced when the tidal stress at Loki is tensile. The flux is lower when Loki experiences compression.

In future, we will add additional data sets, apply statistical techniques to determine the significance of any correlations, and compare the results to Loki's previously-reported 540-day periodicity [9].

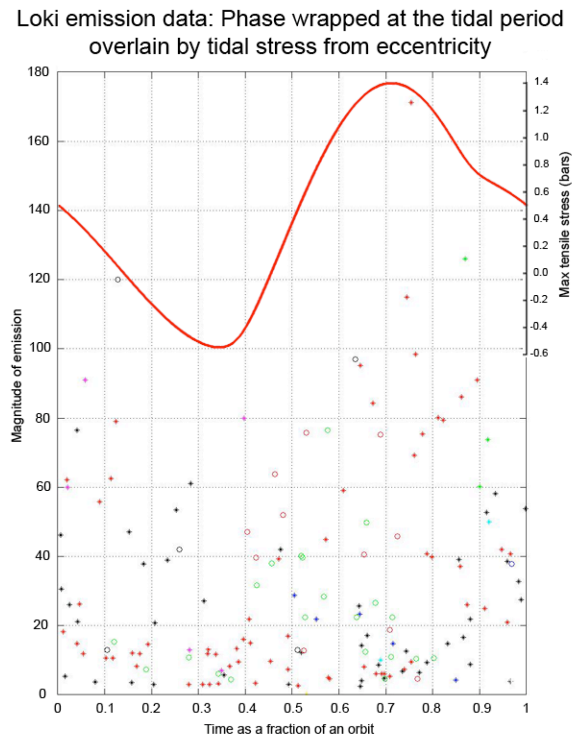

Figure 1: Observations of the thermal emission at Loki overlain with the tensile tidal stress at Loki (red line). The colored symbols represent different data sets. See section 2 for details of the observations.

3. Conclusions

Tectonic features on both Io and Europa have been linked to daily-varying tidal stress caused by orbital eccentricity. Our preliminary work shows that Loki Patera may also be influenced by tidal stress. Thermal emission at Loki changes with time and appears to correlate with tidal tensile stress.

Acknowledgements

The authors wish to thank Julie Rathbun for providing the observation data, and Robert Howell and Ashley Davies for helpful discussions.

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