ENCELADUS' PLUME TEMPORAL VARIABILITY FROM ANALYSIS OF CASSINI ISS IMAGES.

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Introduction: Early analyses on sparsely sampled Cassini ISS images of the Enceladus plume spanning the first 6 years of the mission showed that a diurnal variation in plume brightness (hence, mass) with a peak near ~200° in mean anomaly was attributable to the cyclic but out-of-phase variation of tidal stresses across the moon's surface [1, 2]. Using images extending to mid-2015, Ingersoll and Ewald [3] noted a decade-long decline in brightness and suggested 3 possible causes with no preference for any: a long-period Dione:Enceladus resonance, reduced eruptions due to secular clogging of the vents, or seasonal effects. Nimmo et al. [4] also analyzed an extended image data set and found *two* long periods, ~4 yr and ~11 yr, arguing for the action of two periods associated with the Enceladus/Dione 2:1 resonance and dismissing secular clogging or seasonal effects. Neither work used the full set of ISS plume images extending to late 2017.

Here, we present our latest analysis of temporal changes in plume brightness using the final set of ISS plume images spannning the entire Cassini mission.

PeriodicityAnalysis: Images used to study the plume's brightness variations were reduced in a fashion similar to that in [3]: For each of ~2000 clear filter images taken over 11 yrs and used here, the integrated brightness in a horizontal slab crossing the plume, perpendicular to the moon's spin axis, and extending from 100 to 500 km altitude was measured and plotted versus Enceladus' orbital position, or mean anomaly (Fig. 1). Changes over time in the amplitudes of the main peak and of the secondary peak at MA ≈ 55° are clear.

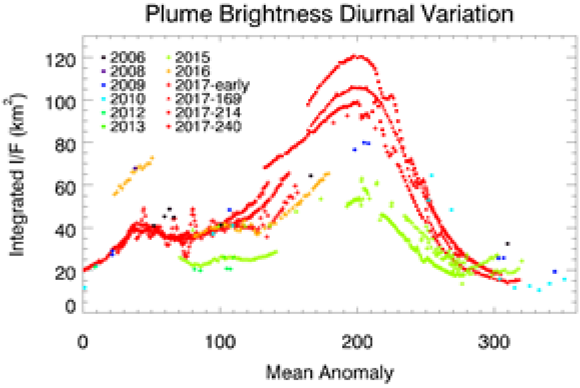

Figure 1. Daily variation in plume brightness, Integrated I/F, with mean anomaly from 2006 through 2017. Long-period changes in amplitude are clearly seen.

Residual integrated I/F's were calculated by subtracting the best-fit diurnal model from the data in Fig. 1. These were then fitted, in turn, to a series of sinusoidal model periods from 3 to 14 years. The results, shown in Fig. 2a, reveal two long-period variations. ["Decimated" case uses only the largest I/F obtained within a specified time interval (0.0003 years). "All Observations" case weights the sparse measurements taken prior to 2015 by a factor of 30 in the misfit calculation.] In Fig. 2b, the deviation of Enceladus' orbit from simple Keplerian motion, minus the diurnal variation due directly to the Dione/Enceladus 2:1 mean motion resonance, has been similarly modelled and plotted, clearly revealing the ~4 yr period due to a Dio-

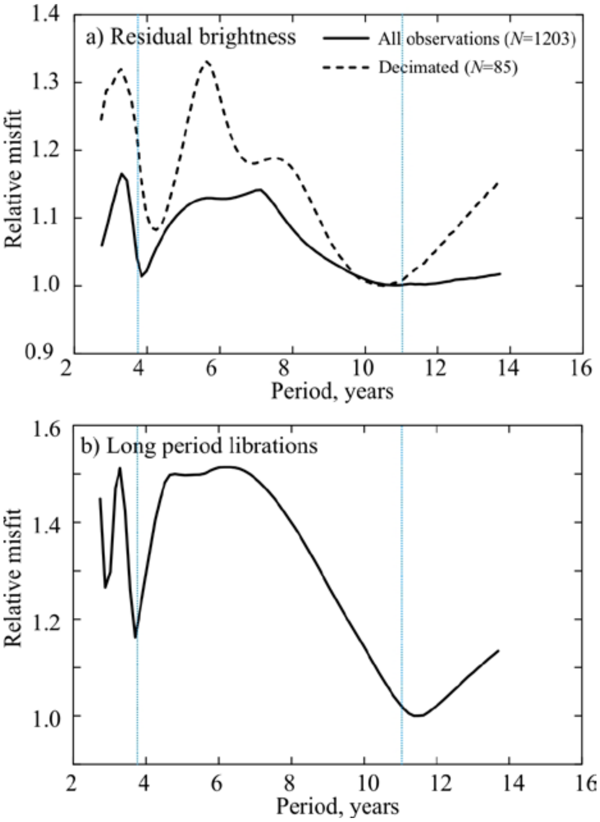

Figure 2. a) Misfit of sinusoidal model to residual I/F's as a function of model period. b) Misfit of sinusoidal model to the long-period libration angle calculated from Enceladus' orbit from 2002 to 2020. Vertical lines are predicted dominant libration periods from [5].

ne/Enceladus co-rotation resonance, and the ~11 yr period due to the libration of the 2:1 resonance.

Conclusions: We affirm the conclusions that the plume mass varies with a total of 3 periods -- diurnal, 4-yrs and 11-yrs – attributable to the dynamically caused cyclic variation in stresses on the moon's ice shell, and that long-term secular effects can be dismissed. We note that the amplitude of the secondary peak near MA ≈ 55º has also changed in amplitude over the course of the mission: While very prominent when observed in 2006 and again in 2016, throughout 2017 it was hardly visible. The origin of this peak has been explored [6] but is still unexplained.

In future work, we will examine the phase of the long-period response relative to the stresses arising from the long-period librations, in order to ascertain whether there is a time lag similar that observed for the short-period response [1]. Doing so will help ascertain the physical origin of the short-period lag which is currently unclear. We will also examine the diurnal and long-timescale changes in the vertical structure of the plume.

References: [1] Nimmo F. et al. (2014) *Astron. J., 148,* 46-59. [2] Behounkova M. et al. (2015) *Nat Geoscience*, *8*, 601-604. [3] Ingersoll A. P. and Ewald S. P. (2017) *Icarus 282*, 260-275. [4] Nimmo F. et al. (2016) AGU, Fall General Assembly 2016, abstract id. P33A-2118. [5] Rambaux N. et al. (2010) GRL *37*, L04202. [6] Helfenstein P. and Porco C. (2015) *Astron. J., 150,* 96-109.

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