

TIDAL CONTROL OF JET ERUPTIONS OBSERVED BY CASSINI ISS. T.A. Hurford¹ and P. Helfenstein² and J.N. Spitale³, ¹NASA Goddard Space Flight Center (Greenbelt, MD 20771; Terry.A.Hurford@nasa.gov), ²CRSR (Cornell University, Ithica, NY 14853), ³Planetary Science Institute (1700 E. Ft. Lowell, Suite 106, Tucson AZ 85719).

Introduction:

Observations by Cassini's Imaging Science Subsystem (ISS) of Enceladus's south polar region at high phase angles has revealed jets of material venting into space [1]. Observations by Cassini's Composite Infrared Spectrometer (CIRS) have also shown that the south polar region is anomalously warm with hotspots associated with geological features called the Tiger Stripes [1,2]. The Tiger Stripes are large rifts near the south pole of Enceladus, which are typically about 130 km in length, 2 km wide, with a trough 500 m deep, and are flanked on each side by 100m tall ridges [1]. Preliminary triangulation of jets as viewed at different times and with different viewing geometries in Cassini ISS images taken between 2005 and 2007 have constrained the locations of eight major eruptions of material and found all of them associated with the south polar fractures unofficially the 'Tiger Stripes', and found four of them coincident with the hotspots reported in 2006 by CIRS [2,3].

While published ISS observations of jet activity suggest that individual eruption sites stay active on the timescale of years, any shorter temporal variability (on timescales of an orbital period, or 1.3 Earth days, for example) is more difficult to establish because of the spotty temporal coverage and the difficulty of visually isolating one jet from the forest of many seen in a typical image. Consequently, it is not known whether individual jets are continuously active, randomly active, or if they erupt on a predictable, periodic schedule. One mechanism that may control the timing of eruptions is diurnal tidal stress, which oscillates between compression/tension as well as right and left lateral shear at any given location throughout Enceladus' orbit and may allow the cracks to open and close regularly [4,5].

We examine the stresses on the Tiger Stripe regions to see how well diurnal tidal stress caused by Enceladus' orbital eccentricity may possibly correlate with and thus control the observed eruptions. We then identify possible mechanisms by which tidal stress can provide access to the surface for volatile material and implications for observed jet activity.

Tidal Stress at Jet Source Locations:

In figure 1, the location of the eight sources identified by Spitale and Porco [3] are shown with respect to the tiger stripes. Sources I, II, III and VI correspond to locations along Damascus and Baghdad sulcus where Cassini CIRS has observed the hottest temperatures and thus the greatest power emitted from the surface [6]. Here we assume that positive detections of plumes

for Sources I, II, III and VI are reliable and are associated with a portion of the Tiger stripe closest to their triangulated source locations. Thus, we focus on the stress at these four source locations and on this basis we compare models of tidal stress variation with the observational record.

We first characterize tensile stress across the Tiger stripes within source regions I, II, III and VI, over the course of Enceladus' orbit, assuming orbital eccentricity is the only source for the stress. Fig. 2 summarizes the results for each of the four source regions, superimposed are the observational results from Spitale and Porco [3]. Here the maximum tensile stress and the maximum absolute shear experienced in the tiger stripe source regions are shown along with the theoretical percent of the region in tension, as a function of orbital position. For each source region, the tiger stripe first experiences tension shortly after pericenter, and in most cases the transition from compression to tension is rapid. By the time Enceladus reaches apocenter, each source region is completely in tension. After apocenter passage the stresses become more compressional, until after pericenter passage, when the cycle repeats.

Throughout the orbit at all source regions, the maximum absolute shear stress experienced remains fairly steady at about half a bar (Fig. 2). During the orbit the shear stress oscillates between right and left lateral senses of shear and the magnitude of shear changes at any given location, but the maximum absolute shear remains somewhat steady over the source region. This is consistent with previous studies which identified source regions are places along the Tiger stripes that experience greater shear [5].

Discussion/Conclusions:

In order for jet activity to occur a conduit from the surface to tap into the reservoir of volatile material must be established. This can be done by 1) tensile stresses directly opening a conduit or by 2) shear failure allowing conduits to form.

Under the assumption that fissures can actively erupt material only while in tension and can remain active as long as the conduit remains open, the majority of the observations of jet activity do occur when each source region is in tension. Of the 26 detections of activity among the four source regions (I, II, III, and VI), 17 or 65% occur at times when the source region is in tension (Fig. 2). This may be a result of the fact that jet observations are more likely to fall in the first half of the orbit when cracks are predicted to experience tension. However, some observations consistently

show activity for each source region at a time when each region is predicted to experience compression. In all, 9 or 35% observations occur when compression is predicted in their source regions. Of these 9, 7 occur while the maximum stress while compressive is becoming more tensile in their source regions. It may be that the assumption of eruptions coinciding with just conditions of tidal tensile stress may be too simplistic. For example, if a subsurface head of volatile material were to build up while a fracture is in compression, significant activity may be possible as soon as a crack begins to experience tension as long as the built up pressure can overcome compressive forces. Indeed, we see that even while in compression, source regions experience minimal compression compared to the levels of tension they experience. Thus, in some regions tidal compression may not be enough to prohibit jet activity altogether. In fact, under the assumption that tidal activity is possible as long as a fracture is transitioning to greater tensile stress or experiencing tensile stress, 92 % of the observations would be possible.

Thus far, we have focused on the link between tension and jet activity, however tidal shear stress may also play a role in eruption activity. Even when a fracture is experiencing compression, shear stress, if large enough, can produce slip along the fault [7]. If the fault were completely smooth and of constant orientation then slip would not produce conduits for volatile escape, however real faults are not smooth and do vary in orientation. Thus, during slip failures openings may form, allowing trapped volatiles to escape and produce jets above the surface. This provides another mechanism to allow observed jet activity to occur even under periods of compression. This mechanism may be best to explain observed activity at Source VI, where jet activity is observed while the fracture is experiencing compression, but the magnitude of the shear stress is great than the compressive stress by over a factor of 2, making near surface slip possible even if friction along the fault is high.

Thus, tidal stress conditions exist that would enable jet activity to occur at the times Cassini ISS observed activity in the 2005-2007 time frame.

References:

- [1] Porco, C.C. et al. (2006) *Science* 311, 1393-1401. [2] Spencer, J.R. et al. (2006) *Science* 311, 1401-1405. [3] Spitale, J.N. and Porco, C.C. (2007) *Nature* 449, 695-697. [4] Hurford, T.A. et al. (2007) *Nature* 447, 541-552. [5] Nimmo, F. et al. (2007) *Nature* 447, 289-291. [6] Howett, C. J. A. et al. (2011) *JGR* 116, 3003. [7] Smith-Konter, B. and Pappalardo, R.T. (2008) *Icarus* 198, 435-451.

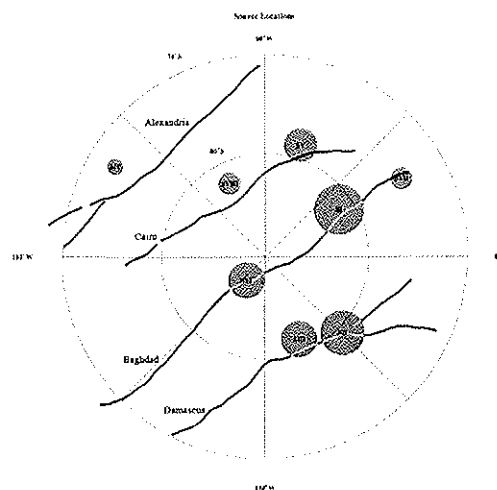


Fig. 1. Source Locations with Respect to Tiger Stripe Cracks. The four major tiger stripe features are shown in the south polar region of Enceladus. The circles indicate the regions active jet as identified by Spitale and Porco [3] and are labeled with a source number designation. When exploring the role of tidal stress on the Tiger Stripes associated with each source region, we focus on the portions of Tiger Stripes (shown in light gray) that lie within the possible source regions of Sources I, II, III, and VI.

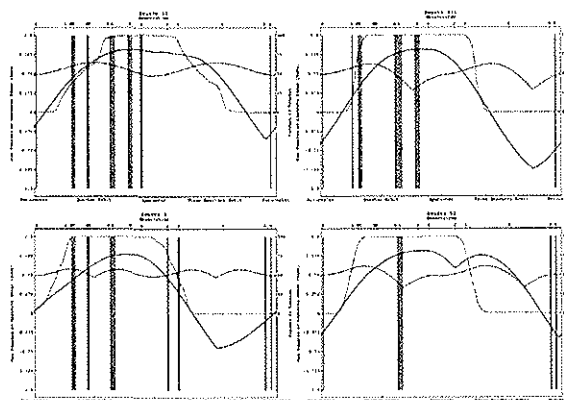


Fig. 2. Activity at each Source Region - Eccentricity Driven Tidal Stress Only. For four source regions along Baghdad and Damascus Sulcus, the maximum tensile stress (solid line) and the absolute shear stress (dashed line) experienced by any part of each source region are shown throughout the orbit along with the fraction of the region experiencing tensile stresses across them (dotted line). For comparison, the observations of jet activity are shown as green shaded bars where they occur in the orbit [3].