

**How the Jets, Heat and Tidal Stresses across the South Polar Terrain of Enceladus Are Related.** C. Porco<sup>1</sup>, D. DiNino<sup>2</sup>, F. Nimmo<sup>3</sup> <sup>1,2</sup>CICLOPS, Space Science Institute, Boulder CO, <sup>3</sup>Earth and Planetary Sciences, UC, Santa Cruz, CA

**Introduction:** The jetting activity observed across the south polar terrain (SPT) of Enceladus and monitored by the Cassini imaging investigation (ISS) over the last 8 years, has previously been shown [1,2] to be roughly spatially coincident with the excess thermal radiation emitted by the 'tiger stripe' fractures crossing the SPT [3,4]. It is also roughly coincident with those localized regions on the fractures undergoing greatest tidal shear stress [2]. The relationship, however, among all three phenomena...shearing, anomalous thermal emission, and jetting...is unclear. Do the shear stresses, and possible associated frictional heating along the sub-surface walls of the fractures, melt the ice there to form liquid water which, in turn, supplies the jets? Or do tidal stresses simply create a deeply rooted system of cracks extending 10s of kilometers to the putative regional sea below, thereby providing the vertical pathways for sea-derived liquid droplets and water vapor, and the latent heat they carry, to reach the surface?

**Results:** To address these questions, we completed our survey of the SPT as imaged at high resolution (< 1.3 km/pixel) by Cassini ISS beginning in 2005 and extending through the very last Enceladus flyby in May 2012. Ninety-either (98) jets have been identified either on the main trunks or branches of the 4 fractures. A handful of these jets are obviously time-variable, appearing 'on' at times and 'off' at others. We have used the methodology of Nimmo et al. (2007) [5] to compute the time-varying tidal stresses – magnitudes, phases and orientations, both shear and tensional – within the ice shell and across the fractures, and compared these to the strength, spatial distribution, and time-variability of the jetting activity from this work, we investigate the relationships among all these phenomena. We examine the correlations between stress magnitudes (shear and normal) and the magnitude of the jetting activity, as well as search for synchronicity between the phasing of the observed variable jets and that of the eruption states (on/off) predicted by the tidal stress model of jet variability presented by Hurford et al. (2007) [6]. We examine also the likelihood that cracks can propagate vertically upwards through the bulk of the ice shell, and remain open long enough to deliver vapor and liquid to the surface.

Finally, we compare recent observations by the Cassini VIMS experiment of individual hot spots in the

vicinity of the south pole on Baghdad fracture [7] to our map of jets in the same region.

Despite finding no difference in the correlations between the spatial distribution of jetting activity and that of either shear or normal stresses, we find reasons to conclude that normal (tensional), and not shear, stresses play the primary role in determining the major properties of the activity occurring on the south polar terrain.

First, the jets tend to occur where normal stresses are the largest along the tiger stripe fractures. Second, though we find no evidence, on a jet-by-jet basis, for synchronicity between the state of the jet (on/off) and the phasing of the tensile opening/closing of the fracture segments from which they erupt, there is evidence for variability in the cap-integrated plume brightness seen by VIMS as a function of Enceladus' orbital position [8]. Third, we find that the hot spots seen by VIMS can be mapped, under reasonable assumptions, to individual jets observed on Baghdad, confirming at high resolution the correlation between jetting and thermal emission found earlier in the Cassini mission at low resolution [1]. Fourth, reports that these thermal spots are no bigger than a few 10s of meters [9] confirm that shear heating cannot be directly responsible for the observed thermal emission: shear heating would produce instead a surface thermal signature comparable in size to the thickness of the brittle layer of the moon's ice shell: ie, ~ few km's [5]. The VIMS spots are more likely produced by the deposition of latent heat on the near-surface walls of the fractures from rising vapor (and liquid) from the sea below [10]; the expected spatial scale of a thermal signature produced on Enceladus in this way is a few 10s of meters [11], consistent with what's observed. A small fraction of the rising liquid/vapor mixture (~10%), as it explosively leaves the vent through boiling and the exsolution of volatile gases, forms the jets; the escaping liquid component freezes and forms the solid component (icy particles) seen in high phase ISS images. Finally, following the formulation of Crawford and Stevenson [12], we show that the two main conditions, mechanical and thermal, for water-filled cracks to propagate upward through Enceladus' ice shell are met: i) maximum normal stresses must exceed ~ 5 kPa and on Enceladus, tidal stresses can be as large as 100 kPa; and ii) water-filled cracks more than ~1m wide will remain unfrozen all the way

from the sea to surface since the propagation time through the ice shell is less than the freezing time.

**Conclusions:** We conclude that shear stresses and their associated heating neither produce the bulk of the observed thermal emission nor the liquid and vapor that form the jets, nor do they play a role in determining the distribution of jetting across the surface. Instead we conclude that the erupting mixture rises under pressure from the sea below through a deep system of narrow, tension-produced conduits within the major tiger stripe fractures in the ice shell, creating the jets and depositing latent heat. This picture is consistent with the finding by the Cassini Cosmic Dust Analyzer team [13] that the observed salinity of the near-surface jet particles -- comparable to that of the Earth's oceans -- points to a source not in the near-surface ice but in the sea below. To touch the jets of Enceladus is to touch the most accessible salty, organic-rich, extraterrestrial body of water and, hence, habitable zone, in our solar system.

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