SOUTH POLAR THERMAL ANOMALY ON ENCELADUS: MODELING AND OBSERVATIONS. O. Abramov and J. R. Spencer, Southwest Research Institute, 1050 Walnut St., Suite 400., Boulder, CO 80302. (abramovo@boulder.swri.edu)

Introduction: The south polar region of Enceladus, a small icy satellite of Saturn, consists of young, tectonically deformed terrain dominated by roughly parallel, 2-km wide linear depressions dubbed "tiger stripes" [e.g., 1]. Recent observations by multiple instruments on the Cassini spacecraft describe an anomalously high heat flux associated with these tiger stripes, along with an active plume of water vapor and ice particles that presumably originates from them [1-4].

Several explanations for the observed elevated temperatures and the resulting plume have been proposed, including venting from an underground reservoir of liquid water [1], sublimation of ice [2], and decompression of clathrates [5]. These mechanisms differ primarily in vent temperatures required: 145 K for the decompression of clathrates [5], 180 K for sublimation of H_20 [2], and up to 273 K for the shallow reservoir of liquid water [1]. The elevated vent temperatures would conductively heat the nearby surface, perhaps producing the elevated temperatures observed by Cassini. The thermal modeling presented in this work, coupled with observations from Cassini, seeks to constrain the vent temperatures and thus potentially elucidate the underlying physical mechanism.

Observations: The south polar hotspot was first detected by CIRS, a thermal IR instrument onboard Cassini [6], during the July 2005 flyby of Enceladus. A subsequent flyby in November of 2006 observed the hotspot from a smaller emission angle, but yielded the same spectra and temperature estimates, albeit with relatively broad uncertainties. This suggests that the thermal emission is dominated not by the fissures themselves, which would probably show higher fluxes at smaller emission angles, but by the surrounding conductively heated surface. Also, no change in total power output was seen in 18 months, suggesting a relatively steady-state process at this timescale.

Modeling technique: Temperature distributions around tiger stripes on Enceladus were modeled using HEATING 7.3, a multidimensional, finite-difference heat conduction code developed at Oak Ridge National Laboratory [7]. Our two-dimensional model includes heat transfer by conduction in the subsurface and radiation at the surface. Thermophysical parameters appropriate for pure water ice are used, and the thermal conductivity and heat capacity of ice are temperature-dependent for the entire range of temperatures in the model. For all models, the bottom and right boundaries are insulating, and heat is lost by radiation through the upper boundary, which is radiatively heated to an equilibrium temperature of 75 K. The left boundary represents a narrow fracture, and is heated to a constant temperature in steady-state models.

The model dimensions are 40 km in the horizontal and 10 km in the vertical. The right boundary is sufficiently far away from the fracture to avoid boundary effects, essentially creating an infinite half-space. The horizontal resolution is 10 cm between 0 and 40 meters, 10 m between 40 meters and 4 km, and 50 m between 4 km and 40 km. The vertical resolution is 50 m between 0 and 9 km, 10 m between 9 km and 9980 m, and 10 cm between 9980 m and 10 km. This allows very fine-scale, 10-cm resolution in the area of interest at the surface and near the fracture.

Both steady-state and transient models have been developed. In the steady state model, the left boundary is held constant at 273, 225, or 175 K to model the heating of the fracture walls by plume gases [8] or liquid water [1]. The resulting temperature distribution is then fed to a transient model to determine the thermal evolution of the area after the heating is shut off.

After the models are run, the resulting surface temperature distribution is used to calculate a 9 to 16 μm (600 to 1100 cm^{-1}) emission spectrum at the resolution of CIRS, with the footprint centered on the fracture.

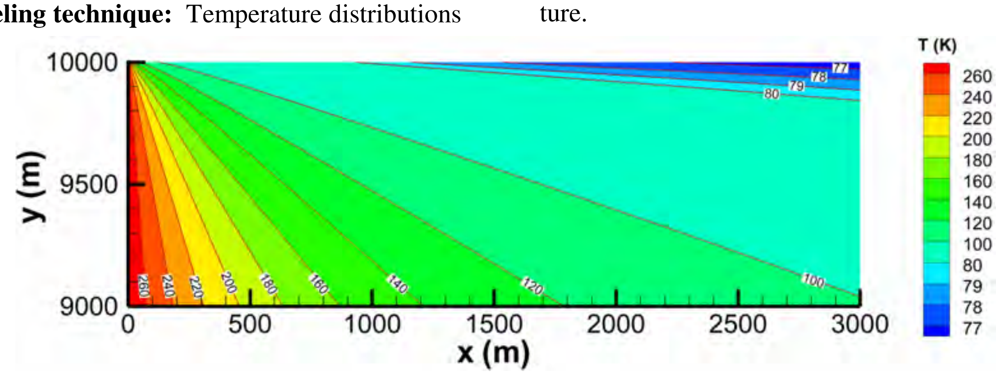

Figure 1. Steady-state thermal model of the vicinity of a vent on Enceladus. Thermal and physical parameters of pure ice are assumed, and vent temperature is held constant at 273 K.

Results: The steady-state temperature distribution near an active vent in Enceladus is shown in Figure 1. In addition to the fracture temperature of 273 K, temperatures of 225 K and 175 K were also investigated. Figure 2 shows a comparison of thermal emission curves derived from surface temperatures produced by the model and the Cassini CIRS spectra acquired in the south polar region in the vicinity of tiger stripes. Excellent fits are obtained in region 5, for a model fracture temperature of 225 K, and region 6, for a model fracture temperature of 175 K, even though no large fissure is apparent in region 6.

Cassini CIRS observations of global thermal properties on Enceladus suggest a thermal inertia that is 100 times smaller than that of water ice, implying a highly unconsolidated surface [2]. Thus, a model that included a 10-cm surface insulating layer with a thermal conductivity 10^4 times smaller than that of pure ice was constructed. This model yielded surface temperatures that were on the whole lower and more spread out, producing a spectrum that was a poorer match for CIRS data, suggesting higher thermal inertias near the tiger stripes.

Given the stability of the thermal emission seen by Cassini over 18 months, we also investigated whether this stability required constant heat input or might be due to long thermal time constants. A transient heating model was put together, starting with the temperature distribution near a 273 K fracture (Figure 1), then turning off the heat and allowing it to cool. The surface cools below the detectability limit of the CIRS instrument in ~10^3 years.

Conclusions: The hottest temperatures detected by CIRS in the south polar regions of Enceladus are consistent with a model vent temperature of 225 K. This relatively high temperature potentially strengthens the case for the presence of pressurized liquid water reservoirs in the subsurface of Enceladus, although this temperature is cooler than would be expected for a fracture filled with liquid water. The match between model and observations also strengthens the case for heat being transported to the surface by warm vapor moving through fractures rather than by conduction or shear heating alone [8]. Models with vent temperatures below 200 K may be harder to reconcile with the observations unless the fracture itself contributes much of the emission, a possibility that can be constrained by the limited variability in thermal emission with emission angle.

Also, this relatively high temperature, coupled with a short cooling timescale, suggests that the heating mechanism is currently active, or at least cyclical on timescales less than 10^3 years. However, no indication of variability was found by two CIRS observations 18 months apart.

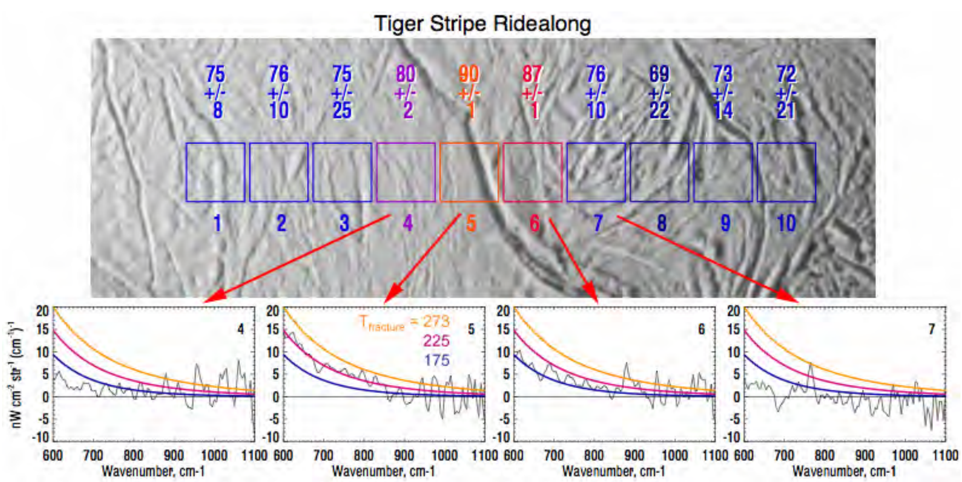

Figure 2. (top) Each box shows a single CIRS field of view and its associated brightness temperature, with uncertainties. (bottom) CIRS spectra obtained from each indicated region, with superimposed model fits for fracture temperatures of 273 K, 225 K, and 175 K. Note that the model assumes the warm fracture is in the center of each CIRS field of view.

References: [1] Porco, C.C., et al. (2006) *Science*, *311*, 1393-1401. [2] Spencer, J.R., Pearl, J.C., Segura, M., Flasar, F.M., Mamoutkine, A., Romani, P., Buratti, B.J., Hendrix, A.R., Spilker, L.J., and Lopes, R.M.C. (2006) *Science*, *311*, 1401-1405. [3] Hansen, C.J., Esposito, L., Stewart, A.I.F., Colwell, J., Hendrix, A., Pryor, W., Shemansky, D., and West, R. (2006) *Science*, *311*, 1422-1425. [4] Hunter Waite, J., Combi, M.R., Wing-Huen, I., Cravens, T.E., McNutt, R.L., Kasprzak, W., Yelle, R., Luhmann, J., Niemann, H., Gell, D., Magee, B., Fletcher, G., Lunine, J., Wei-Ling, T. (2006) *Science*, *311*, 1419-1422. [5] Kieffer, S.W., Lu, X., Bethke, C.M., Spencer, J.R., Marshak, S. and Navrotsky, A. (2006) *Science*, *314*, 1764-1766. [6] Flasar, F.M., et al. (2004) *Space Sci. Rev.*, *115*, 168-297. [7] Childs, K.W. (1993) *HEATING 7.2 User's Manual*, *ORNL/TM-12262*, Oak Ridge National Laboratory. [8] Nimmo, F., Spencer, J.R., Mullen, M.E. (2007) *LPSC XXXVIII*.