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NEW MODELS OF ENDOGENIC HEAT FROM ENCELADUS' SOUTH POLAR FRACTURES

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Introduction: The south polar region of Enceladus, a small icy satellite of Saturn, consists of young, tectonically deformed terrain dominated by four roughly parallel, ~2-km wide linear depressions dubbed "tiger stripes". Observations by multiple instruments on the Cassini spacecraft describe anomalously high heat fluxes associated with these tiger stripes, along with active plumes of water vapor and ice particles that originate from them. Several explanations for the observed elevated temperatures and the resulting plume have been proposed, including venting from a subsurface reservoir of liquid water, sublimation of ice, decompression and dissociation of clathrates, and shear heating. These mechanisms predict a range of vent temperatures: ~140 K for clathrate decompression , >180 K for sublimation of H_2O, and up to 273 K for the shallow reservoir of liquid water. In addition, constraining the width of the crack may further elucidate the mechanism: subsurface ice melting is likely unless the crack width is greater than ~10 cm.

The present work involves: (i) making improvements to the Abramov and Spencer (2009) model (**Fig. 1**), as outlined below, and (ii) applying the model to new Cassini Composite InfraRed Spectrometer (CIRS) tiger stripe spectra, which represents up to an order of magnitude improvement in spatial resolution over the data sets used in Abramov and Spencer (2009), as well as a greatly improved signal-to-noise ratio.

Technique summary: The parameters of the new model include (i) the temperature of the vent, (ii) the number of vents within a tiger stripe – multiple parallel fractures have been observed in high spectral resolution ISS images to lie within regions of the plume sources, (iii) the width of each individual vent, and (iv) geometry of the surface. In addition, dynamic model resolution has been implemented. The new model rapidly explores parameter space by automatically generating temperature distributions in and around tiger stripes based on specified constraints, acquiring synthetic CIRS spectra of the model surfaces, and comparing them to CIRS observations using statistical methods (**Fig. 2**).

Temperature distributions around tiger stripes on Enceladus are modeled in two dimensions using HEATING 7.3, a multidimensional, finite-difference heat conduction code developed at Oak Ridge National Laboratory. The model includes heat transfer by conduction in the subsurface from a vertical fracture held at constant temperature, and by radiation at the surface.

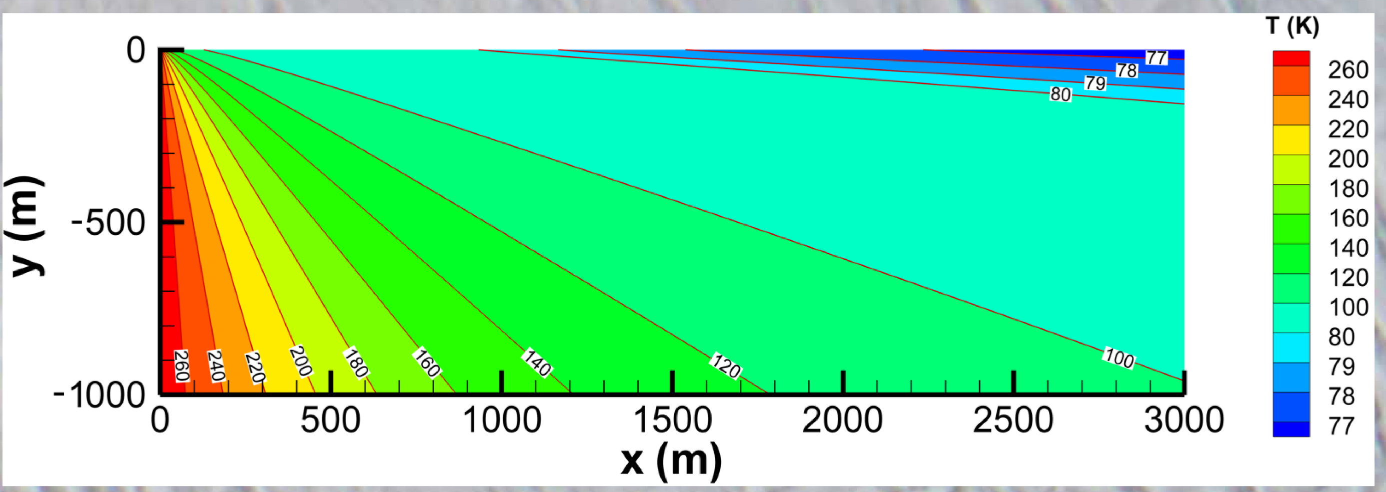

Figure 1. Schematic of the basic thermal model, showing temperature vs. depth (y) and distance from the warm fracture (x) for a fracture temperature of 273 K, the highest tested. From Abramov and Spencer (2009).

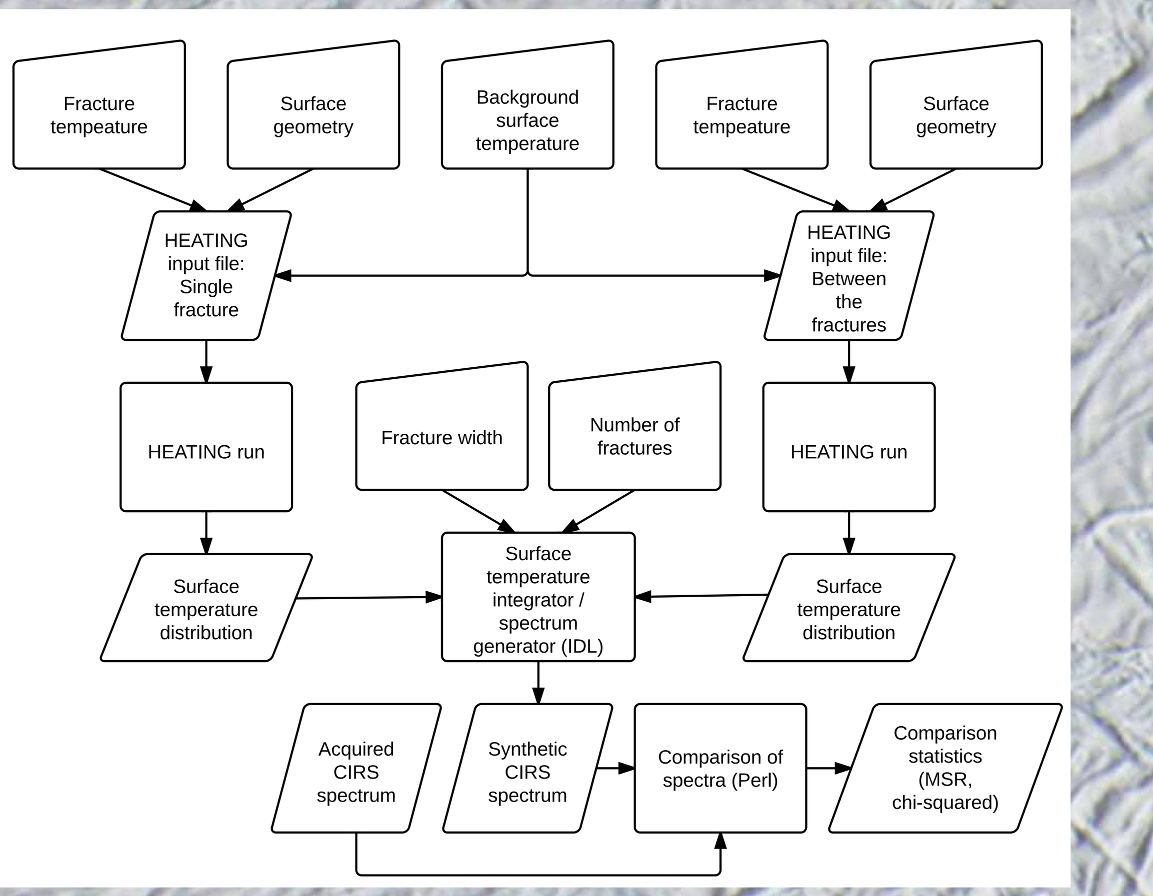

Figure 2. Flowchart of the current model.

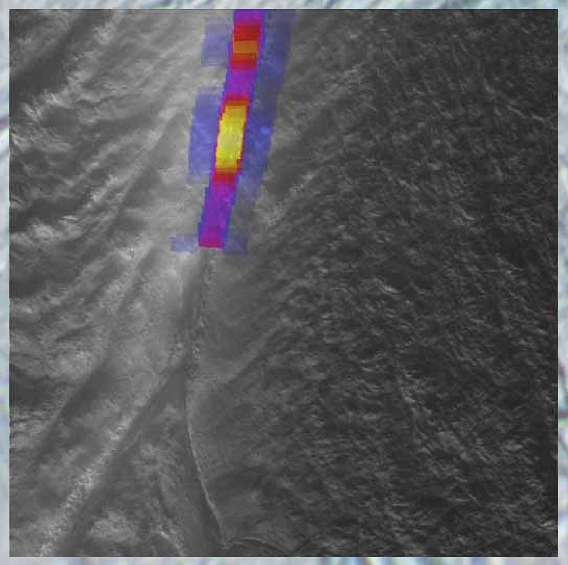

Figure 3. CIRS thermal map of the Damascus tiger stripe at 0.8 km/pixel, obtained during the August 2010 flyby, draped over simultaneously-acquired ISS image. From NASA News Release, December 1, 2010. Image ID # PIA13620.

Preliminary results: A chi-square statistic was used to compare the synthetic spectrum to the combined FP3/FP4 CIRS spectrum of Damascus Sulcus, acquired during the August 2010 flyby (**Fig. 3**). The automated parameter exploration, including the number of fractures, fracture temperature, and fracture width, was mapped in chi-squared space (**Fig. 4**) to visualize trends. Temperatures of the vents were varied from 170 K to 273 K in increments of 1 K; number of vents was varied from 1 to 6; and vent widths were varied from 0 to 20 m in increments of 1 cm. The best model match to data occurred at four 19-m fractures, each at 185 K. This moderate temperature does not necessitate invoking near-surface liquid water. This result is also in good agreement with a temperature of 197 ± 20 K and a width of 9 m derived from an April 2012 VIMS observation of Baghdad Sulcus.

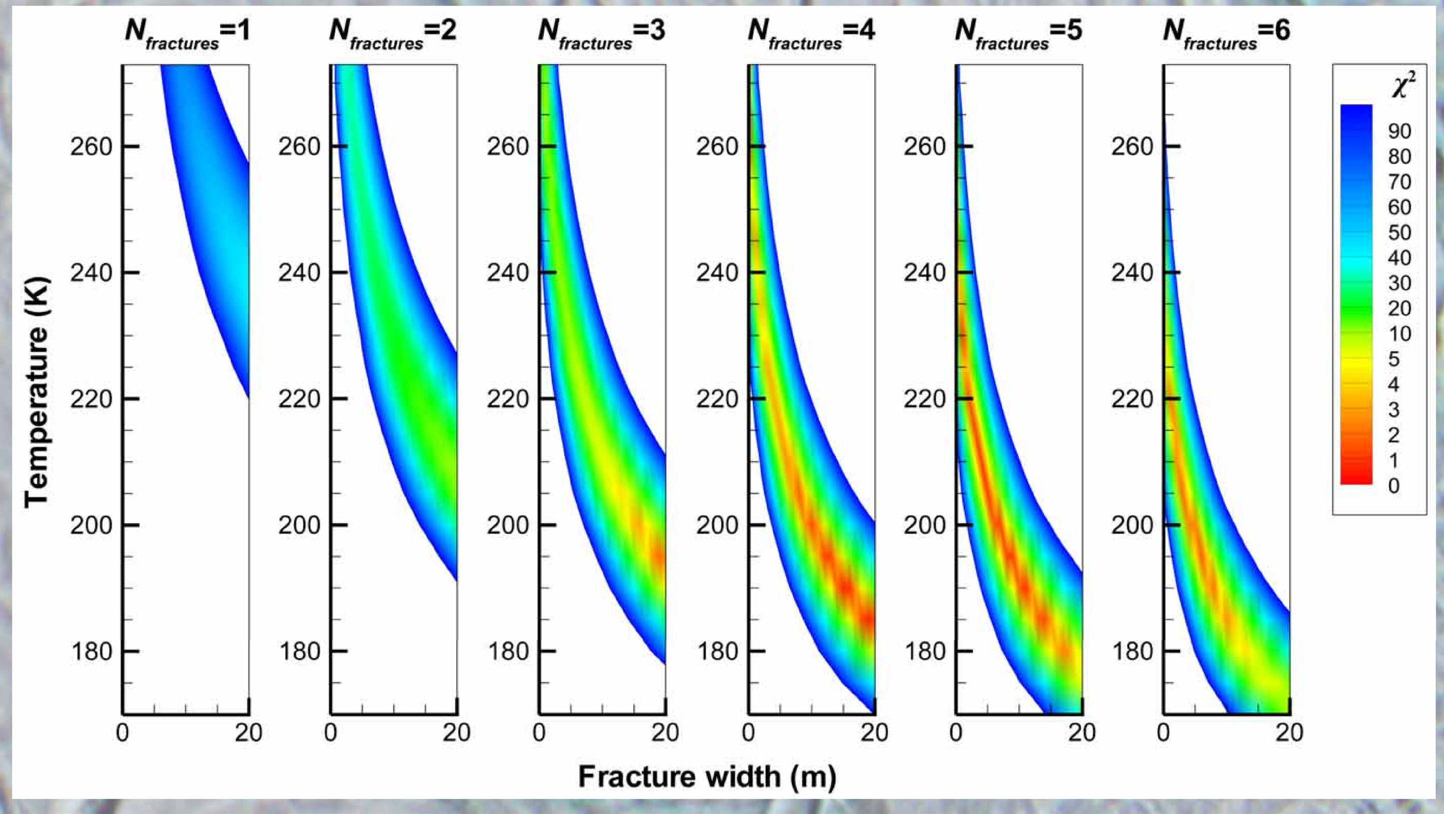

Figure 4. Automated exploration of parameters in chi-squared space. CIRS data is the combined FP3/FP4 observation of the Damascus tiger stripe at 0.8 km/pixel, obtained during the August 2010 flyby. Three parameters are varied: fracture temperature, fracture width, and number of fractures.

The comparison of the synthetic spectrum produced by this combination of parameters and the actual CIRS FP3/FP4 spectrum of Damascus tiger stripe is shown in **Fig. 5**. The excellent agreement between the model and the data, combined with Cassini ISS observations suggestive of multiple fractures in this region, validate the model and pave the way to further applications of this model to PDS-archived CIRS data.

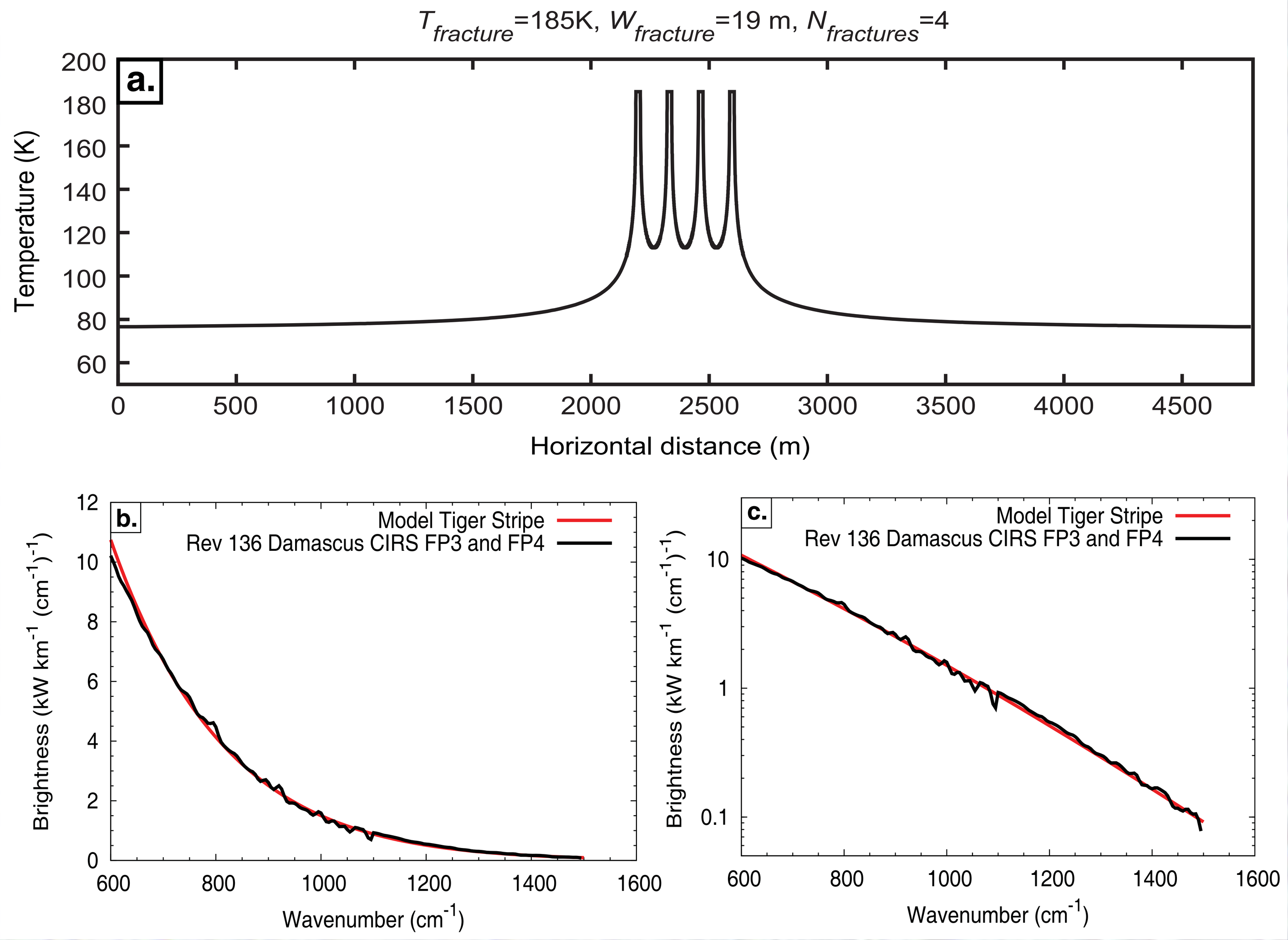

Figure 5. Best model match to the CIRS FP3/FP4 spectrum of Damascus tiger stripe, obtained during the August 2010 flyby. CIRS footprint is 800 m, centered on the fractures. (a) Model surface temperature distribution. (b) Comparison between model and CIRS data. (c) Comparison between model and CIRS data on a log scale.

Future work: Tiger stripe topography will be incorporated into the model, based on DEMs derived using stereo and shape-from-shading from high-resolution ISS images from Cassini orbits 80, 88, 91, 121 and 131. An example is given in **Fig 6**.

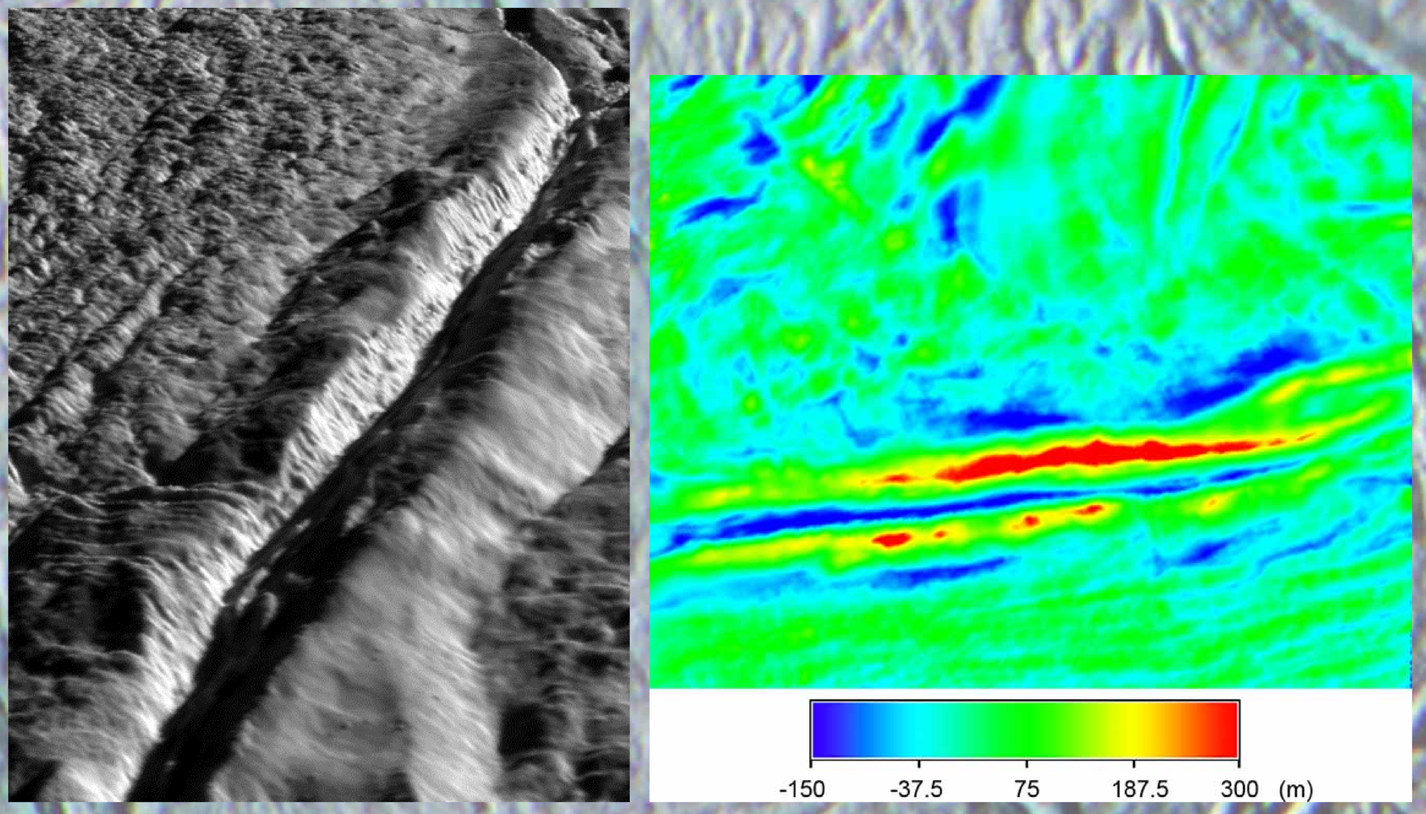

Figure 6. (left) Perspective view of Damascus Sulcus, produced by Dr. Paul Schenk using ISS images from the August 2008 flyby, acquired at 12 to 30 m/pixel. The ridges are 100 to 150 m high, and the medial trough between the ridges is 200 to 250 m deep. (right) Digital elevation model of a tiger stripe on Enceladus generated using combined stereo image and photoclinometric analysis.

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