Endogenous Activity at Cerberus Fossae: A Quantitative Evaluation.

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Introduction:
Endogenic heat sources are a target of prime interest in the planetary community because of their geodynamical and exobiological value. They can help constrain heat production mechanisms, planetary heat loss, and thus interior dynamics. Endogenic heat sources can be associated with anomalous high surface temperatures compared to surrounding terrains, and form "hot spots". Numerous missions throughout the Mars exploration history carry heat-sensing instruments whose goals are to identify hot spots, including the Viking infrared thermal mapper (IRTM, Kieffer et al., 1972) on board the Viking orbiters, the Thermal Emission Spectrometer (TES, Christensen et al., 2001) on board the Mars Global Surveyor, the Thermal Emission Imaging System (THEMIS, Christensen et al., 2004) on board the 2001 Mars Odyssey orbiter, or the Mars Climate Sounder (MCS, McCleese et al., 2007) aboard the Mars Reconnaissance Orbiter. However, none of the observations collected by these instruments over the past two decades show sustained surface temperatures that are inconsistent with passive warming/cooling driven by the diurnal solar illumination cycle (Christensen et al., 1998; Christensen et al., 2003; Piqueux et al., 2021). Consequently, no endogenic heat activity has yet been detected on Mars.

In the early 2020s, the InSight mission recorded numerous Marsquakes with some of the largest originating from the Cerberus Fossae region (e.g., Giardini et al., 2020; Stähler et al., 2022). Cerberus Fossae is a young geologic area found between 20°N and 0° at ~160°E, characterized by fissures and faults cutting the youngest (2.5–10 m.y.) lava flows on the surface of Mars (Vaucher et al., 2009). They might have hosted explosive eruptions as recently as 50-200 ka ago (Horvath et al., 2021). The analysis of the quakes recorded by InSight shows an ongoing opening of the Cerberus Fossae faults, driven by magmatic activity at depth (~30 km) (Stähler et al., 2022). If magmatic activity is indeed present in this region, then one might expect to observe an endogenic signature in the thermal infrared measurements.

THEMIS-IR images show high nighttime temperatures on the canyon walls and bottom (+30 K compared to the surrounding surface, see, for instance, Figure 1.). Christensen et al. (2003) interpreted these high temperatures as bedrock exposures, which are warmer at night than loose, unconsolidated sand. Milazzo and McEwen (2005) also looked at the THEMIS temperatures measured in these regions but did not conclude on the presence of an endogenic heat source. Finally, Antoine et al. (2011) suggested that the high night-time temperatures were not correlated to bedrock exposure in the faults, ruling out the argument of Christensen et al. (2003). They also ruled out any geometrical effects, and suggest that endogenic heat sources might explain these anomalous high temperatures. However, all these studies emphasized that demonstrating the presence or absence of endogenic heat sources requires both a precise knowledge of the surface's thermophysical properties at high spatial resolution and comprehensive 3D modeling. Indeed, previous investigations, such as those conducted on the Moon, have shown that elevated nighttime temperatures in areas of complex topography can often be accounted for by intricate illumination patterns and radiative coupling within the terrain (Horvath et al., 2022). In this study, we propose to quantitatively determine if the presence of an endogenic heat source is required to explain Cerberus Fossae night-time temperatures.

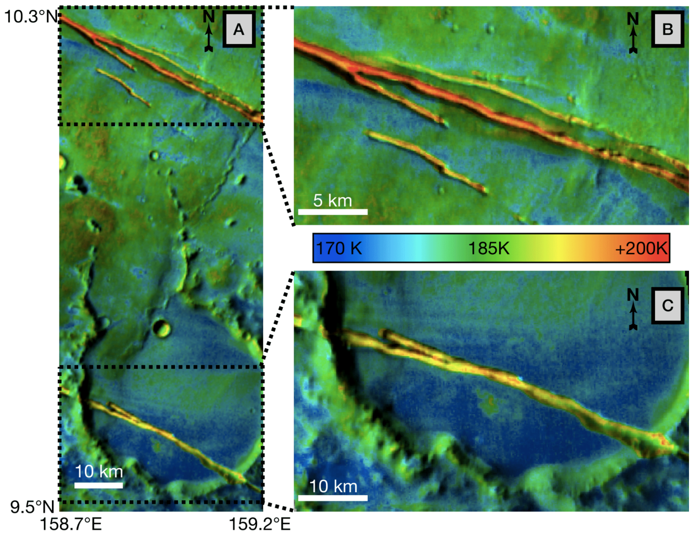

Figure 1: High nighttime (3:30 am) temperatures measured by THEMIS at Ls = 12° (image ID:I01836004)

Methods:

For this study, we use the KRC - K for conductivity, R for rho the density, C for the specific heat-thermal model described in Kieffer (2013), which has been widely used for Martian thermophysical studies. As KRC is originally designed for 1D simulations, we have improved the treatment of the visible and thermal infrared fluxes in KRC. These improvements now allow KRC to model complex shadowing and radiative coupling between adjacent surfaces. Accurate estimations of geometric factors—such as view factors or shadowing angles—are required for these two quantities. These are computed once during the initial stage, using parallel processing to ensure that simulations can be performed within a reasonable computation time. Ongoing work aims to validate this model by comparing it with other models that are based on more accurate ray-tracing computations (e.g., Sorli et al. 2025), and by comparing its outputs with THEMIS temperature measurements made on simple topography-like craters.

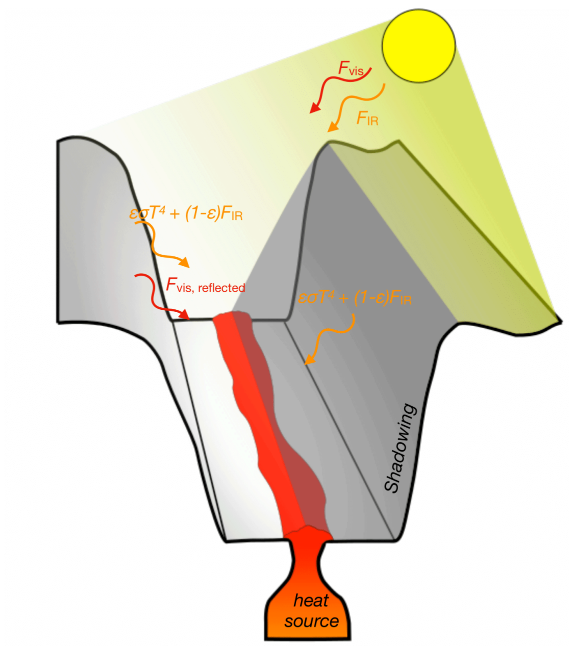

Figure 2: . Topographic effects included in KRC, and which might be relevant to explain the high nighttime temperatures studied here.

Now that 3D simulations can be performed with KRC, we need accurate input values of the thermophysical properties of the surface at a fine scale for our model. To achieve this, we are collecting all THEMIS visible and infrared images from this region to derive the albedo and thermal inertia at high resolution. Diurnal and seasonal variations of the temperatures will allow us to determine possible layering in the shallow subsurface (e.g., thin dust mantle above bedrock, see, for instance, Piqueux et al., 2021 for the method). Anisothermality between observations at THEMIS thermal infrared wavelengths will also allow us to estimate the rock abundance in these regions (Christensen 1986; McKeeby et al. 2022). We are performing rigorous pre-processing to correct any geometric/projection effect that might bias our analysis.

With these high-resolution inputs and our improved model, we will perform 3D simulations of the surface temperatures within the faults of Cerberus Fossae and determine quantitatively whether an endogenic heat source is required to explain the high night-time temperatures. Results will be presented at the conference. Future works will also consider other warm nighttime materials as lava tubes or pits found at the surface of Mars.

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References:

Antoine, R., Lopez, T., Baratoux, D., Rabinowicz, M., Kurita, K., 2011, *Thermal analysis of fractures at Cerberus Fossae, Mars: Detection of air convection in the porous debris apron.*, Icarus 214, 433–446. doi:10.1016/j.icarus.2010.12.025

Christensen, P.R., 1986, *The spatial distribution of rocks on Mars.*, Icarus 68, 217–238. doi:10.1016/0019-1035(86)90020-5

Christensen, P.R. and 11 colleagues, 1998, *Results from the Mars Global Surveyor Thermal Emission Spectrometer.*, Science 279, 1692. doi:10.1126/science.279.5357.1692

Christensen, P~R. and 25 colleagues, 2001., *Mars Global Surveyor Thermal Emission Spectrometer experiment: Investigation description and surface science results.*, Journal of Geophysical Research 106, 23823–23872. doi:10.1029/2000JE001370

Christensen, P.R. and 21 colleagues, 2003, *Morphology and Composition of the Surface of Mars: Mars Odyssey THEMIS Results*, Science 300, 2056–2061. doi:10.1126/science 1080885

Christensen, P.R. and 10 colleagues, 2004, *The Thermal Emission Imaging System (THEMIS) for the Mars 2001 Odyssey Mission.*, Space Science Reviews 110, 85–130. doi:10.1023/B:SPAC.0000021008.16305.94

Giardini, D. and 62 colleagues, 2020, *The seismicity of Mars*, Nature Geoscience 13, 205–212. doi:10.1038/s41561-020-0539-8

Horvath, D.G., Moitra, P., Hamilton, C.W., Craddock, R.A., Andrews-Hanna, J.C., 2021, *Evidence for geologically recent explosive volcanism in Elysium Planitia, Mars*, Icarus 365.

doi:10.1016/j.icarus.2021.114499

Horvath, T., Hayne, P.O., Paige, D.A., 2022., *Thermal and Illumination Environments of Lunar Pits and Caves: Models and Observations From the Diviner Lunar Radiometer Experiment.* Geophysical Research Letters 49. doi:10.1029/2022GL099710

Kieffer, H.H., 2013, *Thermal model for analysis of Mars infrared mapping*., Journal of Geophysical Research (Planets) 118, 451–470. doi:10.1029/2012JE004164

Kieffer, H. H., Neugebauer, G., Munch, G., Chase, S. C., Miner, E., 1972, *Infrared Thermal Mapping Experiment: The Viking Mars Orbiter,* Icarus 16, 47–56. doi:10.1016/0019-1035(72)90136-4

McCleese, D.~J. and 9 colleagues, 2007, *Mars Climate Sounder: An investigation of thermal and water vapor structure, dust and condensate distributions in the atmosphere, and energy balance of the polar regions.*, Journal of Geophysical Research (Planets) 112. doi:10.1029/2006JE002790

McKeeby, B.E., Ramsey, M.S., Tai Udovicic, C.J., Haberle, C., Edwards, C.S., 2022, *Quantifying Sub-Meter Surface Heterogeneity on Mars Using Off-Axis Thermal Emission Imaging System (THEMIS) Data*. Earth and Space Science 9. doi:10.1029/2022EA002430

Milazzo, M.P., McEwen, A.S., 2005, *Endogenic Thermal Activity at Cerberus Fossae, Mars?*, 36th Annual Lunar and Planetary Science Conference.

Piqueux, S. and 19 colleagues, 2021, *Soil Thermophysical Properties Near the InSight Lander Derived From 50 Sols of Radiometer Measurements,* Journal of Geophysical Research (Planets) 126. doi:10.1029/2021JE006859

Piqueux, S. and 7 colleagues, 2024, *Mars thermal inertia and surface temperatures by the Mars Climate Sounder*, Icarus 419. doi:10.1016/j.icarus.2023.115851

Sorli, K.C., Hayne, P.O., Cueva, R.H., Long, C.J., McMahon, J.W., Scheeres, D.J., 2025, *A 3D thermophysical model for binary asteroid systems: Application to the BYORP effect on (175706) 1996 FG3.*, Icarus 434. doi:10.1016/j.icarus.2025.116527

Stähler, S.C. and 10 colleagues, 2022. *Tectonics of Cerberus Fossae unveiled by Marsquakes,* Nature Astronomy 6, 1376–1386. doi:10.1038/s41550-022-01803-y

Vaucher, J., Baratoux, D., Toplis, M.J., Pinet, P., Mangold, N., Kurita, K., 2009. *The morphologies of volcanic landforms at Central Elysium Planitia: Evidence for recent and fluid lavas on Mar*s., Icarus 200, 39–51. doi:10.1016/j.icarus.2008.11.005