EVIDENCE FOR MARTIAN ATMOSPHERIC DUST PENETRATION INTO CLOSED SURFACE ASSETS — IMPLICATIONS FOR PARTICLE SIZE AND BEHAVIOR IN THE MARTIAN ENVIRONMENT.

J. W. Ashley[1], S. W. Ruff[2], P. R. Christensen[2], M. D. Smith[3], and J. R. Hill[2], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109; james.w.ashley@jpl.nasa.gov, [2]Mars Space Flight Facility, School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287, [3]Goddard Space Flight Center, Greenbelt, MD 20771.

Introduction: Extended missions for landed assets on Mars permit the incidental monitoring of environmental conditions and their effects on robotic and instrumental systems. Of particular concern for the Mars Exploration Rover (MER) Miniature Thermal Emission Spectrometers (Mini-TES) was the impact of atmospheric dust contamination on their optical elements. Airfall dust can be removed from terrain and solar array surfaces by locally strong winds (although a small portion tends to remain, probably resulting from electrostatic adhesion). Wind shadows, and local traps and sinks within structural design components can protect accumulated deposits. We witnessed both punctuated and slow deterioration of spectral quality from the effects of dust over extended missions representing nearly two Mars years with both Mini-TES instruments, culminating in uncorrectable spectra for both instruments around the time of the June 2007 global dust event.

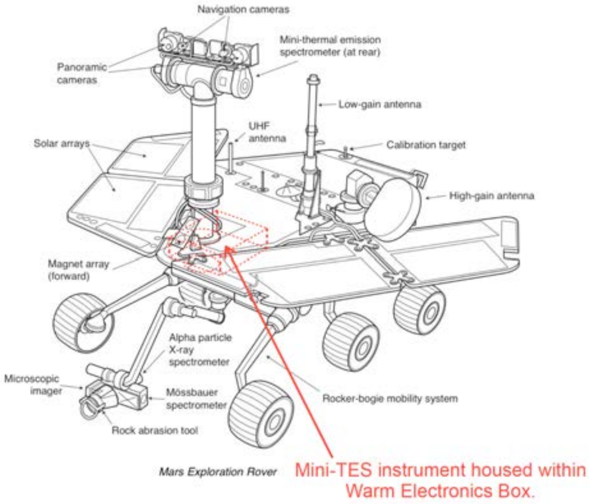

Figure 1. Mars Exploration Rover schematic. The location of the Miniature Thermal Emission Spectrometer (within the Warm Electronics Box) is shown in red outline. The optical components are located within the Pancam Mast Assembly.

Background: Martian dust is extremely fine, existing as both individual particles and aggregates [e.g., 3,4], appearing to separate into a high-altitude component with very low settling rates, and a less-easily lofted surface fall component. Air-fall accumulation rate estimates for normal (non-storm) conditions from MER Panoramic Camera (Pancam) calibration targets is one grain diameter per 100 to 125 sols (martian days) for the two MER landing sites (Gusev crater, Spirit; Meridiani Planum, Opportunity) [5]. Efforts to characterize the mineralogy of martian dust are made difficult both by the extremely fine particle size, which confounds spectral measurements, and insufficient concentrations for MER Mössbauer measurements. Current understanding considers the dust to be a mixture of framework silicates (most likely plagioclase feldspar) and carbonate, sulfate, pyroxene, olivine, hematite, and magnetite, with poorly crystalized material comprising lesser portions [e.g., 6]. Additional phases may include zeolites [7], nanophase iron oxides [e.g., 8], and carbonates [9,10].

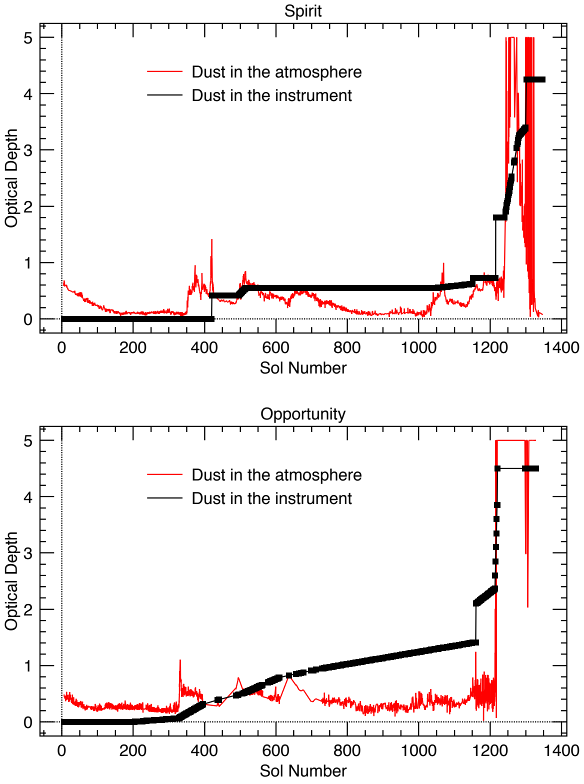

Figure 2. Spirit and Opportunity rover atmospheric and instrument dust opacity (tau) with time. Note the steady accumulation punctuated by loading spikes, particularly from the global dust event around sol 1217.

Mini-TES is a Fourier transform infrared spectrometer operating over a spectral range of ~ 5 to 29 μm (1997.06 to 339.50 cm^{-1}) with a spectral sampling of 9.99 cm^{-1} [11]. The instrument uses a deuterated triglycene sulfate detector with a KBr beamsplitter. Measurements are collected through the rover's Pancam Mast Assembly (PMA), which functions like a periscope [12], and are delivered to the Mini-TES instrument through a Cassegrain optical system. The instrument itself is mounted inside the warm electronics box within the rover chassis (Figure 1). The PMA contains three Mini-TES-related optical elements, including a fixed mirror, a movable elevation mirror (which cannot point more than 30 degrees above the horizon when collecting atmospheric measurements), and a CdTe window at the base of the PMA tube. A shroud secured to the elevation mirror rotates into place between observations to minimize the introduction of dust to the PMA.

Mini-TES Operations/Observations: The Mini-TES instruments on Spirit and Opportunity conducted routine atmospheric observations and remote sensing of surface targets that were typically composed of silicate, sulfate, and oxide-dominated mineralogy, and also of dust of atmospheric origin [13-15]. Both Mini-TES instruments experienced dust accumulation throughout their operational life. For Spirit's Mini-TES, mirror-dust contamination was first recognized as an abrupt change in spectra on sol 420 following the onset of dust devil activity [16-17] and then again beginning with global dust storm activity on about sol 1220 [18]. On the Opportunity rover, mirror-dust slowly accumulated beginning early in the mission and accelerated around sol 325 (offset from Spirit by ~21 earlier sols) when atmospheric dust activity suddenly increased.

A correction for mirror-dust contamination was first developed and implemented for use with Mini-TES atmospheric observations [17] and later demonstrated to be valid for surface observations from Spirit [18], but not after sol 1220 due to additional dust accumulation on multiple optical surfaces. It is suspected that at least one (and possibly all three) of these optical surfaces received coatings of wind-blown dust following the Mars global dust event beginning around sol 1217 (June 2007).

The mirror-dust correction for Mini-TES surface spectra from Opportunity became ineffective for all but portions of spectra below ~530 cm^{-1} sometime after sol 350, also due to increasing contamination [13]. Measurements became unusable after massive dust loading around sol 1223, again due to the June 2007 global dust event, but were still acquired through sol 2243. Because of the shroud, the nature of performance from a dust contamination standpoint is one of intermittent potential exposure and protection. However, the gradual increase in dust opacity visible in Figure 2 suggests that some dust may have entered the system while the shroud (which did not produce an air-tight seal) was in a closed position (see Figure 3).

The observed trends with Mini-TES demonstrate the impact that ambient (non-storm event) atmospheric dust of the martian environment can have on system performance. Rover longevity at both landing sites was largely a function of dust removal from solar arrays by wind. Thus future designs could benefit by 1) avoiding traps that can permit dust accumulation along optical pathways to detectors, and/or 2) installing capability to fully expose optical elements to wind, or mechanically remove dust at each exposure point.

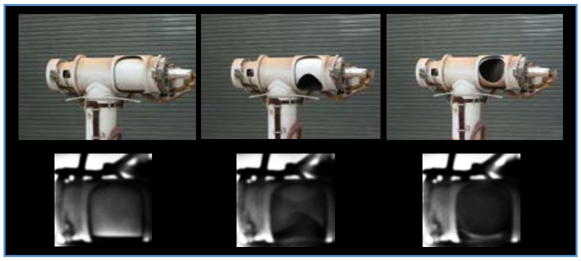

Figure 3. Top image row shows action of moving mirror and shroud on rover in JPL's testbed. Bottom row images of Opportunity's moving mirror and shroud collected by the Microscopic Imager during Mini-TES troubleshooting pursuant to Summer 2007 dust event.

References: [1] Arvidson, R.E., et al. (2004) *Science*, 305(5685), 821-824. [2] Arvidson, R.E., et al. (2004) *Science*, 306(5702), 1730-1733. [3] Herkenhoff, K.E. et al. (2004) *Science* 305(5685) 824-826. [4] Kraft and Greeley (2000) *J. Geophys. Res.*, 105(E6), 15107-15116. [5] Kinch, K.M. et al. (2007) *J. Geop hys. Res.*, 112(E6). [6] Hamilton, V.E., et al. (2005) *J. Geophys. Res.*, 110(E12). [7] Ruff, S.W. (2004) *Icarus*, 168. [8] Bell, J.F. et al. (2000) *J. Geophys. Res.*, 105(E1), 1721-1755. [9] Bandfield, J.D. et al. (2003) *Science*, 301, 1084-1087. [10] Christensen, P.R. et al. (2004) Science, 305, 837-842. [11] Christensen, P.R. et al. (2003)) *J. Geophys. Res.*, 108(E12), 5-23. [12] Squyres, S.W. et al. (2003) *J. Geophys. Res.*, 108(E12). [13] Glotch, T.D. and Bandfield, J.D. (2006) *J. Geophys.* Res., 111, doi: 10.1029/2005JE 002671. [14] Glotch, T.D. et al. (2006) *J. Geophys. Res.*, 111, doi:10.1029/2005JE 002672. [15] Ruff, S.W. and Hamilton V.E. (2017), *Amer. Min.* 102 (2): 235-251. [16] Ruff, S.W. et al. (2006), *J. Geophys. Res,* 111, doi:10.1029/ 2006JE002747. [17] Smith, M.D. et al. (2006), *J. Geophys. Res.,* 111, doi:10.1029/2006 JE002770. [18] Ruff, S.W. et al. (2011), *J. Geophys. Res,* 116.