CALIBRATION ISSUES IN VISIBLE AND INFRARED SPECTROSCOPIC OBSERVATIONS OF MERCURY AT HIGH TEMPERATURE. Rachel L. Klima[1], Noam R. Izenberg[1], Scott L. Murchie[1], Gregory M. Holsclaw[2], William E. McClintock[2], and Sean C. Solomon[3,4]. [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA, Rachel.Klima@jhuapl.edu; [2]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80303, USA; [3]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA; [4]Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA.

Introduction: The Mercury Atmospheric and Surface Composition Spectrometer (MASCS) Visible and Infrared Spectrograph (VIRS) has collected almost 9.5 million measurements of Mercury's spectral reflectance since the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft was inserted into orbit in March 2011. The VIRS instrument measures reflectance over a wavelength range (0.3–1.45 μm) that may contain electronic transition absorptions indicative of silicate mineralogy when transition metals are present. These wavelengths are also sensitive to space weathering and differences in regolith scattering properties. VIRS detector operating temperatures have exceeded the maximum expected throughout this time, requiring modifications to the pre-orbit data calibration pipeline. We here describe effects observed during high-temperature observations and the processing applied to mitigate them.

Overview of Instrumentation and Calibration: The MASCS instrument consists of two spectrometers, the Ultraviolet and Visible Spectrometer (UVVS) and VIRS, both of which are fed light by a Cassegrain telescope [1]. The VIRS wavelength range is separated into two detector channels: the visible (VIS), covering 0.3-0.9 μm using a linear silicon (Si) array, and the near-infrared (NIR), covering 0.9-1.45 μm using an indium-gallium-arsenide (InGaAs) linear array. UVVS focuses on exosphere measurements with some targeted UV surface observations, whereas VIRS is designed primarily for surface observations. The Si detector maintains an acceptable signal-to-noise ratio (SNR) even at higher operating temperature (≥30°C), but the SNR for the InGaAs detector declines markedly at high temperature.

A key part of the calibration approach is subtraction of background measurements that are collected periodically by closing a mechanical shutter. These measurements are interleaved throughout an observation to monitor changes in the background, composed of an electronic offset and dark current, with temperature. A shutter cadence of ~25-90 s is typical, and short observations are monitored more frequently. A curve is fit to the background observations as a function of temperature for each detector element, providing a smoothed, modeled, dark level in units of raw data number (DN) (B_d). Radiance at the sensor (L) for a given spectrum and wavelength in units of W m^{-2} sr^{-1} μm^{-1} is then calculated as:

$$L = \left(\frac{(C - B_e - B_d - B_g)}{t}\right)\left(\frac{1}{S}\right) \quad (1)$$

where C is the raw data value in DN, B_e is the background due to an electronic offset (in DN), B_g is grating-scattered light (in DN), t is the integration time (in s), and S is the radiometric sensitivity measured in the laboratory in units of DN s^{-1}(W m^{-2} sr^{-1} μm^{-1})$^{-1}$. Temperature dependence of the sensitivity has been measured and for the Si detector is greatest at longer wavelengths [2]; adjustments for these effects is included in the standard calibration pipeline.

Data Coverage and Temperatures in Orbit: Collected over almost three Earth years, VIRS spectra provide near-global coverage at a spacing of several tens of kilometers. Detector temperatures in orbit vary from ~10°C through ~50°C, as much as 20°C above expectations. Despite the challenges presented by these operating temperatures, data from the Si detector are comparable to those obtained by the Mercury Dual Imaging System (MDIS; Fig. 1). Because of orbital constraints, observations at elevated temperatures occur consistently over the same regions of the surface (Fig. 2). To obtain global coverage, it is essential to include higher-temperature data.

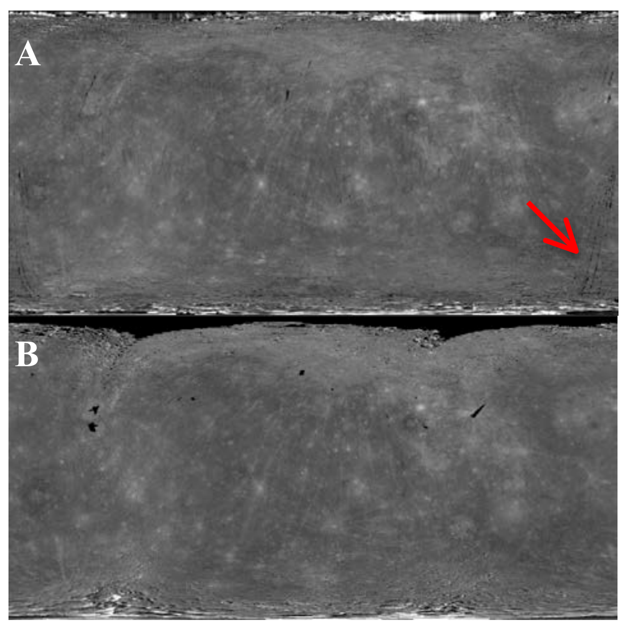

Fig. 1. (A) Simple cylindrical map (central longitude 0°E) of reflectance at 750 nm from VIRS, interpolated between adjacent tracks. **(B)** Reflectance at 750 nm from MDIS. VIRS coverage is denser in the south, leading to longer interpolation distances in the north. Several dark stripes resulting from improper closure of the shutter can be seen (e.g., red arrow).

High-temperature Issues: High temperatures have resulted in two major issues: (1) increased background and saturation of some InGaAs detector elements, and (2) "sticking" of the shutter mechanism, affecting both the VIS and NIR channels of VIRS.

Saturation and background noise of the InGaAs (NIR) detector. The most obvious effect of higher IR detector temperature is increased background signal. The increased background leads to some detector elements saturating as their wells are filled by thermal electrons, at which time they are insensitive to surface radiance. Because each detector element has a slightly different offset, saturation occurs at a variety of characteristic temperatures (Fig. 3). Saturated measurements are flagged as invalid in data records, and only unsaturated shuttered darks are used for modeling dark current for surface observations.

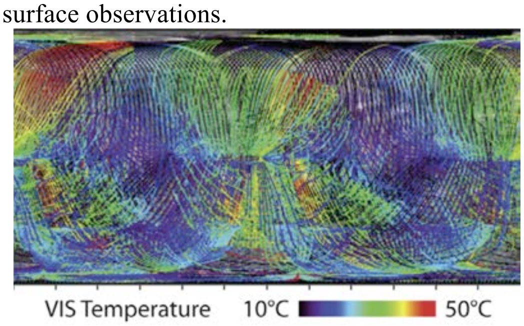

Fig 2. Visible detector temperature for observations across the surface. Hotter observations are centered near 0°E and 180°E; observations near 90°E and 270°E are generally cooler.

To manage data volume early in the first year of orbit, detector elements at adjacent wavelengths were binned by two before downlink. This binning resulted in corrupted values in the data records because the two elements comprising the bin often contained a valid surface measurement along with a saturated value. Binned observations were discontinued, and a calibration update was implemented to accommodate this effect. We identified the unique saturation temperatures for each detector element, and we used those values to flag binned pixels that include a saturated element as invalid. Work is also underway to recover the unsaturated portion of these binned measurements.

Statistical noise also becomes greater with increasing temperature, particularly in the NIR channel (Fig. 4). For short observations at higher temperatures, this noise can strongly affect values measured during shuttered dark observations, leading in some cases to corrupted dark subtractions. Elevated noise at higher temperatures also implies a reduction in SNR.

Improper closure of the shutter. During the hottest periods of operation, the shutter mechanism sometimes does not close when commanded to do so. One of the data quality flags included in the data records indicates which observations are intended to be shuttered, but this information is derived from commanding, and thus falsely reports closure even when the mechanism fails. This discrepancy has resulted in observations of the surface being included in the background fits for both VIS and NIR, with the consequence of too much background being subtracted. The majority of affected observations have been located and removed from deliveries to the Planetary Data System, but some remain in the delivered data, as evidenced by the dark stripes in Fig. 1a. Work is ongoing to improve detection of shutter closure failures so that files can be manually corrected or removed.

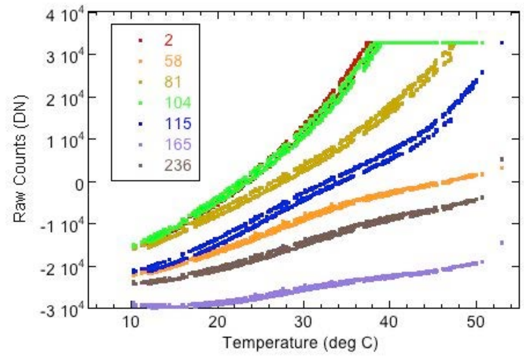

Fig. 3. Raw counts for selected InGaAs detector elements showing the increase in B_d with increasing temperature.

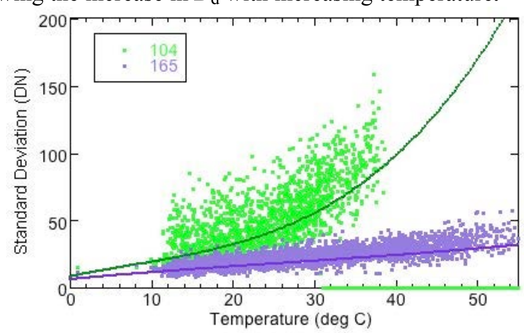

Fig. 4. Standard deviation of shuttered measurements for two InGaAs detector elements as a function of temperature. The standard deviation is fit by a third-order polynomial. Values at zero for detector element 104 indicate detector saturation.

Summary: Higher than expected operating temperatures result in decreased SNR in VIRS NIR data and saturation of some or all NIR detector elements. Given the increase in NIR channel noise as a function of temperature, users are advised to focus on NIR data acquired at lower detector temperatures (perhaps < 25°C), though the ultimate SNR of the data is a function of several variables, including photometric geometry and heliocentric distance. In contrast, despite high operating temperatures in orbit, visible-wavelength VIRS data maintain high SNR and do not saturate. At operating temperatures above ~40°C, the shutter mechanism sometimes does not close properly, affecting both detectors. Most of the affected observations have been removed, but users should be wary of visible-wavelength data with unusually low radiance values.

References: [1] McClintock W. E. and Lankton, M. R. (2007) *Space Sci. Rev., 131,* 481-521. [2] Izenberg et al, (2011) *LPS, 42*, abstract 2391.