# MARS ODYSSEY THEMIS-VIS CALIBRATION.

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**Introduction:** The Visible Imaging Subsystem (VIS) on the NASA Mars Odyssey spacecraft's THEMIS instrument has been obtaining high spatial resolution images of Mars since mapping began in February 2002. [1,2]. VIS is a 1024 x 1024 interline transfer CCD camera. It acquires multispectral or monochrome images using any combination of 5 narrowband (~50 nm FWHM) interference filters that are centered at 425, 540, 654, 749, and 860 nm. These filters are bonded directly to the CCD, each covering approximately 200 CCD pixels along the orbit track and spanning the entire detector in the cross-track direction. VIS images are contaminated by a significant amount of light leaking around the edges of the filters. This light accumulates both in the photosites during the nominal exposure period, and in the interline registers during the readout process. Here, we summarize the process of calibrating VIS images to remove these light leakage effects and to produce estimates of absolute radiance, focusing on the limitations of the procedure that must be taken into account when interpreting the data. Detailed documentation of the calibration process can be found at http://pdsimg.jpl.nasa.gov/Atlas/DocLinks.html#2001_MARS_ODYSSEY.

**Automated Calibration Procedure:** The automated VIS calibration procedure consists of, at present, seven steps: 1) 8-bit to 11-bit decoding, 2) identification of bad pixels, 3) bias subtraction, 4) “shutter” (frame transfer) smear subtraction, 5) correction of pixel sensitivity variations (*i.e.*, “flatfielding”) 6) stray light subtraction, and 7) radiance calibration. The results of these 7 steps are archived with the Planetary Data System as “Reduced Data Records” (RDRs) with radiance units (W $cm^{-2}$ $\mu m^{-1}$ $sr^{-1}$). Steps 1 – 3 do not warrant discussion here because they are relatively straightforward and are not significant sources of error. Each of steps 4 through 7 will be discussed briefly below.

*“Shutter” (Frame Transfer) Smear.* During the readout process, photosite charge is shifted to interline registers, which then shift the charge line-by-line up the detector array to the horizontal register. Some the leaked light reaches both the interline registers and the horizontal registers, resulting in an accumulation of signal during the readout process. Note that it is the light leak signal, rather than scene information, that is being “smeared” during readout. The smear signal is measured in flight by acquiring zero-exposure-time images on the dayside of the orbit.

Since the leaking light comes from just outside of the VIS field of, its relative signal strength is not completely predictable. Residual “shutter” smear usually manifests as sharp boundaries between mosaiced frames, and, in the worst cases, as vertical stripes. Note that the smear stripe artifacts have a somewhat different shape and fall in a slightly different portion of the frame than the stray light artifacts. Residual smear is usually a problem only when the exposure time is short and the scene contrast is very high.

*“Flatfielding.”* The vignetting near the edges of the filters is a multiplicative rather than an additive effect like stray light or “shutter” smear. The flatfield that we apply is a function only of detector row. It is derived from the variance of pixels in the in-flight data set, rather than the mean, in order to separate it from the stray light effect. Post-calibration vignetting artifacts existing only when 1) there is very little overlap between adjacent frames in the mapped VIS data, so that badly vignetted pixels are part of the mosaic; or 2) the frame-transfer smear or stray light calibrations give poor results.

*Stray Light Subtraction.* The stray light removal proceeds by using the entire in-flight VIS data set to fit for each pixel’s deviation from the mean signal within its filter as a fraction of the mean broadband brightness of the scene.

This technique has two serious limitations. First, the stray light signal actually depends on the brightness of the scene just outside of the detectors field of view, so that significant large scale gradients in scene brightness will lead to over or under-correction of the stray light pattern. A strong left-to-right gradient can lead to over correction on one edge of a VIS frame and under correction on the opposite edge. For the 654 nm filter, which is used for most monochrome VIS images, residual stray light is quite frequently negligible. At the opposite extreme, residual stray light renders the 860 nm filter data essentially unusable in the vast majority of VIS images.

Second, the stray light removal technique can only detect the spatially variable component of the stray light. Once the spatially variable stray light component is removed, there is still a spatially uniform stray light component, which has the effect of reducing contrasts in VIS images. Preliminary attempts to estimate the significance of this spatially uniform stray light suggest that in contributes about 50% of the observed signal in the 425 nm filter, 20% of the observed signal in the 540 nm filter, and a much smaller portion of the signal in the 654 nm and 749 nm filters.

*Radiance Calibration.* The radiance calibration is based on 1) comparison of the VIS frame-mean signal levels to concurrent observations of the same location on Mars by the Hubble Space Telescope HST; 2) pre-flight integrating sphere measurements of known sources. The accuracy of the HST-based method is limited by the fact that HST and VIS never view Mars from the same phase angle. The accuracy of the pre-flight method is limited by the fact that the spectrum of the spatially uniform stray light component is most likely different in Mars orbit than it the lab, due to difference in the spectrum of the light source. The radiance calibration coefficients used for any particulary RDR are stored in the "History" section of the RDR's text header.

**Conversion to Bidirectional Reflectance.** VIS radiance measurements should be expressed in terms of bidirectional reflectance for comparison with measurements of laboratory samples. To accomplish the conversion, multiply the VIS radiances stored in the RDR by the Mars-Sun distance at the time of the measurement, expressed in Astronomical Units, and then by the appropriate number in the table below.

| **Filter** | 425 | 540 | 654 | 749 | 860 |
|---|---|---|---|---|---|
| **Reflectance coefficient** | 5.84 | 5.39 | 6.40 | 7.91 | 10.15 |

These coefficients were derived by convolving the solar spectrum with measured spectral response curve for each VIS filter.

**Additional Calibrations.** We have developed several techniques that may be applied on an image-by-image basis to correct some of the calibration residuals. Some of these may ultimately lead to improvements in the automated calibration procedures used to produce the RDRs. The most important of these techniques is a method for estimating the amount of spatially uniform stray light so as the remove spurious color variation. This is done by identifying additive offsets that force nearby flat surface and sun-facing slopes to have the same spectrum. As another example, the removal of the spatially variable component of the stray light can be improved by interactively adjusting the assumed magnitude of the stray light for the left and right edges each frame until obvious artifacts are minimized.

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**References:** [1] Christensen P. R. et al. (2003) *Science, 2003,* 2056-2061. [2] Bell III, J.F. et al. (2003) Mars 6, Abstract #3238.