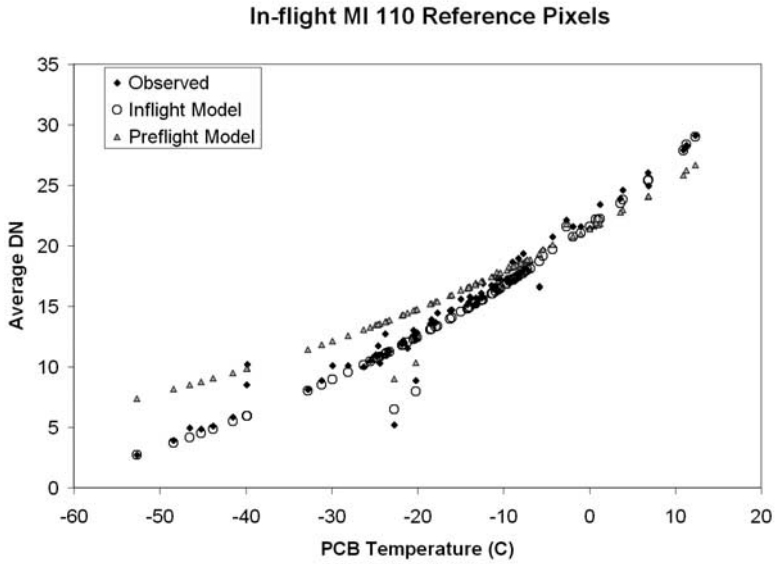

Figure 4. Average of observed reference pixel data in samples 4–14 and lines 412–612 compared with models based on preflight and in-flight calibration data. PCB is printed circuit board in the MI electronics box.

the shape of the histograms on the left side of the peaks represents the distribution of dark noise alone, radiation affects only 0.04% (~419) of the pixels in the 0 s dark frame (Figure 2, top). In this case, the CCD was affected by radiation only during the 5.2 ms frame transfer time and the 5.2 s readout time. More radiation effects accumulated during the 100 s dark frame (Figure 2, bottom), so that about 20% (~210,000) of the pixels are affected by radiation and some of the pixels are saturated (see right side of Figure 3, bottom). The late-cruise dark data show similar levels of radiation effects. These results provide a crude estimate of the effects of radiation on MI data acquired on the surface of Mars: about 2000 pixels are affected per second of exposure time. This rate is expected to decrease during the mission as the Mössbauer reference source decays. Most Opportunity MI images were taken with exposure times of less than one second (maximum 1.8 s), so that less than 0.2% of the pixels in a typical MI image will be affected by radiation. Radiation statistics from the Spirit MI are essentially identical [*Herkenhoff et al.*, 2006].

[8] The zero-exposure dark images taken in cruise (Figure 2) also show linear features that are caused by a few slightly "hot" pixels being smeared during image transfer. While the capability exists in camera flight software to automatically correct such "bad" pixels onboard the rover, the magnitude of the spurious signal generated in these few pixels is too low to be a concern. Therefore, a table of bad pixel locations has not been loaded onto the rover and no correction is made.

[9] The MI CCD temperature was within the calibrated operating range (−55 to 5°C) for all images acquired during the first 340 sols of Opportunity's mission. Later in the mission the CCD temperature sometimes exceeded 5°C, reaching 20°C on sol 560. The MI dark current model matches dark (including cruise checkout) data taken at up to 26°C and with exposure times less than 3 s to within 4 DN. The dark current model was applied to the 100 s MI dark frame taken during the first cruise checkout, and reduced the standard deviation in a 101 × 101 pixel area at the center of the image from 91 DN to 47 DN. Similarly, the standard deviation in the same area in the 100 s dark frame taken during the second cruise checkout was reduced from 39 DN to 36 DN. These reductions in noise are not as great as seen when the model was applied to preflight dark images, due partly to a change in the "fixed" pattern of dark noise [*Herkenhoff et al.*, 2004a]; radiation also causes additional noise in the cruise data. Because MI images of the Martian surface were taken with exposure times of 1.8 s or less, the contribution of dark noise to relative calibration uncertainty is probably less than 4 DN. Therefore, in the absence of MI dark current data taken after landing, we conclude that dark current subtraction using the Opportunity MI dark current model contributes less than 4 DN to the uncertainty in both relative (pixel to pixel) and absolute radiometric calibration.

2.2. Reference Pixels

[10] The frame transfer CCD used in the MI shifts 1024-pixel lines, one at a time, into a serial register during image readout. The MER camera serial register includes 16 additional pixels at each end beyond the 1024 pixels used to receive image data from the CCD [*Bell et al.*, 2003]. These additional pixels are called "reference pixels" and they record the camera offset (or electronic bias, a constant value added to all image data) each time a line of pixels is read out of the MI. The offset of each camera can be adjusted by command, and the Opportunity MI (camera serial number 110) video offset was conservatively chosen to ensure that DN values would always exceed zero [*Herkenhoff et al.*, 2004a]. MI reference pixel data products were occasionally returned to Earth to verify that data clipping at 0 DN did not occur and to check the MI offset correction algorithm. The reference pixel data