*1997 HST Calibration Workshop*
*Space Telescope Science Institute, 1997*
*S. Casertano, et al., eds.*

# NICMOS Sensitivity to Cosmic Rays

Daniela Calzetti

*Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218*

**Abstract.** NICMOS dark frames obtained during Servicing Mission Observatory Verification (SMOV) were used to derive the sensitivity of the detectors to cosmic ray hits. The number of cosmic ray events ($5\sigma$ detections) is about 1.2–1.6 events/camera/sec, comparable to the WFPC2 detection rate for the same detector area. The mean size of the $5\sigma$ cosmic ray hits is 1.65 to 2 pixels, similar to the value measured during the NICMOS System Level Thermal Vacuum (SLTV) experiments. The number of pixels affected by cosmic ray hits is between 2 and 3 pix/camera/sec. This value depends on the position of the telescope relative to the South Atlantic Anomaly (SAA), and variations up to 60% in the rate of affected pixels have been observed between different dark frames during the same orbit. Information in the affected pixels can be partially recovered with the use of the MULTIACCUM readout mode. However, seldomly (once–twice per month), cosmic ray hits have been observed to persist between frames during an orbit.

## 1. Introduction

The impact of cosmic rays (CRs) on the detectors of an instrument strongly affects the observing strategies which can be adopted, and NICMOS is no exception to this. Here, images (dark frames) obtained during SMOV are used to characterize the sensitivity of the NICMOS detectors to CR hits. As we will see in the next sections, NICMOS detection of CRs is comparable to WFPC2. However, the multiple non-destructive reads of the MULTIACCUM readout mode allow observers to partially recover the information in the affected pixels. Recommendations for observing strategies are given in the Discussion section.

## 2. The Data

Sets of darks were obtained during the SMOV program 7051 for each of the 3 NICMOS detectors and during the ERO program 7119 for NIC2 and NIC3. For each camera, sets of 5 to 9 MULTIACCUM frames were obtained, with exposure times between 250 and 2,000 sec.

Each camera was analyzed independently to control systematics. Data from the two different programs were compared in the case of NIC2 to check for variations in the number of CR-affected pixels due to variations in the observing conditions. A total of 18,432 seconds of dark exposure are available for each camera from program 7051, and additional 1,280 seconds are available for NIC2 (2,560 seconds for NIC3) from program 7119. Because of the presence of the "pedestal" effect, the first frame of each set shows more average counts (between 35 and 55 DN) per pixel than the others. The analysis was pursued both discarding and including the first image of each set of darks. The results do not show dependence on the inclusion/exclusion of the first image, and should be considered robust against this characteristic of the dark frames.

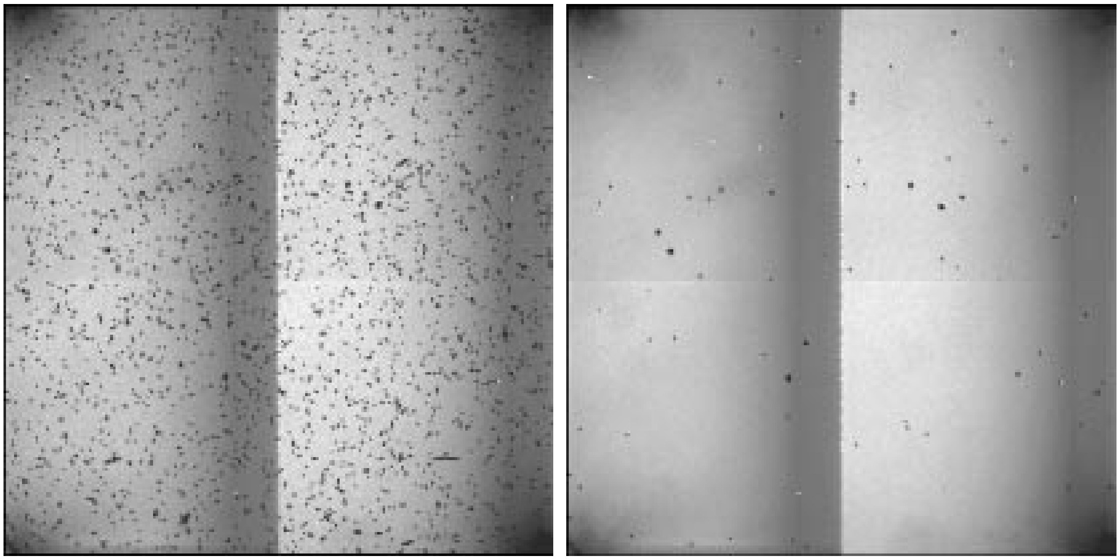

Figure 1. A NIC2 dark frame exposed for 2,048 sec is shown, before (left) and after (right) CR-removal. There are about 4,000 CR-affected pixels ($T_{CR}=5\sigma$ and $T_S=5\sigma$) in the left panel. In the combined dark (right panel) the remaining dark spots are bad pixels.

## 3. The Analysis

The detection of CR events was performed using both the `crrej` routine in the STSDAS package and the generic `imcombine` routine in IRAF. The products of `crrej` are a "CR-free" image and one image of the rejected pixels for each input image. The latter are used to count CR-affected pixels. A rejection threshold $T_{CR}=5\sigma$ was used to identify "CR-hits"; the radius of the region around a CR-hit subject to further scrutiny was set to 1.5 pixels, and the rejection threshold for this area was set to two different values: $T_S=5\sigma$ (see Figure 1) and $T_S=3\sigma$. The case $T_{CR}=3\sigma$ and $T_S=3\sigma$ was also considered. The central 236×236 pix$^2$ were analyzed in each frame, to avoid edge effects and the biases in the statistics introduced by the amplifier glow. The standard deviation calculated by CRREJ combines the readout noise with the statistical noise on the counts. The detector's parameters were set to gain=5.5 $e^-$ for NIC1 and NIC2 and gain=6.5 $e^-$ for NIC3, and readout noise of 30 $e^-$. The latter is the dominant term for the rejection threshold, since the dark current is comparatively small (about 0.05 $e^-$/sec for the darks of program 7051) The dark frames were also processed with `imcombine`, adopting median scaling and the crreject option, to compare the "CR-free" image so produced with the output from `crrej`. No differences were found between the combined frames produced by the two tasks.

## 4. Results

The number of CR-affected pixels from program 7051, given in units of /camera/second, are reported in Table 1, for each camera and for the three combinations of $T_{CR}$ and $T_S$ considered. Although only the central portion of each frame was analyzed, the numbers reported are normalized to the entire area of the camera. The typical number of pixels above the $3\sigma$ threshold in each 2048 sec dark is about 5,400 versus an expected number of 177 pixels/camera due to chance events; above the $5\sigma$ threshold there are typically 4,100 pixels versus an expected number of $<1$ pixels/camera due to chance. The number of CR events has been counted for the $T_{CR}=5\sigma$ case (column 4 of Table 1), giving about

1.2 events/camera/sec. For comparison, the number of CR-hits experienced on-orbit by WFPC2 is 1.24 events/s/cm2, very close to the number observed for NICMOS (each NICMOS detector has an area of 1.049 cm$^2$). The size of the CRs in the $T_{CR}=5\sigma$ frames is between 1.55 and 1.70 pixels (mean value about 1.65 pixels), similar to the value reported from the SLTV data.

Table 1. Cosmic Ray Event Statistics

| Camera | Threshold | Affected Pixels (#/camera/sec) | Number Events (#/camera/sec) |
|---|---|---|---|
| NIC1 | $T_{CR}=5\sigma$, $T_S=5\sigma$ | 2.11 | 1.28 |
| NIC1 | $T_{CR}=5\sigma$, $T_S=3\sigma$ | 2.50 | |
| NIC1 | $T_{CR}=3\sigma$, $T_S=3\sigma$ | 2.74 | |
| NIC2 | $T_{CR}=5\sigma$, $T_S=5\sigma$ | 1.99 | 1.21 |
| NIC2 | $T_{CR}=5\sigma$, $T_S=3\sigma$ | 2.28 | |
| NIC2 | $T_{CR}=3\sigma$, $T_S=3\sigma$ | 2.43 | |
| NIC3 | $T_{CR}=5\sigma$, $T_S=5\sigma$ | 1.90 | 1.15 |
| NIC3 | $T_{CR}=5\sigma$, $T_S=3\sigma$ | 2.53 | |
| NIC3 | $T_{CR}=3\sigma$, $T_S=3\sigma$ | 2.79 | |

The comparison between the CR-hit characteristics in programs 7119 and 7051 is reported in Table 2 for NIC2. In 7119 the rate of CR-affected pixels is about 60% higher than in the case of 7051. The size of the typical CR is also larger: 2.00 pixels versus 1.65 pixels. However, the larger size does not compensate entirely for the increased rate of affected pixels, and the rate of CR-hits increases slightly, to 1.6 events/sec/camera. The 7119 darks show a decreasing trend in the number of affected pixels from one frame to the next both in NIC2 and NIC3, going, for NIC3, from 3.35 pix/sec/camera to 1.50 pix/sec/camera over a period of 42 minutes (half orbit). The largest counts were observed while the telescope was close to the SAA, while the minimum was observed when the telescope was the farthest from the SAA. Between the two programs (7119 and 7051) the main difference in term of observing conditions is the distance of the telescope from SAA impacted orbits.

Table 2. Cosmic Ray Events in NIC2 (7119 versus 7051)

| Program ID | Threshold | Affected Pixels (#/camera/sec) | Number Events (#/camera/sec) |
|---|---|---|---|
| 7119 | $T_{CR}=5\sigma$, $T_S=5\sigma$ | 3.21 | 1.61 |
| 7119 | $T_{CR}=3\sigma$, $T_S=3\sigma$ | 3.96 | |
| 7051 | $T_{CR}=5\sigma$, $T_S=5\sigma$ | 1.99 | 1.21 |
| 7051 | $T_{CR}=3\sigma$, $T_S=3\sigma$ | 2.43 | |

*In general, the average number of about 2-3 pix/sec/camera lost to CR hits ($5\sigma$ level) implies that about 10% of the detector area will affected by CRs after about 2,000 to 3,300 seconds. These figures are a factor between 2.2 and 3.5 shorter than the average time necessary to reach the same coverage in WFPC2 (about 7200 sec).*

## 5. Discussion

The CR-affected pixels have a frequency distribution which decreases for increasing energy (DN) values (Figure 2), and individual pixels typically do not saturate after a single CR event. This characteristic, together with the non-destructive readout capability available in NICMOS, can be used to partially recover the signal in CR-affected pixels. Let's make the case of an exposure obtained using a series of $N-1$ non-destructive reads, before the final (destructive) read is taken (total of N readouts); if a CR hits a pixel between any two of

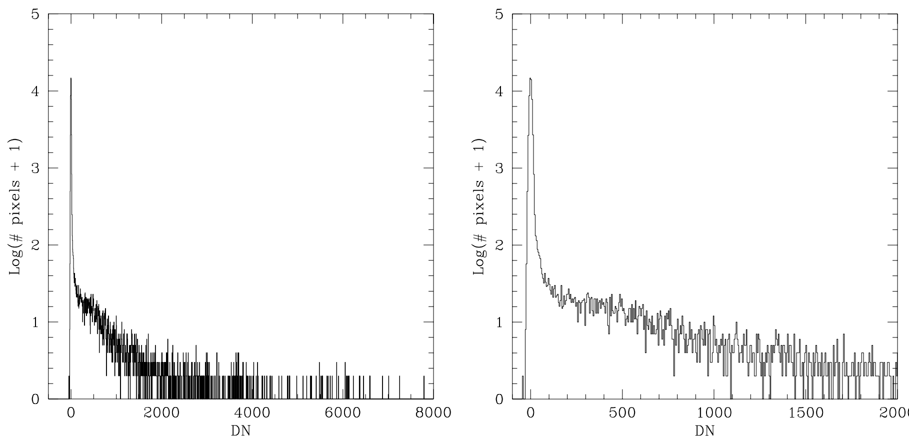


Figure 2. The pixel distribution of one of the NIC2 residual images, obtained from the subtraction of the combined dark from one of the original 2,048 sec dark frames. The distribution is shown for two magnification scales, with the abscissa expressed in DN. The measured $5\sigma$ is 33.0 DN, slightly above the theoretical expectation (30.5 DN). The energy distribution of the CR-affected pixels is thus given by the positive tail above 33 DN. The saturation is reached at about 32,700 DN. Most of the pixels are characterized by low energy values.

the N reads, the remaining, unaffected N−1 readouts can be recovered in most cases. If the CR has deposited enough energy onto the pixel to saturate it, then only the reads before the CR-hit can be recovered. Indeed, the NICMOS calibration pipeline is designed to deal with these cases when non-destructive readouts (MULTIACCUM sequences) are present.

Theoretically, one could think that with this technique very long exposure times could be employed, the only limitation being the probability that any given pixel is hit twice by CRs or that the exposure becomes background limited. However, observers interested in long exposures (faint targets) may select one of the MULTIACCUM MIF sequences, if on-orbit experience prove the multiple initial and final reads advantageous for the reduction of the readout noise. For pixels hit by CRs this advantage will be lost, since the intermediate, non-destructive reads used for the information-recovery are obtained with single readouts. In addition, although quite seldomly (once/twice per month), CR-hits have been observed to persist from one frame to the next during the course of an entire orbit. All this sets a practical limit to the longest exposure that observers interested in faint, non-extended sources may want to use. Depending on the details of the observation, the maximum exposure time advisable will be in the neighborough of 1,000–2,000 sec. One added problem is the difficulty of discriminating between noise and low-energy CR-affected pixels (Figure 2). The shape of the distribution of Figure 2 is such that low-energy CR-affected pixels will be undetected by the calibration pipeline software, since they'll look like noise. The basic effect will be an small increase in the general noise level of the images.

## 6. Summary

The in-flight rate of CR-hits is about 1.2 to 1.6 events/sec/camera for the NICMOS detectors, consistent with the rate observed by WFPC2 on the same area. The size of each CR is between 1.6 and 2 pixels. The CRs affect on average between 2 and 3 pix/s/camera, depending on the orbital position of the telescope relative to the SAA, with an observed peak in the counts of 3.35 pix/s/camera in NIC3 and 3.60 pix/s/camera in NIC2 for the dark frame closest the the SAA. The percentage of detector's area lost to CR-hits has a rate between 2 and 3.5 times bigger than WFPC2, owing to the bigger size of the NICMOS pixels ($40\mu m^2$ versus $15\mu m^2$). However, the use of the non-destructive readout capability of NICMOS can partially compensate for the CR-sensitivity. This solution, although it greatly improves the NICMOS performance, is not perfect, since CR-affected pixels cannot take advantage of the reduction in readout noise potentially provided by the multiple initial and final reads. In addition, CR have been infrequently observed to leave persistence on the detectors. Therefore, for studies of faint targets a limit to the length of the usable exposure time is probably about 1,000–2,000 seconds. To avoid the potential problems induced by the infrequent, but possible, CR-persistence, dithering between exposures within the same orbit is advisable.