

NICMOS Instrument Overview

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This chapter presents a brief overview of the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) instrument capabilities, its readout modes, and data products.

14.1 Instrument Overview

NICMOS was built by Ball Aerospace Corporation for the University of Arizona, under the direction of Rodger I. Thompson, the Principal Investigator. A basic description of the instrument and its on-orbit performance through the Servicing Mission Orbital Verification program is provided by Thompson et. al (1998).¹ We encourage all NICMOS users to reference this paper and to review the related papers in the special *ApJ Letters* which describe the Early Release Observations and demonstrate the scientific capabilities of NICMOS.

NICMOS provides imaging capabilities in broad, medium, and narrow band filters, broad-band imaging polarimetry, coronagraphic imaging, and slitless grism spectroscopy, in the wavelength range 0.8–2.5 μm . NICMOS is an axial instrument and has three adjacent but not contiguous cameras, designed to operate independently and simultaneously. Each camera has a different magnification scale, and is equipped with a dedicated 256 x 256 HgCdTe Rockwell array. The pixel size and field of view are 0".043 and 11"x11" in Camera 1 (referred to as

1. Thompson, R.I., M. Rieke, G. Schneider, D.C. Hines, and M.R. Corbin, 1998, *ApJL*, 492, L95.

NIC1), $0''.075$ and $19''.2 \times 19''.2$ in NIC2, and $0''.2$ and $51''.2 \times 51''.2$ in NIC3. Information about detector performance can be found in the *NICMOS Instrument Handbook* and at the NICMOS WWW page:

http://www.stsci.edu/ftp/instrument_news/NICMOS/topnicmos.html

Each camera is provided with its own set of filters, mounted on three independent wheels. There is a total of 20 filter positions on each wheel, of which one is BLANK and three of the others are occupied by either polarizers or grisms. The remaining 16 positions of each filter wheel are occupied by broad, medium, and narrow band filters. The list of these filters is given in the *NICMOS Instrument Handbook*. The filters (including polarizers and grisms) cannot be crossed with each other, and are used as single optical elements.

NIC1 and NIC2 each contain three polarizers, whose principal axes of transmission are separated by 120 degrees. The spectral coverage is fixed for each camera. The polarizers cover the wavelength range $0.8\text{--}1.3\ \mu\text{m}$ in NIC1, and $1.9\text{--}2.1\ \mu\text{m}$ in NIC2. Observations in the three polarizers of each camera are used to derive the Stokes parameters of linearly polarized light.

The filter wheel of NIC3 contains three grisms which can be used to perform slitless spectroscopy in the wavelength range $0.8\text{--}2.5\ \mu\text{m}$. The three grisms cover the range $0.8\text{--}1.2\ \mu\text{m}$, $1.1\text{--}1.9\ \mu\text{m}$, and $1.4\text{--}2.5\ \mu\text{m}$, respectively.

In NIC2, a coronagraphic spot is imaged onto the focal plane and provides a circular occulted region of $0''.3$ in radius (with a useful effective radius of $0''.4$). For coronagraphic imaging, an acquisition sequence is required at the beginning of the observation to center the target under the occulting spot.

Each 256×256 detector array is divided into four 128×128 quadrants, each of which is read out by an amplifier at the corner of the quadrant. There are four amplifiers in each camera. Unlike CCDs, infrared array pixels are read independently, implying that problems like charge transfer efficiency or bleeding are not present. The three cameras operate independently, implying that optical elements, integration times, and readout modes can be different in each.

14.2 Detector Readout Modes

NICMOS does not have a physical shutter mechanism, and exposures are obtained through a sequence of reset and read operations. In particular, a typical exposure will be the product of the following steps:

1. **Array reset:** the pixels are set to the bias level.
2. **Array read:** the charge in each pixel is measured and stored in the on-board computer's memory. This read is performed immediately after the reset, and contains the reference level for the exposure (zeroth read). In practice, the readout is performed 0.203 seconds after the reset, implying that it represents a finite, though very short, exposure. This readout is performed non-destructively—the charge in each pixel is left intact.

3. **Integration:** NICMOS integrates for the user-specified time.
4. **Array read:** the charge in each pixel is measured and stored in the on-board computer's memory. Again, the readout is non-destructive.

The beginning of an integration is marked by the zeroth read, which is always preceded by a reset. Since all readouts are non-destructive, namely, do not change the value of the charge accumulated on the pixel, the last two steps of the sequence above can be repeated multiple times, and the last read of the sequence will be called the *final read*. The total integration time of an exposure is defined as the time between the final and the zeroth read of the first pixel in the array. The scientific image is given by the difference between the final and the zeroth readouts. Four readout modes have been defined for NICMOS, exploiting the flexibility allowed by the non-destructive reads:

- MULTIACCUM.
- ACCUM.
- BRIGHTOBJ.
- RAMP.

Each mode is described in the following sections, with larger emphasis on MULTIACCUM, which is by far the most used and best calibrated mode.

14.2.1 MULTIACCUM

In a MULTIACCUM (MULTIple ACCUMulate) exposure, the zeroth read is followed by several other non-destructive readouts during the course of a single integration. All of the readouts are stored in the on-board computer's memory and sent to the ground. Because the readouts are non-destructive, accumulated counts are built up from one readout to the next, with the last readout containing the accumulated counts from the entire integration time of the observation. In an exposure, the number of readouts after the zeroth and the temporal spacing between each read is selected by the user from a set of 16 pre-defined SEQUENCES. The user specifies the number of readouts through the NSAMP keyword during the Phase II. NSAMP+1 (including the zeroth read) images will be returned to the ground. For NICMOS the maximum value of NSAMP is 25 in each sequence (for a total of 26 images returned to the ground).

Since MULTIACCUM gives information not only at the beginning and at the end of an exposure, but also at intermediate times, it is the mode of choice for the vast majority of astronomical observations, from objects with large dynamical range to deep field integrations. The intermediate reads can also be used to remove the effects of cosmic ray hits and of saturated pixels from the final processed image.



The images returned to the ground by the MULTIACCUM readout are *raw* detector readouts, since not even the bias level (the zeroth read) is subtracted. This operation is performed by the ground calibration pipeline.

14.2.2 ACCUM

ACCUM is a simplified version of MULTIACCUM: the zeroth read is followed by one read (the final readout) after an amount of time specified by the integration time. The difference between the final and the zeroth readouts is computed on board, and the resulting image is sent to the ground. In this form, the ACCUM mode produces data very similar to the more familiar CCD images. A variation to this basic operation is available, which replaces the single initial and final readouts with multiple (initial and final) readouts. After the initial reset pass, n non-destructive reads of the detector immediately follow, as close together in time as allowed by the detector electronics. The average of the n values is stored as the initial value for each pixel. At the end of the integration, there are again n non-destructive readouts with the final value for each pixel being the average of the n reads. The number n of initial and final reads is specified by the observer and is recorded in the value of the NREAD (number of reads) header keyword in the science data files. The returned image is the difference between the averaged final and initial values. The integration time is defined as the time between the first read of the first pixel in the initial n passes and the first read of the first pixel in the final n passes. The advantage of the multiple initial and final (MIF) readout method is that, in theory, the read noise associated with the initial and final reads should be reduced by a factor of \sqrt{n} , where n is the number of reads. The currently supported NREAD values are 1 and 9.

14.2.3 BRIGHTOBJ

The BRIGHTOBJ (BRIGHT OBJECT) mode provides a way to observe objects that would usually saturate the detector in less than the minimum available exposure time (which is the amount of time it takes to read out the array and is 0.203 seconds). In BRIGHTOBJ mode each individual pixel (per quadrant) is successively reset, read, integrated for a time requested by the observer, and read again, and then these steps are performed for the next pixel in the quadrant. The returned image contains the number of counts accumulated between the initial and final reads for each pixel (just like ACCUM mode). Since each quadrant contains 16,384 pixels, the total elapsed time to take an image in this mode is 16,384 times the requested exposure time for each pixel.

This readout mode has proven difficult to use because of the non-linearity of the detector in the presence of bright targets, even for very short exposure times.

14.2.4 RAMP

RAMP mode makes multiple non-destructive reads during the course of a single exposure much like MULTIACCUM, but only a single image is sent to the ground. The RAMP mode divides the total integration time T into n equal intervals $t = T/n$. Each readout is differenced (on-board) with the previous readout and used to compute a running mean of the number of counts (per sample interval) and an associated variance for each pixel. Large deviations from the running mean are used to detect saturation or a cosmic ray hit. At the end of the exposure, the data sent to the ground comprise a mean countrate image, plus the variance and the number of valid samples used to compute each pixel value. The effective exposure time for the returned image is the sample interval t .

Although this mode could be used in principle to obtain the same benefit of a MULTIACCUM exposure without the large data volume, the difficulty of implementing infallible algorithms for the cosmic ray rejection has made this mode of secondary use relative to MULTIACCUM.

