In this chapter we deal with techniques for small scale motions to remove localized detector non-uniformities, for mapping areas larger than the size of the field of view of the NICMOS cameras, and the issue of removing the thermal background of the telescope.

Special procedures have been created to enable observers to perform these operations, and these are significantly different than those described in earlier versions of this handbook.
Introduction

Multiple exposures with small offsets in the pointing of the telescope are usually necessary or recommended for NICMOS observations. We distinguish three particular circumstances which may require small offsets:

- **Dithering** to permit the removal of dead or non-calibrated (i.e., non-correctable) pixels on the detectors, and detector’s non-uniformities (i.e. sensitivity variations),

- Dithering or **chopping** to measure the background associated with an astronomical source,

- **Mosaicing** to map a source larger than a single detector field of view.

The techniques described in this chapter may be used to accomplish any one or any combination of these goals.

Experience with NICMOS has shown that the background is considerably fainter than was expected prior to deployment (see Chapter 4). The background appears spatially uniform (variations no larger than a few percent across the NIC3 field of view) and does not vary much with time (variations of less than 5% on orbit timescales). The description of the thermal background in Chapter 4, Chapter 9 and the Exposure Time Calculator provide a basis for estimating the relative contributions of source and background. It is strongly advised that provision for direct measurement of the background be included in proposals whenever the background is significant relative to the source(s) of interest. The frequency of such measurements should be about once per orbit, and more frequent measurements should be planned when the background must be measured to high accuracy.

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All observations at wavelengths beyond 1.7 µm should consider the need for background measurements.

Background images are obtained by offsetting the telescope from the target to point to an “empty” region of the sky. The ability to routinely offset the telescope pointing is a fundamental operational requirement for NICMOS. Starting in cycle 9, HST programs will use a standard *pattern* syntax, which will replace the old pattern optional parameters, and the even older scan parameters form. The new syntax allows multiple observations to be made at each point in the pattern, if desired. Observers should check the “Phase 2 Proposal Instructions” for the exact syntax of the special requirement that invokes the pattern, and the “pattern parameter form” that describes the motion. For simplicity, a set of pre-defined observing patterns has been built; these patterns combine exposures taken under them into one
or more associations. A pattern, then, is a set of images of the same astronomical target obtained at pointings offset from each other, e.g. for the purpose of mapping an extended target or for creating background images. The associations of exposures are created for the purpose of simultaneously processing all the images (through a given filter) from a single pattern. Dithered images can thus be easily reassembled into a single image with the effects of minimizing bad pixels, or images taken in the long wavelength regime can be corrected for the thermal contribution, or observations of extended targets combined into a single large map.

Two distinct types of telescope motion are defined:

- **Dither**: Individual motions are limited to no more than 40 arcsec. These are intended to be used to perform small dithers, to measure backgrounds for compact sources, and to accomplish sequences of overlapping exposures for the construction of mosaics. Such sequences will be assembled into a single final image by the calibrations pipeline.

- **Chop**: Motions up to 1440 arcsec are permitted. These are intended for the measurement of the background at one or more locations significantly removed from the target pointing. Each non-contiguous background pointing will be assembled into its own final image in addition to the target pointing by the calibration pipeline.

Telescope motions involve overheads for physically moving the telescope and, if necessary, for re-acquiring the guide stars. Therefore, significant time overheads may be incurred by observations which need background subtraction or propose to map extended regions of the sky. A careful estimate of the overheads associated with a specific observation or set of observations is necessary to evaluate the number of orbits required (see Chapter 10).

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**Strategies For Background Subtraction**

The most efficient strategy for removing the background from a science exposure strongly depends on the nature of the target and of the science to be accomplished. In general, two types of targets can be defined: compact and extended.

### Compact Objects

For compact objects, such as point sources, background subtraction can be achieved by moving the target across the camera field of view (see Figure 11.1). A dither pattern, which involves movements of a few arcsec
from one exposure to the next, can then be used. This is an efficient way to build background images, since the target is present in each exposure, and a background image can be created from the stacking and filtering of all exposures.

Figure 11.1: Dithering

![Dither Diagram](image)

**Extended Objects**

For an extended object which occupies a significant portion of the NICMOS field of view, the dithering technique does not apply to building background images. In this case, offsets to an adjacent field (chopping) chosen to be at least one camera field away in an arbitrary (or user specified) direction, are necessary. By offsetting in different directions a stacked and filtered sky image can be created which removes the effect of contaminating objects in the offset fields (see Figure 11.2). As in the case of compact objects, these offsets might be quite small, but for large galaxies for example, they may need to be over considerable distances. The user will have the ability to specify the offset values and directions and the number of offsets, in the Phase II pattern parameters form.
There are a set of fifteen pre-designed patterns available for NICMOS observations. Users may define their own patterns as well, using the Pattern Parameters Form, during phase II development. The pre-defined patterns include four dithering patterns, four chopping patterns, five dither-chop patterns, and two mapping patterns. For each of these, the observer will be able to specify the number of positions desired (2 to 40), the dither size (0 to 40 arcsec), the chop size (0 to 1440 arcsec, also used for mapping), and
the orientation of the pattern with respect to either the detector or the sky. The POS–TARG special requirement will still be available for offsetting the telescope and creating custom-design patterns as well, but there are a number of advantages to using the pre-designed patterns:

- They simplify the specification of complex observations in the Phase II proposal,
- All the observations pertaining to an exposure logsheet line in a pattern result in one association and are simultaneously calibrated and combined in the data calibration pipeline, including background calibration, cosmic ray removal, and flat field averaging. Observations obtained with POS–TARG do not result in associations, and will have to be combined manually by the observer,
- They permit the observation of a mosaic with a fixed position angle without fixing spacecraft roll, which increases the number of opportunities to schedule the observations.

Multiple exposures may be obtained at each position by the use of the number-of-iterations ($N_{\text{EXP}}$) optional parameter. This may be useful for cosmic ray removal. In addition, exposures in different filters at each pattern position can be obtained.

The fifteen patterns are listed in Table 11.1, together with applicable parameters, such as the allowed values for the number of steps in the pattern, the dither size, or the chop size. In addition, the figure number where the pattern is graphically shown is given in column 5 of Table 11.1. Offset sizes and number of steps in a pattern affect the amount of overhead time required to perform an observation (see Chapter 10). The effects of dithering or chopping on an astronomical image are shown in a set of examples in the next section.
Note on Orientation:
The new pattern parameter syntax requires additional input on orientation. Specifically, the pattern must be defined in either the POS-TARG (camera) frame or the CELESTIAL (sky) frame. An orientation angle may be specified as well (the usual default is 0°). In the POS-TARG frame, this is the angle of the motion of the target from the first point of the pattern to the second, counterclockwise from the x detector axis (the directions are defined in Figure 6.1). In the CELESTIAL frame, the angle is measured from North through East.

Some of the chopping patterns in Table 11.1 are doubled, they can be specified either as POS-TARG default or CELESTIAL default.

Move the sky or the telescope?
The new pattern syntax attempts to resolve the confusing dichotomy in the old pattern implementation, as to whether the pattern moves the telescope or the target. It does this by providing the two reference frames described above. Patterns done in the POS-TARG reference frame will move the target, just as the “POS-TARG” special requirement does. Patterns done in the CELESTIAL reference frame will move the telescope.
as was done with the original implementation of the NICMOS patterns. The target will move in the opposite direction on the image, in the CELESTIAL frame.

Dither Patterns

The dither patterns are recommended for the background subtraction from observations of point sources (beyond 1.7 microns), and for the reduction of sensitivity variations and bad pixel effects. The four types of canned dither routines are SPIRAL-DITH, SQUARE-WAVE-DITH, XSTRIP-DITH, and YSTRIP-DITH. Most of the names are self-explanatory: the SPIRAL-DITH pattern produces a spiral around the first pointing; the SQUARE-WAVE-DITH pattern covers extended regions by moving along a square-wave shape; the XSTRIP-DITH and YSTRIP-DITH patterns move the target along the x and y directions of the detector, respectively. The difference between the XSTRIP-DITH and the YSTRIP-DITH patterns is that the first moves by default along the grism dispersion (more or less), while the second moves orthogonal to the grism dispersion axis. These patterns are illustrated in Figure 11.3

Note that there is an additional parameter for dithering patterns, to center the pattern on the target. The default is to start the dithering at the target position.
Chop Patterns

The chop patterns are recommended for measuring the background adjacent to extended targets. For each chop pattern, half of the exposures are taken on the target (position 1). There are two basic patterns, **ONE-CHOP** and **TWO-CHOP**. The **ONE-CHOP** pattern produces one image of the target and one image of the background. The **TWO-CHOP** pattern produces one image (with two exposures) of the target and two background images, with the background fields positioned on opposite sides of the target. These patterns may be repeated if necessary: note that rather than specifying the number of points in the pattern, the observer specifies the number of repeats of the pattern. For example, calling the **NIC-TWO-CHOP** pattern with number of patterns of 1 will produce four
images, one on the target, one off to one side (default -x detector direction, see next para.), one back on the target, and one off to the other side. If the number of patterns is set to 2, the observer will get eight images, and so forth. Chop patterns are illustrated in Figure 11.4.

Because chopping is best done to empty regions of the sky, we provide a set of chopping patterns that are in the CELESTIAL coordinate system, as well as the standard set (that are in the POS-TARG frame). These have the word SKY in their name, and must have an orientation angle (degrees E from N for the first motion of the pattern) supplied. These should be used when the region around the target contains some objects that should be avoided when measuring the background. SKY patterns are illustrated in Figure 11.6.

Figure 11.4: Chop Patterns

**Combined Patterns**

The combined patterns permit dithering interleaved with chops to measure the background. They are recommended for simultaneous minimization of detector artifacts and background subtraction, for observations beyond 1.7 microns. Three types of combined patterns are implemented: SPIRAL-DITH-CHOP, XSTRIP-DITH-CHOP, and YSTRIP-DITH-CHOP. Their characteristics are analogous to the dither patterns SPIRAL-DITH, XSTRIP-DITH, and YSTRIP-DITH, respectively, with the addition that each dither step is coupled with a background image obtained by chopping. These combined patterns are shown in Figure 11.5.

In a manner similar to the regular chopping patterns, the combined patterns have “SKY” versions implemented in the CELESTIAL frame. Since these require an orientation angle, there is no YSTRIP-DITH-SKY-CHOP, however: this is redundant with XSTRIP-DITH-SKY-CHOP. These are illustrated in Figure 11.6.
Map Patterns

A new addition to the suite of “canned” patterns are the two MAP sequences. These allow the telescope to be pointed at a regular grid of points, doing a series of exposures at each point. These are done in the CELESTIAL frame, so an orientation angle must be supplied, and the telescope motion on the sky is specified (rather than the target motion relative to the detector, see note above). The SPIRAL-MAP sequence is basically the SPIRAL-DITH sequence in the CELESTIAL frame, and automatically maps the (square or rectangular) region around the target.
The MAP sequence defines an arbitrary parallelogram on the sky. The observer may specify the number of points in each of two directions, and the position angle (E of N) of each direction.

As with the dithering patterns, the observer has the option of specifying whether the target is centered in the pattern or not. The target will be centered in the SPIRAL-MAP pattern if there are 9, 16, 24,... points in the pattern, but will not necessarily be centered otherwise. The observer can specify if the target should be centered along one axis or the other, or both, of the parallelogram defined by the MAP sequence. These are illustrated in Figure 11.6.

Figure 11.6: Patterns on the sky
The next few pages show some selected examples of how the patterns work on astronomical observations.
Figure 11.7: NIC-TWO-SKY-CHOP pattern.

Spacing (chop throw) = 1 detector width,
Pattern Orient = 270°,
Visit Orient = 225°,
(Frame=CELESTIAL)

Images Taken:

#1
#2

#4
#3
Spacing = detector size/$\sqrt{2}$, Frame= CELESTIAL, Pattern2 Orient = 284˚, Pattern1 Orient = 14˚, No visit level orient specified: nominal roll puts detector Y at position angle 310˚

Could cover the area more efficiently with Spacing = 0.866xdetector size, and Pattern1 Orient = Pattern2 Orient + 60˚

In either case, the lack of visit orient specification greatly increases the chance of scheduling the observation.
Phase II Proposal Instructions for Patterns

We discuss the Phase II instructions for patterns in this section in order to illustrate the options available. This is not, however, an exhaustive description and is not the appropriate reference to use when preparing a Phase II proposal. While writing your Phase II you should refer to the Phase II Proposal Instructions, which contain a complete and up-to-date guide.

This section is not crucial for preparing the Phase I proposal, but it may be relevant to know beforehand which parameters will be available, and what values these parameters can have. The pattern parameters form allows for two nested parameters (pattern 2 is performed at each point in pattern 1) but many of the predefined patterns already use this capability: you cannot always “nest” the “canned” patterns. A pattern can apply to a series of exposure logsheet lines, and the entire sequence is done at each point in the pattern. Thus the special requirement \texttt{PATTERN n [<exposure list>]\texttt{)} (where n is the number of the pattern parameter form to be applied to these observations) should only apply once to any exposure logsheet line, and should only be specified on one exposure in \texttt{<exposure list>.} Be very careful not to “call” a line in two different patterns!

The set of exposures resulting from a pattern is sorted by filter, and an association is created for each filter.

Patterns may use the FOM instead of moving the whole telescope, however this is an “available” (not “supported”) mode of observation. The FOM doesn’t necessarily come back to exactly the same place, so artifacts on the mirror may appear to move around. Observers requiring very small, and very rapid offsets (or making observations in parallel to another instrument) may benefit from its use and can discuss this with their Contact Scientist during the Phase II proposal process.

Types of Motions

The \texttt{OFFSET} optional parameter defines which type of telescope motion will be performed during a pattern, in order to dither or chop. Telescope motions fall into three categories:

- Small angle maneuvers (SAMs) where FGS Fine Lock guiding is maintained. Such SAMs are typically limited to \(< 2\) arcmin from the point of the initial guide star acquisition. This is the practical limit of the radial extent of the pattern. Often it will be smaller due to guide star availability.
• SAMs without FGS guiding (i.e. GYRO pointing control). These are necessary for larger motions (> 2 arcmin). The telescope will drift at a rate of 1 to 2 milliarcsec per second of time (elapsed time since dropping to gyro— not exposure time).

• SAMs with RE-ACQuisitions of guide stars at each return to the target position. This can be used to chop between a target and an offset background measurement pointing (which would be observed with GYRO pointing control).

The available options for OFFSET are:

• SAM, the default, will use guide stars whenever possible. If a motion, or the sequence of motions, moves the telescope sufficiently from the original position that guide stars are no longer available, then exposures will be obtained using GYRO control. If a subsequent motion returns the telescope to a point where the original guide stars become available than the guide stars will be RE–ACQuired. This incurs an overhead of ~3 minutes for each RE–AC quisition.

• SAM–NO–REACQ will use guide stars (FGS fine lock) until the first instance in the pattern when guide stars become unavailable. The remainder of the pattern will be executed using GYRO control.

• SAM–NO–GYRO will use guide stars for all exposures. If guide stars are not available, the observations will not be scheduled.

• FOM will use the Field Offset Mirror to perform the pattern. See the description above; this is an “available” operating mode, for use only for coordinated parallels.