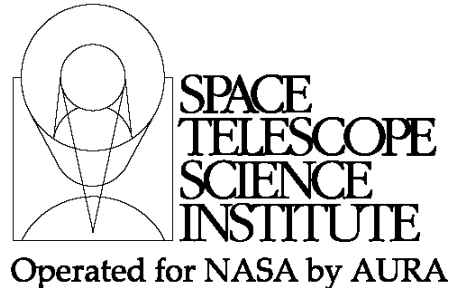




TECHNICAL REPORT



Title: NIRCam Observing Templates Description	Doc #: JWST-STScI-002178, SM-12 Date: July 19, 2010 Rev: -
Authors: Kailash Sahu, Karl Gordon	Phone: 410-338-4390 Release Date: 9 June 2011

1.0 Abstract

The details of the NIRCam observing templates are described. The NIRCam observing templates will be used for all astronomical observations with NIRCam. Currently, there are 2 NIRCam observing templates: Imaging and Coronagraphy. Under current plans, an additional template for long-wavelength grism spectroscopy will also be added. Calibration, wavefront sensing, and engineering observations that cannot be done with the observing templates will be done with special engineering templates that will be defined in a separate report.

2.0 Introduction

The use of templates to define JWST observations will simplify operations, data reduction, and calibration. Fullerton (2008) presents the preliminary concept study for the JWST observation templates. This report expands on the concept study by providing the full details of each of the four NIRCam templates.

- The two current NIRCam templates are Imaging and Coronagraphy.
- The Imaging template will be used for all NIRCam direct imaging, both in the LW (long wavelength) and SW (short wavelength) channels.
- The Coronagraphy template will be used for coronagraphy in SW and LW channels.
- In both these imaging templates, a point on the sky will be simultaneously imaged in SW and LW channels.
- In addition, a spectroscopic template for the LW channel will also be available. This may be coupled with the imaging template in the SW channel.

NIRCam performs the facility Wavefront Sensing (WFS) function, in addition to serving as a science imager. Such observations will be carried out through engineering templates, which are not discussed in this document.

Operated by the Association of Universities for Research in Astronomy, Inc., for the National Aeronautics and Space Administration under Contract NAS5-03127

Check with the JWST SOCCER Database at: <http://soccer.stsci.edu/DmsProdAgile/PLMServlet>
To verify that this is the current version.

2.1 Basics of NIRCam Readout Patterns

NIRCam detectors (SCAs) can be read out non-destructively. Non-destructive readout (i.e. sampling up the ramp) provides lower readout noise for an integration of a given length than is possible if the detector is simply read out once at the end of the integration and also makes it possible to reject cosmic ray hits in the time domain. During integration, the ASIC digitizes samples and transfers them to the NIRCam Focal Plane Electronics (FPE). The pixels are sampled at a rate of 10.0 $\mu\text{sec}/\text{pixel}$; small overheads at the ends of rows and frames increase the average effective sampling period to 10.1 μsec . There are 4 parallel output channels in full-array mode, each with 512x2048 pixels, resulting in a full-frame readout time of 10.6 seconds. NIRCam arrays are reset pixel-by-pixel, and a reset also takes 10.6 seconds. This reset mode is found to provide better latent-image mitigation than other available reset types, has the advantage that the total exposure time per pixel is not a function of position on the SCA, and results in extremely stable power dissipation and thermal stability of the SCA. Table 1 gives the details of the various Readout patterns for NIRCam MULTIACCUM exposures (For full details, see Sahu et al. 2010, NIRCam OCD). Note that for NFrames > 1 the samples are co-added by the FPAP before downlink. The figure 12 of the OCD shows two multiaccum data ramps, or *integrations*. An *exposure* can contain one or more integrations.

NIRCam has 9 different Readout patterns as described in the OCD, which is reproduced in Table 1 below.

Table 1: NIRCam MULTIACCUM Patterns for Imaging and Mapping

TGROUP (sec)	NGROUPS	NFRAMES	NSkip	$t_{\text{integration}}$ Max/Min	Data Vol. (Gb/day)	Notes & MULTIACCUM Pattern Name
212	1 – 20	8	12	4110 / 84.8	137	DEEP8 Deep surveys. Low bkgnd/N filters. High redundancy. Low dynamic range.
	1 – 20	2	18	4050 / 21.2		DEEP2 Deep surveys. Moderate bkgnd/W filter. Low redundancy. High dynamic range.
106	1 – 10	8	2	1040 / 84.8	274	MEDIUM8 Medium/shallow surveys. Low bkgnd/N filters. Higher redundancy. Lower dynamic range.
	1 - 10	2	8	975 / 21.2		MEDIUM2 Medium/shallow surveys. Moderate bkgnd / W filters. Low redundancy. Higher dynamic range

Check with the JWST SOCCER Database at: <http://soccer.stsci.edu/DmsProdAgile/PLMServlet>
To verify that this is the current version.

TGROUP (sec)	NGROUPS	NFRAMES	NSkip	$t_{\text{integration}}$ Max/Min	Data Vol. (Gb/day)	Notes & MULTIACCUM Pattern Name
53	1 - 10	4	1	519 / 42.4	548	SHALLOW4 Shallow surveys / bright objects. Moderate bkgnd / N or M filters. Higher redundancy. Lower dynamic range.
	1 - 10	2	3	498 / 21.2		SHALLOW2 Shallow surveys / bright objects. Moderate – high bkgnd / W filters. Lower redundancy. Higher dynamic range.
21.2	1 - 10	2	0	212 / 21.2	1370	BRIGHT2 Bright objects. High bkgnd / W filters. Higher redundancy. Lower dynamic range.
	1 - 10	1	1	201 / 10.6		BRIGHT1 Bright objects. High bkgnd / W filters. Lower redundancy. Higher dynamic range
10.6	1-10	1	0	106 / 10.6	2740	RAPID Shortest available group time.

TGROUP:

Time to acquire a single group. It is equal to the total number of frames within a group (NFRAMES + NSkip) \times τ_f where τ_f is the sample time for the frame. For NIRCcam, for example, sample time τ_f , for the full frame, is 10.6 seconds. In subarray mode τ_f is approximately given by #pixels \times 10.11 μ sec, where #pixels is the total number of pixels in the subarray.

NGROUP:

The number of groups collected before resetting the array.

NFRAME:

The number of frames to coadd on board before storing the result for a group in the solid state recorder.

Nskip:

The complementary number of frames within a group that do not get included in the coadd.

Data Volume:

Volume of data generated by the FPAP in 24 hours assuming continuous data taking, a lossless compression factor of 2, and taking data on all 10 SCAs simultaneously. The conversion factor used is 3.36×10^8 bits / group. The data volume associated with storing frame0 is not accounted for, and it increases the data volumes

Check with the JWST SOCCER Database at: <http://soccer.stsci.edu/DmsProdAgile/PLMServlet>
To verify that this is the current version.

particularly for the short integration times. However, the short integration times are likely to be used for point-source imaging on 2 SCAs, not 10-SCA mapping, so the data volumes given in Table 1 are likely to be upper limits on what will actually be seen in routine operation. Note that data rates for the shorter group times will probably violate the steady-state allowed data rate, and some mechanism will be necessary to encourage observers to favor the longer group times.

Integration time:

The general expression for the integration time is given by:

$$I_t = [(NGROUP-n) * (NFRAME + NSkip) - NSkip] * \tau f$$

where:

n=1 for NGROUP>1 (in which case the difference signal is used by default by the pipeline to calculate the source brightness). In a special case where the total signal is used to calculate the source brightness even when NGROUP>1 (for example, for a bright target where the background is negligible compared to the source), the effective value of n is 0.

n=0 for NGROUP=1 (in which case the total signal is used by the pipeline to calculate the source brightness).

Note that $t_{\text{integration}}$ is the actual time for which the detector is exposed, which is the same as I_t with n=0.

2.2 Source Specification

The specification of the source position and brightness will be done in a manner consistent between all the instruments on JWST. A draft of the information needed for a fixed source is given by Fullerton (2008) and reproduced in Table 2 for completeness. Additional entries will be required to specify “generic”, “offset” or “moving” targets. Some of this information may be retrieved from exposure time calculator computations (e.g. flux of the source in a specific NIRCcam band) and these details are expected to be refined in a later study.

Table 2: Schematic Template Input for Source Description

Input	Details	Default	Remarks
Identification	Target Number	...	Programmatic reference
	Target Name	...	From a preferred catalog
	Target Class (Fixed, Generic, Moving, Offset)	...	Menu
	Alternate Names	...	[Optional] Multiple entries permitted
	Target Type (astrophysical)	...	Menu
	Target Description	...	Menu: depends on target type
Position	RA (ICRS)	...	
	Dec (ICRS)	...	
	RA Uncertainty	0.1"	[default for ICRS]
	Dec Uncertainty	0.1"	[default for ICRS]
Proper Motion	RA PM	0.0 "/year	[units are TBD]
	Dec PM	0.0 "/year	[units are TBD]
	Epoch	...	
Reference Flux*	Waveband or wavelength	...	Many different possibilities
	Flux (magnitude)	...	depending on target type
	Units	...	
	Uncertainty	...	
	Other Fluxes [multiple entries]	...	More information on spectral energy distribution
Optional Information	Radial Velocity	...	In km/s or as a redshift
	Parallax	0.0 "	
	Comments	...	Text block

*We may have to revisit this “Reference Flux” issue. This information may be useful for target-acq purposes for coronagraphic and subarray observations of point sources. However, it is not clear if this information is useful for wide-field observations. Also, this information may not be useful when the image contains many sources of differing brightness.

2.3 Special Requirements

Templates and sets of templates can have special requirements attached to them. A possible set of special requirements is described in Fullerton (2008). Such special requirements normally deal with specifying the orientation and/or time a template or set of templates will execute. These special requirements are not restricted to templates from a single instrument, but can include templates from multiple instruments for the same proposal. For example, NIRCcam and MIRI Imaging templates of a Kuiper Belt object could be grouped with a special requirement that they be executed back-to-back to enable simultaneous near- and mid-IR imaging of the object at the same rotation angle.

2.4 Parallel Science Observations

Parallel science observations using two or more instruments are not currently planned for JWST. At a future date, it may become possible to enable such parallel observations. For a discussion on the details of some issues for such parallel science observations, see Gordon and Wright (2008).

Check with the JWST SOCCER Database at: <http://soccer.stsci.edu/DmsProdAgile/PLMServlet>
To verify that this is the current version.

3.0 NIRCam Imaging Observations

The NIRCam Imaging Template will be used for all direct imaging with NIRCam. NIRCam has two imaging categories: survey mode and small source mode. In addition, there is a coronagraphic mode, and a planned slitless grism-spectroscopic mode in the LW channel.

3.1 Small Source Imaging

Sources small enough to fit within the FOV of a single NIRCam SCA should be imaged using the Small-Source Imaging Activity Descriptor (AD). A single SW SCA will be used for all point-source imaging, and the target image will be placed near its center. It will be possible to simultaneously image the target in the LW channel. A menu of subarrays will be predefined for general observers such that the target falls in the center of both the SW and LW subarray. Parallel observations can be obtained in the other imaging module, but only at the same wavelength(s) as for the primary module and using the same multiaccum parameters. Parallel data from the other SCAs in the module used for small-field imaging will automatically be saved, whether in full or subarray mode.

3.2 Survey Imaging

In survey-mode both modules and all FPAs will be used to provide simultaneous coverage of a 2.2'x4.4' FOV at two wavelengths. Both modules must be configured with the same filters, one short- and one long- wave, and the same multiaccum parameters must be used in both channels. If the background is high compared to the source, compromises may have to be made to balance dynamic range considerations with operating in the background-limited regime.

3.3 Coronagraphic Imaging

For a coronagraphic observation, an observer chooses both target-acquisition and science multiaccum patterns, an occulting mask, and one (for either bar or spot masks) or more (for spot masks only) filters. Normally the user will not have a choice of which module will be used, although this restriction may be relaxed if there are difficulties in finding appropriate guide stars for some targets. Target acquisition will be done using the same module as the science observations.

In principle any occulting mask can be used with any filter in the filter wheel, but the round masks in particular are designed to work at specific wavelengths (2.1, 3.35 and 4.6 μ m). Those masks will work with the other shorter-wavelength filters with somewhat degraded inner working- angle performance but not with longer wavelength filters. The bar occulters can be used with any filter in the filter wheel within the 1.5-5.0 μ m spectral band of the coronagraph, and the observatory will place the target at the correct position along the bar to provide optimal performance. None of the masks can be used with filters in the pupil wheel because that wheel must be in one of the two coronagraphic-pupil positions.

Use of any of the coronagraphic masks requires that the target be placed accurately (to within 30 mas) behind the mask. Because the observatory can only provide pointing with

Check with the JWST SOCCER Database at: <http://soccer.stsci.edu/DmsProdAgile/PLMServlet>
To verify that this is the current version.

an accuracy of 0.7" (1- σ per-axis) without target-acquisition, a target acquisition process precedes each coronagraphic visit. Once the target has been acquired and placed behind the chosen mask, coronagraphic science imaging can begin. If one of the round occalters is in use, images may be acquired through a few filters without re-acquiring the target. For the bar occalters, images may only be taken through one filter; if images at other wavelengths are desired a new target acquisition is performed.

4.0 NIRCam Imaging Template

4.1 Target Acquisition

Target acquisition is not needed for direct imaging, except for observations with the smallest subarray of 16x16 pixels. The target acquisition can be done with any combination of allowed filters (see below).

4.2 Filters

Each channel of a module is equipped with two filter selection mechanisms, which are referred to as "pupil wheel" and "filter wheel". The pupil wheel contains pupil masks, wavefront sensing optics, a few filters, and calibration sources. The pupil wheel is followed in the optical train by the filter wheel which contains a selection of filters. Table 3 lists the contents of the pupil and filter wheels. Filter names indicate the center wavelength in units of 100 μ m, and the last letter indicates the approximate filter width (for "W" $R=\lambda/\Delta\lambda \approx 4$, for "M" $R \approx 10$, and for "N" $R \approx 70 - 80$). For example, F140M stands for a Filter with 1.40 μ m central wavelength and Medium bandpass. The elements used for wavefront sensing are highlighted in blue. The F162M and F225N filters in the short wavelength pupil wheel will be used in series with the F150W2 filter, because there is no "clear" position in the filter wheel. For the same reason, the F164N filter in the pupil wheel will be used in series with either the F150W or the F150W2 filter. The flat-field illuminator in the pupil wheels blocks the light entering NIRCam from the OTE, and doubles as the dark position. Section 3.3.1.2 of the OCD explains our strategy for measuring dark current. Most imaging will be done using either the imaging pupils or the coronagraphic wedges (which include a Lyot stop), the only exception being the filters mounted on the pupil wheel. The filters located in the pupil wheels will have holders designed to function as pupils, and will deliver performance similar to that expected from the combination of the imaging pupil plus filter-wheel filter.

The allowed combinations of the NIRCam short-wavelength and long-wavelength channel optical elements are listed in Tables 4 and 5, respectively. Green indicates "allowed" mode with no restriction on the combination. Yellow indicates "restricted" mode where the combination may be used, but the user will have to use more care in planning the observations and/or the calibration of the data may be of lower quality. These are not fully calibrated, and will need special permission for use. Red indicates "engineering only" mode where the combination is not expected to yield useful scientific or engineering data, and will not be supported by the normal observation planning tools or the pipeline.

Table 3: Complete Filter Set for Each Channel

Short - λ Channel		Long - λ Channel	
Filter Wheel	Pupil Wheel	Filter Wheel	Pupil Wheel
F070W	Clear	F277W	Clear
F090W	Flat	F356W	Flat
F115W	F164N [FeII]	F444W	F405N [Bra]
F150W	MASKBAR (Coronagraph pupil 1)	F300M	MASKBAR (Coronagraph pupil 1)
F200W	Pinholes	F480M	F323N [H ₂]
F212N [H ₂]	GDHS0 (WFS, 0° orientation)	F410M	GRISMV2, DFS Grism2 (WFS, 0° orientation)
WLP4 (WFS, +4 waves)	F162M CO(6-3)	F360M	F466N [CO]
F187N [Pa]	MASKIPR (PAPPA)	F430M	MASKIPR (PAPPA)
F210M	WLP8 (WFS, +8 waves)	F460M	F470N
F182M	MASKRND (Coronagraph pupil 2)	F250M	MASKRND (Coronagraph pupil 2)
F140M	WLM8 (WFS, -8 waves)	F335M	Pinholes
F150W2 (WFS, DHS filter)	GDHS60 (WFS, 60° orientation)	F322W2	GRISMV3, DFS Grism3 (WFS, 90° orientation)

Check with the JWST SOCCER Database at: <http://soccer.stsci.edu/DmsProdAgile/PLMServlet>
To verify that this is the current version.

Table 4: *Allowed combinations of the NIRCam short-wavelength channel optical elements. Green indicates no restriction on the combination; Yellow indicates that the combination may be used, but the user will have to use more care in planning the observations and/or the calibration of the data may be of lower quality; Red indicates the combination is not expected to yield useful scientific or engineering data, and will not be supported by the normal observation planning tools or the pipeline. The F212N filter on the WL3 element is a 3% bandpass, while the F212N element is a 1% bandpass. Int and Ext in the column “PAPPA” refer to internal and external sources. Also note that N418N and F225N have been removed from NIRCam.*

Short wavelength channel		Pupil wheel (grouped by function)											
		Clear	Flat/Dark	Coronagraph 1 (round)	Coronagraph 2 (bar)	F164N	F225N	F162M	PAPPA	WL1 (+8)	WL2 (-8)	DHS 1 (0°)	DHS 2 (60°)
Filter wheel	F070W	Green	Green	Red	Red	Red	Red	Red	Ext. Yellow	Yellow	Yellow	Red	Red
	F090W	Green	Green	Red	Red	Red	Red	Red	Ext. Yellow	Yellow	Yellow	Red	Red
	F115W	Green	Green	Yellow	Yellow	Red	Red	Red	Ext. Green	Yellow	Yellow	Yellow	Yellow
	F150W	Green	Green	Yellow	Yellow	Green	Red	Red	Ext. Green	Yellow	Yellow	Yellow	Yellow
	F200W	Green	Green	Yellow	Yellow	Red	Red	Red	Ext. Green	Yellow	Yellow	Yellow	Yellow
	F212N	Green	Green	Green	Green	Red	Red	Red	Ext. Green	Green	Green	Yellow	Yellow
	WL3 + F212N	Green	Yellow	Red	Red	Red	Red	Red	Ext. Green	Green	Green	Red	Red
	F187N	Green	Green	Yellow	Green	Red	Red	Red	Ext. Green	Green	Green	Yellow	Yellow
	F210M	Green	Green	Green	Green	Red	Red	Red	Ext. Green	Yellow	Yellow	Yellow	Yellow
	F182M	Green	Green	Yellow	Green	Red	Red	Red	Ext. Green	Yellow	Yellow	Yellow	Yellow
	F140M	Green	Green	Green	Green	Red	Red	Red	Ext. Green	Yellow	Yellow	Yellow	Yellow
	F150W2	Green	Green	Yellow	Yellow	Green	Green	Green	Ext. Green	Yellow	Yellow	Green	Green

Check with the JWST SOCCER Database at: <http://soccer.stsci.edu/DmsProdAgile/PLMServlet>
 To verify that this is the current version.

Table 5: Allowed combinations of the NIRCcam long-wavelength channel optical elements. Color codes are as described in the Table 4 caption.

Long wavelength channel		Pupil wheel (Grouped by Function)											
		Clear	Flat field pinhole/Dark	Coronagraph 1 (round)	Coronagraph 2 (bar)	F323N	F405N	F418N	F466N	F470N	PAPPA	DFS Grism 1	DFS Grism 2
Filter wheel	F277W			335							Ext.		
				430							Int.		
	F356W			335							Ext.		
				430							Int.		
	F444W			335							Ext.		
				430							Int.		
	F300M			335							Ext.		
				430							Int.		
	F480M			335							Ext.		
				430							Int.		
	F410M			335							Ext.		
				430							Int.		
	F360M			335							Ext.		
				430							Int.		
F430M			335							Ext.			
			430							Int.			
F460M			335							Ext.			
			430							Int.			
F250M			335							Ext.			
			430							Int.			
F335M			335							Ext.			
			430							Int.			
F322W2			335							Ext.			
			430							Int.			

One other “filter” choice may also be allowed. This is the LW grism and using it in direct imaging mode would result in slitless spectroscopic observations of all sources in the direct imaging field-of-view in the LW channel. One science application of slitless grism observations is high precision spectroscopy of transiting planets.

4.3 Readout Region (Subarray)

The faintest sources in the 2MASS survey will saturate in some of NIRCcam’s filters if data are taken in full-frame mode. Subarrays permit shorter integration times, and so are of great interest for extending the dynamic range of NIRCcam to sources that are familiar and well-characterized. Subarrays will also be used in coronagraphic target acquisition and may be necessary to avoid saturation on bright coronagraphic targets. Subarrays may also be useful for taking images at a high cadence, as might be the case for occultation experiments. The frame time, or the time required to digitize all pixels within the subarray, is a function of the size of the subarray. At the rate of 0.1 Mpixels/second, corresponding to a pixel sampling period of 10.11 μ sec, the time to read the smallest

Check with the JWST SOCCER Database at: <http://soccer.stsci.edu/DmsProdAgile/PLMServlet>
To verify that this is the current version.

supported subarray, a $16 \cdot 16$ pixel region, will be 2.6 msec; this represents the shortest exposure time that can be used for imaging a point source. Table 6 summarizes the supported NIRCcam subarray sizes and the frame time for each. All subarrays are available in both the SW and LW channels.

Observers will only be allowed to select subarrays from a pre-defined set. This restriction is in accord with NIRCcam science requirements, and greatly reduces the complexity of defining subarray fields of view for pointing, and the level of effort required to calibrate the various subarrays. To maintain synchronized resets, all SCAs will be read out in subarray mode even when only the data from one SCA is being saved; additionally the pixel dimensions of the subarrays will be the same on all SCAs. Subarrays will be predefined to support all coronagraphic masks and their associated ND spots, SCA centers and/or sweet spots. Because the SCA-center subarrays may be used for simultaneous imaging in both the short- and long-wavelength channels, the location of the subarrays in the two channels will be arranged such that the centers of their FOVs coincide on the sky. (The long-wavelength subarray will encompass an FOV that is about 4 times the angular area of the short-wavelength subarray, because of the different plate scales in the two channels.)

In SUBARRAY mode, only pixels that fall within the specified area of the detectors are read out. The same MULTIACCUM patterns are available in subarray mode as in full-array mode. To avoid strong saturation by nearby sources, a portion of the full SCA will be reset at the end of each subarray integration. These full-array resets are implemented in row-by-row fashion, rather than then pixel-by-pixel reset, in order to reset the full array in the shortest time possible. This coordination of the full array with the end of the subarray integration ramps avoids the possibility of injecting any extra noise from the reset into the subarray data. Rather than using the normal pixel-by-pixel reset, the periodic full-array resets in subarray mode are done line-by-line, with the number of rows reset at the end of each integration optimized according to the subarray size. This decreases the overhead associated with the reset from 10.6 seconds to 21 milliseconds. The frame times in Table 6 also include telemetry overheads.

Table 6: NIRCcam Subarrays

Size (pixels)	FOV (arcsec)		τ_{Frame} (msec)	Comment
	SW	LW		
16	0.512	1.04	9.56	Smallest useful LW subarray without target acquisition (TA)
32	1.02	2.08	19.00	LED imaging; Smallest useful SW subarray w/out TA
64	2.05	4.16	53.24	Nominal LW TA subarray
96	3.07	6.24	107.96	Small-defocus transit photometry, SW channel; WFSC fine-phasing and routine monitoring operations
128	4.10	8.32	183.16	Nominal SW TA subarray
160	5.12	10.4	278.84	Large-defocus transit photometry, SW channel
320	10.24	20.8	1064	Nominal LW coronagraphic subarray

Check with the JWST SOCCER Database at: <http://soccer.stsci.edu/DmsProdAgile/PLMServlet>
To verify that this is the current version.

Size	FOV (arcsec)		τ_{Frame}	Comment
640	20.48	41.6	4172	Nominal SW coronagraphic subarray
1024 ×16	N/A	67 ×1.0	170.84	LW grism spectroscopy (TA may be required)

4.4 Dither Pattern

Dithering improves PSF sampling, allows for accurate photometry from undersampled images, and is an integral part of most NIRCcam observations (coronagraphy being the prime exception). So dithering will be required for almost all NIRCcam imaging observation programs except coronagraphic observations. The only programs that will not be required to dither are those that are focused on high-precision differential photometry, such as transit studies, where the goal is to minimize all possible systematic errors. All other programs will be required to dither. As such, dithering will be an integral aspect of every observing template. The readout pattern chosen for each exposure will set the exposure time per exposure, therefore the total exposure time will be an explicit function of the readout and dither patterns.

Users of JWST will be forced to choose among a restricted set of pre-approved dither patterns. There are two kinds of dithering envisioned for NIRCcam: primary and secondary. Primary dithering involves large-scale shifts and is designed to cover the gaps between detectors and/or modules. Secondary dithering involves small-scale shifts, and is designed to improve the sub-pixel sampling of the scene. Both kinds of dithering will mitigate bad pixels and flat-fielding errors.

The secondary dithers will be nested within the primary-dither pattern, such that the same set of small dithers gets executed at each point in the large pattern. The net result is that the total number of dithers is simply the product of the number of primary and secondary dithers: $ND = NP \cdot NS$. The user will select among several options for both quantity and quality of primary and secondary patterns, such that any total number of exposures should be possible, divided as the user sees fit between particular primary and secondary components.

In addition to choosing the number of primary and secondary dithers, users will also choose how the primary and secondary dithering will be done. For the larger primary dithers, users can choose to focus on the entire 2' x 5' NIRCcam field of view, and thus mitigate both the 5" gaps between SCAs and the 40" gap between the modules. There are a variety of patterns with from 3 to 45 dithers that can cover this contiguous field to any desired depth of coverage.

For the secondary dithers, users can choose any number between 1 and 9 dithers, and a compact pattern will be chosen to achieve the best possible pixel-phase sampling simultaneously for the short- and long-wave channels. The points in the pattern are sufficiently separated that the image of a star will not fall on the same pixels more than once. At the same time, the pattern is sufficiently compact that distortion across the

Check with the JWST SOCCER Database at: <http://soccer.stsci.edu/DmsProdAgile/PLMServlet>
To verify that this is the current version.

detector will not compromise the coherence of the pixel-phases. For programs that require more than 9 secondary dithers, it will not be possible to spread the dithers out and simultaneously maintain pixel-phase coherence everywhere across the field, so a compromise was found that allows up to 64 dithers that are grouped in fours so that each set of four is tight enough to maintain pixel-phase coherence, but the entire pattern extends over many tens of pixels to ensure that the same star will never land on the same pixels more than once. This strategy is very similar to what was adopted for the UDF observations.

4.5 Tabular Summary

Table 7: Inputs to the NIRCam “Imaging” Template

Input		Details	Remarks
A. Source Specification:		See Table 2	
B. Instrument Configuration:			
Detector		Specify readout region	Choose from menu
Filters		Specify filters	Choose from menu
		For each filter:	
		Specify Exp. Time	[per dither step]
C. Observation Implementation:			
Dither? [Y/N]	If “Y”	Select primary and secondary dither patterns	Choose from menu
“Survey” or “small-source”?		Specify via generic form	
Special Requirements	If “Y”	Specify via generic form	

5.0 NIRCam Coronagraphic Imaging Template

The NIRCam Coronagraphic Imaging Template will be used for all coronagraphic imaging with NIRCam. NIRCam has coronagraphic capability in both short and long wavelength channels. A fixed, transparent optical mount is located in the vicinity of the pick-off mirror, with the coronagraphic elements (masks and target-acquisition neutral-density spots) on one surface of this mount. Normally the coronagraph is outside the field of view of the detectors, but by inserting an optical wedge (mounted in the pupil wheel) into the beam, the coronagraph is brought into view. Each module has a coronagraph, to maintain commonality between the two modules and to provide redundancy should there be clustered cosmetic defects on the detectors located near the occulting mask positions.

There are 5 occulting spots on each coronagraph, 3 circular ones (round or spot masks) with “sombbrero” radial profiles having FWHM= $6\lambda/D$ at $\lambda=2.1, 3.35$ and $4.3\mu\text{m}$, plus 2 bar occulters with sinc2 profiles with HWHM= $4\lambda/D$ at wedge centers of $\lambda=2.1$ and $4.6\mu\text{m}$, and $2\lambda/D$ and $6\lambda/D$ at the extremes of the wedges. These five choices permit

Check with the JWST SOCCER Database at: <http://soccer.stsci.edu/DmsProdAgile/PLMServlet>
To verify that this is the current version.

optimal selection of the mask for wavelength and type of observation (e.g. spots for disks, bars for planets).

There are 6 ND regions on each coronagraph optical mount. Each mask is associated with one (or two, in the case of the bars) ND region. Each ND region is a square 5" across, within which is a spatially uniform coating that transmits approximately 0.001 of the incident light. The ND squares are sized to assure that the observatory will place the target behind them 99% of the time, if the pointing requirement (0.7" 1 σ per axis uncertainty) is just met. The locations of the ND regions allow small (<14") pointing offsets when transferring an acquired target from the ND region to the desired coronagraphic mask. The observatory is required to perform such slews with a precision of 20 mas, and the masks have been sized to provide good performance in the presence of pointing uncertainties somewhat larger than that (to allow for inaccuracies in on-board target acquisition, expected to be no more than 7 mas).

For a coronagraphic observation, an observer chooses a target-acquisition and a science multiaccum pattern, an occulting mask, and one (for either bar or spot masks) or more (for spot masks only) filters.

In principle any occulting mask can be used with any filter in the filter wheel, but the round masks in particular are designed to work at specific wavelengths (2.1, 3.35 and 4.6 μm). Those masks will work with the other shorter-wavelength filters with somewhat degraded inner working- angle performance but not with longer wavelength filters. The bar occulters can be used with any filter in the filter wheel within the 1.5-5.0 μm spectral band of the coronagraph, and the observatory will place the target at the correct position along the bar to provide optimal performance. None of the masks can be used with filters in the pupil wheel because that wheel must be in one of the two coronagraphic-pupil positions.

A single SW SCA will be used for all coronagraphic imaging. It will be possible to simultaneously image the target in the LW channel. Since coronagraphic observations are generally for a single source, parallel observations will not be obtained in the other imaging module.

5.1 Target Acquisition

Coronagraphic observations must always preceded with a target acquisition. The coronagraphic elements include attenuating "neutral density" (ND) spots (5" in width, OD = 3, *i.e.* attenuation by a factor of 1000) located ~12.5" from an associated coronagraph mask. During target acquisition the star is first imaged through the associated ND spot. The target acquisition images will always be taken in either the F210M or F335M filter, for short- or long-wavelength coronagraphy, respectively. The multiaccums used for target acquisition are restricted so that they provide three evenly spaced up-the-ramp images. The three images are used to reject cosmic rays, which could otherwise result in an incorrect calculation of the target location. These images will be taken using subarrays that are 642x642 or 1282x1282 pixels, with the subarray

completely behind the ND spot. The on-board scripts use this image data to compute the centroid position of the target, and then translate that into a slew request to place the star behind the mask. To eliminate the possibility of latent images, the opaque position on the NIRCcam pupil wheel will be placed in the beam before initiating the slew to transfer the bright star from the ND spot to the mask. Once behind the mask, the subsequent science activity will begin with the selection of the requested science filter.

5.2 Reference PSF Star

Most coronagraphic observations will require reference point-spread-function (PSF) star observations. These reference observations are required to improve the cancellation of the light from the central point source by allowing PSF subtraction. This is highly desirable given that the JWST primary consists of multiple mirror segments that will change their phasing with time. The small misalignment of the primary mirror segments will cause non-symmetric residuals in coronagraphic observations. The reference star observations will provide a snapshot of these residuals for subtraction. The reference star observations can be taken before or after the target star observations, but should be taken as close in time as possible to avoid changes in the residuals between the target and reference star observations. In no circumstances should a re-phasing of the primary mirror segments separate the target and reference star observations, so it should be possible to specify that these two visits cannot have a re-phase between them.

While there are science cases where reference PSF star observations may not be required (e.g., bright debris disks or companions), the default should be to request/require reference PSF star observations. The reference PSF star observational parameters are a duplicate of the target star observations, except that the user needs to be able to change the total exposure time requested since these two stars are expected to be of different brightness. The same coronagraphs will be used as the target star. All the observations (e.g. different coronagraphs) of the target star should be done before moving to the reference stars (or vice versa) to have the highest efficiency possible.

5.3 Readout region (Subarray)

Coronagraphic observations use a single module, and one SCA each in the SW and LW channels. Any of the subarrays given in Table 6 can be chosen for the coronagraphic observations.

5.4 Readout Mode

Any readout mode described in Table 1 can be chosen for the coronagraphic observations. In practice, however, the targets are expected to be bright; so BRIGHT or RAPID readout patterns would be preferable.

5.5 Total Exposure Time

The user will specify the total exposure time desired. Dithers are not done for coronagraph observations so this will be the total integration time desired. The number of integrations and exposure times per integration will be calculated by the software and displayed for the user. The final total exposure time will be quantized in units of the

Check with the JWST SOCCER Database at: <http://soccer.stsci.edu/DmsProdAgile/PLMServlet>
To verify that this is the current version.

minimum subarray time for the specific readout mode (see Beck 2008 for details) and also displayed for the user.

5.6 Dither Pattern

Dithering is not desired or allowed for coronagraphic observations.

5.7 Tabular Summary

Table 8: Inputs to the NIRCcam “Coronagraphic Imaging” Template

Input		Details	Remarks
A. Source Specification:		See Table 2	
B. Instrument Configuration:			
Target Acq		Specify filter	The filter for acq is determined by the coronagraph chosen
Coronagraph		Specify filters	Choose from menu
		For each filter:	
		Specify Total Exp. Time	
C. Observation Implementation:			
Reference PSF Star	If “Y”	Specify reference source details (A.)	
Special Requirements	If “Y”	Specify via generic form	

6.0 NIRCcam Low-Resolution Slitless Spectroscopy

The medium-resolution gratings in the long-wave channel can be used for slitless spectroscopy. The NIRCcam grism spectroscopy template will be used for all grism spectroscopy with NIRCcam. Grism spectroscopy is analogous to the small-source imaging mode where a grism is used instead of a filter.

6.1 Subarray

Spectroscopic capability is available only in the LW channel, which will require one LW SCA. An additional SCA in the SW channel may be simultaneously used for direct imaging observations. Either full SCAs or the 1024x16 subarrays may be used for the grism observations.

6.2 Target Acquisition

Grism spectroscopic observations using the full SCA generally will not require target acquisition. Observations taken with the 1024x16 subarray will, however, require target acquisition.

6.3 Readout Mode

Any readout mode described in Table 1 can be chosen for the spectroscopic observations. In practice, the targets are expected to be bright, so BRIGHT or RAPID readout patterns may be the best choice for such observations.

6.4 Total Exposure Time

The user will specify the total exposure time desired per dither position. The number of integrations and exposure times per integration will be calculated by the software and displayed for the user (see Beck 2008 for details).

6.5 Dither Pattern

Grism spectroscopy is likely to benefit from observations taken at different dither positions. However, dither patterns for grism spectroscopy have not been defined at this point.

6.6 Tabular Summary

Table 9: Inputs to the NIRCam Grism Spectroscopy Template

Input		Details	Remarks
A. Source Specification:		See Table 2	
A1. Target Acq. Source Specification:		See Table 2	Can be the same as the source.
B. Instrument Configuration:			
Target Acq		Specify filter	Choose from menu
Detector		Specify Exp. Time	[per dither step]
C. Observation Implementation:			
Dither? [Y/N]	If "Y"	Select dither pattern	Choose from menu
Mosaic? [Y/N]	If "Y"	Specify via generic form	
Special Requirements	If "Y"	Specify via generic form	

7.0 Summary

The details of the three NIRCam observing templates (Imaging, Coronagraphy, and grism spectroscopy) are given. These templates will be used for all astronomical observations with NIRCam.

8.0 References

- Beck, T. 2008, JWST-STScI-001439, "Preliminary Definition of Exposure Times in JWST Templates"
- Fullerton, A. 2008, JWST-STScI-001257, Rev A, "Preliminary Definition of Observation Templates for JWST Science Programs"

Check with the JWST SOCCER Database at: <http://soccer.stsci.edu/DmsProdAgile/PLMServlet>
To verify that this is the current version.

Gordon, K. D. & Wright, G., 2008, JWST-STScI-001525, “Mid-Infrared Instrument
(MIRI) Observing Templates Description
Sahu, K.C., et al. 2010, NIRCcam Operations Concept Document, version C.