JWST Master Class 2020

JWST Detectors Assignment

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Understanding JWST detectors: A brief guide for the ESA JWST Masterclass.

This material is designed to familiarize Master Class participants with the JWST detectors and all the relevant parameters to consider when setting up exposures. The definitions presented in this document are used both by the JWST Exposure Time Calculator (ETC) and the Astronomer's Proposal Tool (APT). Once you have read the document you will find a set of questions; if you can answer them, that puts you in an excellent position to get on with the ETC and APT assignments.

1. Introduction

JWST has instruments that work in two different regimes: near- and mid-infrared. Therefore, two different types of detector, with significantly different types of electronics, are used. For wavelengths up to 5 microns we use Mercury-Cadmium-Telluride (HgCdTe) *H2RG* detectors; for longer-wavelength sensitivity (5-28 µm) we use Arsenic doped Silicon (Si:As) detectors (see details in Table 1). The choice of materials is driven by the wavelength range over which photons can be efficiently detected.

Instrument	Number of H2RG detectors		Number of Si:As detectors	Light sensitive pixels
	0.6-2.5 µm	0.6-5 µm	5-28 µm	
MIRI			3	1024x1024
NIRCam	8	2		2040x2040
NIRISS		1		2040x2040
NIRSpec		2		2040x2040

Table 1: JWST instruments and their detectors.

General information about JWST detectors is available in the following JDox pages:

https://jwst-docs.stsci.edu/mid-infrared-instrument/miri-instrumentation/miri-detector-overview https://jwst-docs.stsci.edu/near-infrared-camera/nircam-instrumentation/nircam-detector-overview

https://jwst-docs.stsci.edu/near-infrared-spectrograph/nirspec-instrumentation/nirspec-detectors

https://jwst-docs.stsci.edu/near-infrared-imager-and-slitless-spectrograph/niriss-instrumentation/niriss-detector-overview

2. Detector Readout Method

All JWST detectors use the up-the-ramp (MULTIACCUM) readout method, that reads and records the signal of individual pixels multiple times as it is accumulated during an exposure (see illustration in Figure 1). This allows the recovery of discrete information on how the pixel charge/signal increases with time. This method provides several benefits:

- Fitting to multiple reads reduces the effective readout noise (by approximately the square root of the number of samples).
- By collecting individual reads of the signal in a given pixel, it is possible to see the "jumps" in signal level that indicate a cosmic ray has contaminated the signal (see Fig 2, Left). The integration is effectively divided into two or more sub-ramps, depending on the number of cosmic ray hits; sub-ramps can be used to recover signal information.
- When a pixel saturates the groups (or reads) before saturation can be used to estimate the signal rate. This increases the dynamic range of the image. Note that when the source is so bright that the first pixel read is already saturated information cannot be recovered.

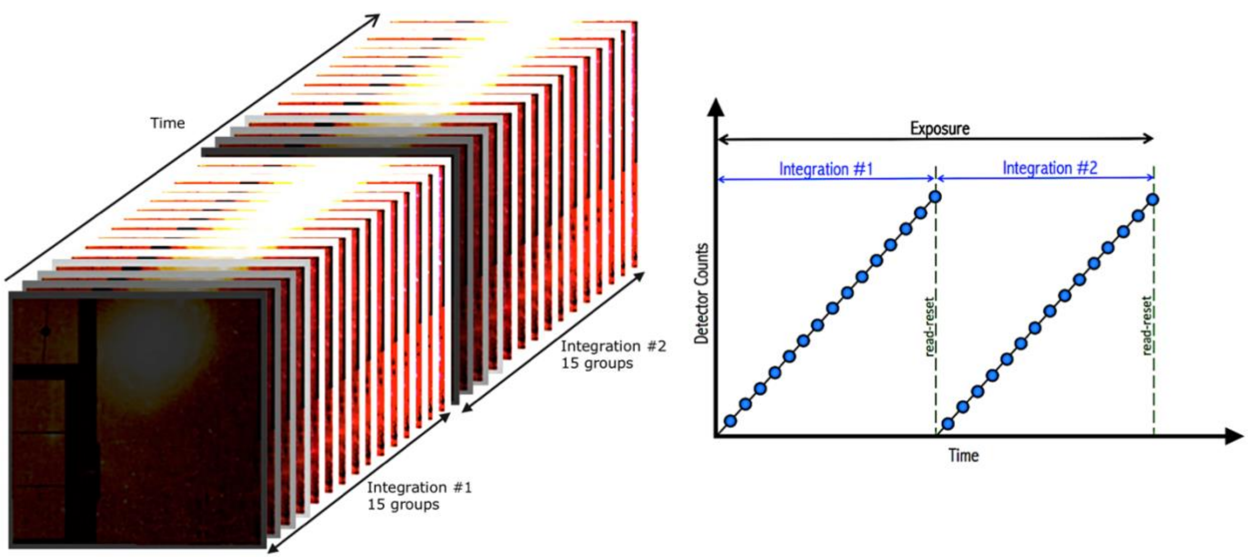

Figure 1: Illustration of the up-the-ramp method. Left: Detector pixels are read multiple times resulting in a datacube. Right: Pixel view illustration. Each point represents a group. The read-reset method is only used in the MIRI detectors. For definitions, see the Detector Parameters Specification section.

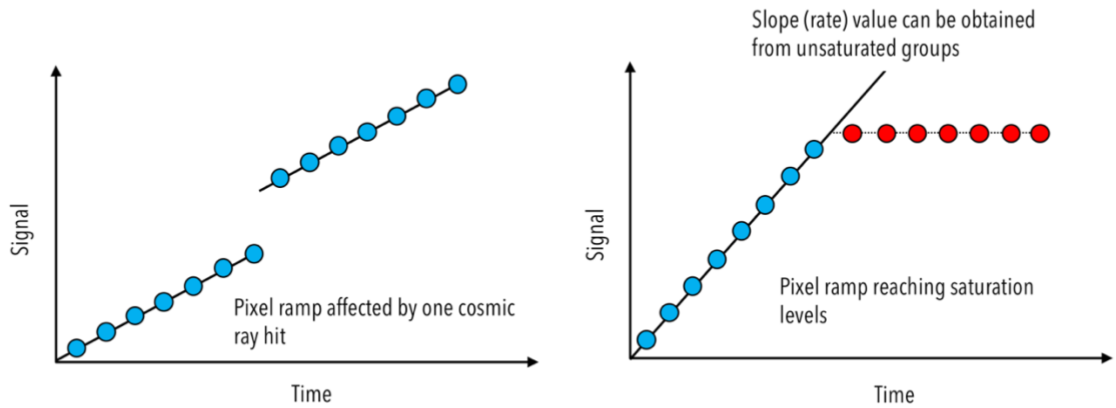

Figure 2: Each point represents a group. For definitions, see the Detector Parameters Specification section. Left: Illustration of the jump effect in a pixel affected by a cosmic ray hit. The added signal of the cosmic ray effectively divides the ramp into two sub-ramps. Right: Pixel ramp reaching saturation. Blue points represent unsaturated groups that can be used to estimate a rate. Red points represent saturated groups.

3. Detector Parameters Specification

When a user specifies exposure times in the JWST Proposal observation tools (Exposure Times Calculator and Astronomer's Proposal Tool) there are several parameters that should be considered (see also Figure 3):

- Subarray: All JWST detectors can be read in FULL or subarray mode. In subarray mode only a portion of the detectors is read out; this effectively reduces readout times and data volume, enabling rapid observations of bright objects without saturation (see more information in JDox links below).
- Frame: A single read of all pixels in the detector array or subarray.
- Group: A group is the on-board average of one or multiple frames. A group is transferred to the solid-state recorder for downlinking to the ground. The time duration of each group depends on the instrument readout mode and readout pattern selected. Please see JDox documentation (links below) for further details. On-board averaging is needed to reduce the data volume/data rate associated with an exposure.
- Drop/skip frames: These are frames between groups that are sampled but not included in the group average.
- Reset: The action of closing the detector readout circuit reset switch to establish the detector bias voltage. This stops the pixels from accumulating charge and resets them to the bias level. Resets are done between exposures and between integrations.
- Integration: An integration is a set of groups starting with the first group after a reset and ending with either the last group before a reset (NIR) or the last read-reset group (MIRI).
- Exposure: An exposure is a set of identical integrations that are separated by only a constant number of resets (nominally 1).

- Readout pattern: A readout pattern is a certain combination of averaging and dropping frames that defines the group time.
- Readout mode: A specific scheme of reading all pixels of a detector array or subarray.

Observers will need to input into APT and ETC the detector readout pattern, the number of groups and the number of integrations, as well as the array in use (full or subarray).

See also:

https://jwst-docs.stsci.edu/understanding-exposure-times

https://jwst-docs.stsci.edu/near-infrared-camera/nircam-instrumentation/nircam-detector-overview/nircam-detector-subarrays

https://jwst-docs.stsci.edu/mid-infrared-instrument/miri-instrumentation/miri-detector-overview/miri-detector-subarrays

https://jwst-docs.stsci.edu/near-infrared-spectrograph/nirspec-instrumentation/nirspec-detectors/nirspec-detector-subarrays

https://jwst-docs.stsci.edu/near-infrared-imager-and-slitless-spectrograph/niriss-instrumentation/niriss-detector-overview/niriss-detector-subarrays

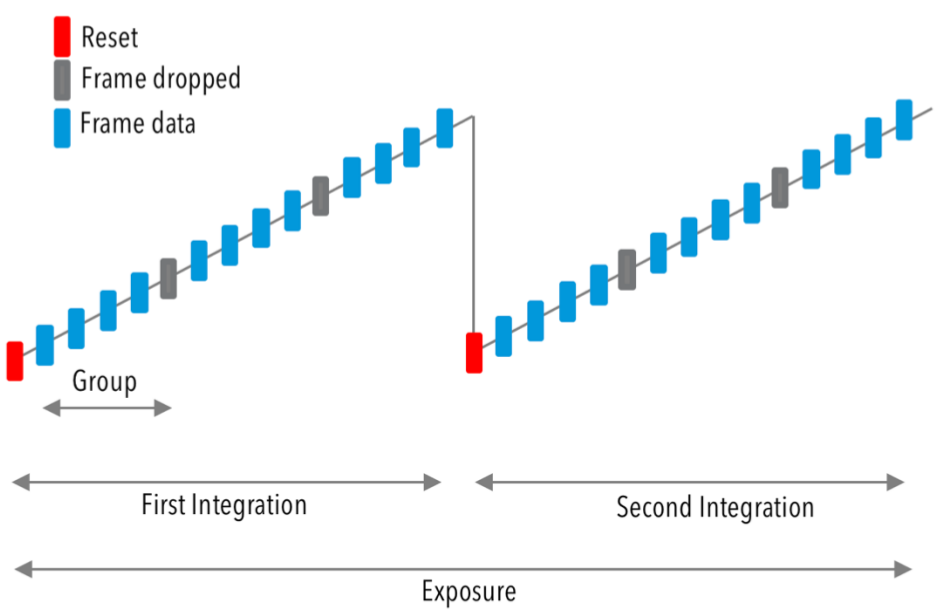

Figure 1: A generic illustration of the MULTIACCUM readout scheme used by JWST detectors. Each exposure consists of some combination of frames, groups, resets and integrations. This illustration shows an example of a single exposure comprising two integrations of three groups (average of four frames) each interleaved by a single dropped frame. Note, the MIRI detectors do not have an extra reset at the beginning of an integration, but operate on a read-reset scheme (See Fig. 2). Observers should refer to

specific instrument detector pages for details. Image adapted from JDox (https://jwst-docs.stsci.edu/understanding-exposure-times).

References

Rieke, G.H. 2007, "Infrared Detector Arrays for Astronomy", Annual Reviews of Astronomy and Astrophysics, Vol. 45, pp. 77-115

Garnett, J. D., Forrest, W. J.Proc. "Multiply sampled read-limited and background-limited noise performance", SPIE Vol. 1946, p. 395-404, Infrared Detectors and Instrumentation, Albert M. Fowler; Ed.

4. Questionnaire

1. What is the difference between the JWST NIR and MIR detectors?
2. What is the fundamental difference between a CCD and a JWST detector readout?
3. What is a frame?
4. What is a group?
5. What is the meaning of "group gap" or "dropframes" in the JWST NIR detectors?
6. What is a reset
7. What is an integration?
8. What is an exposure?
9. Suppose you have data from a CCD and from a JWST detector. They both reach the saturation level in one-half of the total integration time. Can you describe what the main difference is? Can you recover information in the saturated pixels?
10. What will be the impact of a cosmic ray in a JWST integration? Can information be recovered?
11. Which has a higher data rate: a single MIRI Si:As detector running in SLOW mode or a single NIRCAM H2RG detector using the MEDIUM8 readout pattern?
12. Given a certain readout pattern, why is the group time different for full and subarray mode?
13. If a user defines a single NIRCam exposure (i.e. no dithers) with all modules in FULL array and BRIGHT1 readout pattern, that uses 10 groups and 1 integration, the exposure time is 203.99 second. 10 groups and 2 integrations result in 418.73 seconds. Why is the total time of 2 integrations is not twice as long as one? Can you guess why that would not be the case for MIRI?