Noise Sources for Time-Series Observations

On this page, we give an overview of the noise sources in JWST time series observations.

Introduction

Detecting faint signal modulations in a time series observation requires high precision (spectro-) photometric measurements. The highest achievable precision is to reach the photon noise floor of the observation, i.e. where the noise budget is dominated by the Poisson noise of the source and background. Key to reaching the highest precision is a thorough understanding of the noise sources affecting the observation, and the correlations between them. Sources of noise in any observation can be astrophysical or instrumental in nature. A faint exoplanet transit signal can, for example, be masked by flux variations from starspots or other types of stellar variability. On this page we will give an overview of the noise sources arising from the spacecraft and instrumentation for time series observations, and their expected temporal behavior. Note that the information presented here reflects our current pre-launch understanding; updates are expected after launch.

Spacecraft noise sources

> *Main articles: JWST Pointing Performance, JWST Communications Subsystems, JWST Background Model*
> *See also: Fine Guidance Sensor, FGS*

Spacecraft pointing drifts and jitter

Pointing control and slewing of JWST is performed by the Attitude Control Subsystem (ACS) . Fine guiding additionally involves the Fine Guidance Sensor (FGS). Changes in the pointing of the spacecraft can cause the target to drift across the detector, causing correlated noise or discontinuities in the measured time series. Such motions can arise from a number of causes and over varying timescales. A description of pointing issues and their impact on time series observations for other missions such as Kepler and the Spitzer Space Telescope are provided in Beichman et al (2014). On JWST, once fine guiding has been established, the absolute pointing accuracy of JWST with respect to the celestial coordinate system will be determined by the astrometric accuracy of the Guide Star Catalog and the calibration of the JWST focal plane model. The spacecraft pointing accuracy is unlikely to be sufficient for high precision science observations, and target acquisition is therefore recommended (in some cases mandatory) for such observations. Where target acquisition is performed, the pointing accuracy is determined by the required slew distance, with smaller slews giving the highest accuracy. Latest information on pointing accuracy and stability are described on a dedicated page.

The effects of pointing drifts can be further compounded by undersampling of the PSF, uncorrected intra-pixel gain variations and flat fielding residuals (see below).

High-gain antenna moves

The High-Gain Antenna (HGA) is part of the JWST Communications Subsystem that manages the required two-way communication between the Observatory and the ground. The HGA requires periodic pointing adjustments to maintain its attitude towards the Earth. This repointing will take place every 10,000 seconds, and this imposes a 10,000 second limit on regular (non-TSO) science exposures. This limitation is waived for TSO observations, to allow observers to monitor a transient event such as an exoplanet transit, continuously for a longer period of time. The repointing of the HGA will in this case be performed during a science exposure, resulting in a small but measurable pointing jitter.

Background

Many observations with JWST will be background-limited, meaning that the noise will be dominated by the background emission, and not by photon noise from the target or detector read-noise. The overall background seen by JWST instrumentation has contributions from several astrophysical and observatory sources; articles on the observatory background describe these sources in more detail. At wavelengths greater than 15 μm, the background seen by JWST is expected to be dominated by thermal emission from JWST itself.

Of particular importance for TSO is the variability of the thermal background over the duration of a typical observation. An exoplanet transit observation may last several hours; a full phase curve reconstruction perhaps a full day. We don't currently (i.e. prior to launch) have a detailed understanding of the time-variability of the observatory background; measurements during commissioning will provide data on this issue. Modeling suggests that the thermal constant of the mirrors is long (days), and the thermal constant of the sunshield is short (minutes). The actual temporal behavior of the background will be determined after launch. Note that the JWST Exposure Time Calculator assumes a constant background.

See JWST Background Model article for more detailed information.

Instrumental noise sources

Main articles: NIRISS Detector Performance, NIRCam Detector Performance, MIRI Detector Performance, NIRSpec Detector Performance
See also: NIRCam Persistence

Detector gain variations

The NIR and MIR detectors on board JWST are all subject to inter-pixel gain variations, i.e. small pixel-to-pixel differences in the digital numbers generated per electron by the detector electronics. Gain variations are typically a few percent in magnitude in the IR detectors used on board JWST. Such gain variations are traditionally measured and calibrated using a detector flat field. They are multiplicative in nature, and the effect is therefore corrected by division by the flat field.

Uncertainty in the flat field measurement, or changes in pixel gain over time, can leave residual flat field noise in the reduced data.

Intra-pixel gain variations

More challenging than pixel-to-pixel gain variations are changes in pixel responsivity or quantum efficiency across the pixel area; the so-called intra-pixel gain variations. This issue is compounded when the point spread function (PSF) of the instrument is undersampled by the detector pixels. Ingalls et al (2012) describe the effect in detail for the IRAC instrument on board the Spitzer Space Telescope, where this was found to be the largest source of correlated noise. Various methods for correcting this effect can be found in the literature, e.g., Ballard et al. (2010), Stevenson et al. (2011), Krick et al. (2016). We do not expect this issue to affect the JWST instruments to the same extent; a number of factors will aid to mitigate their effect compared with previous IR missions:

- Improved pointing stability of the telescope
- Better sampling of the PSF
- Higher precision astrometry and proper motion information on guide stars
- Improved detector technology

More detailed measurements will be made during commissioning.

Persistence

Persistence is a memory effect in the instrument detectors, leaving a weak positive image that decays exponentially over time. The strength of the image is related to the brightness of the source that illuminated the detector. The physical mechanism causing persistence is thought to be the trapping of a small number of photoelectrons in the detector substrate, which are then released over time after the illumination has ceased (Regan et. al, 2012). This slow release manifests as a weak latent image that decays with time. Because the effect depends on the previous illumination of the detector, it is hard to characterise and correct in a given observation. The impact on precision photometric measurements is most severe when observing a very faint target in the same detector region that previously held a very bright source. It will pose less of a problem for lengthy continuous observations of bright targets at a fixed detector location. Because TSO observations are predominantly targeting bright objects–to maximize SNR over time–many TSO observations are expected to monitor the generation of persistence over time.

Whilst the impact of persistence on JWST time series observations will depend on the observing mode, the target brightness and the observing strategy, detector modelling and testing will help define mitigation strategies or pipeline correction steps. Leisenring et al (2016) provide detailed study results for the NIRCam detectors. Analysis of the effect for the MIRI detectors has shown multiple time decay constants, which makes characterisation challenging; based on testing experience, the time between visits (timescales of minutes) should allow for any persistent images to decay to < 1% of their initial levels. However the effect will require much further characterisation after launch.

Further background on the physical nature and predicted extent of this effect the JWST instruments, as well as HST-WFC3, are provided in the Related Links below.

References

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