JWST Backgrounds

JWST observations will detect background emission from multiple sources – the zodiacal cloud, the Milky Way, and thermal self-emission. Both in-field and scattered emission is important for JWST. The spectrum and temporal variability of these backgrounds is discussed.

On this page

Introduction

Many observations with JWST will be background-limited, meaning that the noise will be dominated by the level of background emission, and not by photon noise from the target or detector read-noise. This page summarizes the sources of background emission that are important for JWST, their relative contribution as a function of wavelength, and temporal variability.

Sources of background emission

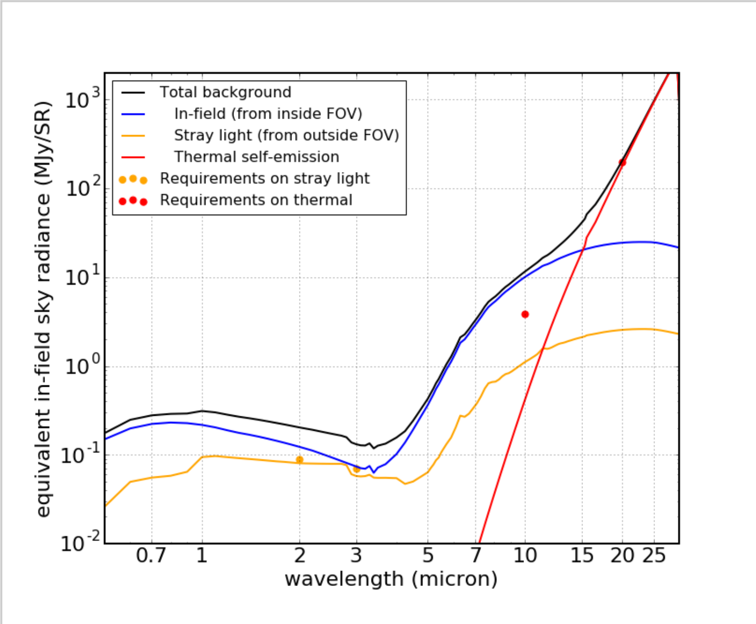
Several sources contribute to the background emission that JWST will detect. The primary in-field sources of this background are the zodiacal cloud of the Solar System and the Milky Way Galaxy. In the thermal infrared, the background is dominated by thermal self-emission, mostly from the JWST primary mirror segments, as well as scattered thermal emission from the sunshield. Since JWST does not have a traditional optical baffle, light from the out-of-field sky can gain access to the focal planes through scattering—this additional source of background is called "stray light."

Figure 1 illustrates the relative contributions of these sources to the JWST background for a benchmark pointing. This pointing (ecliptic Long, Lat = 266.3°, -50.0°; RA, Dec [J2000] = $17^h26^m44^s$, -73°19'56") has a zodiacal emission that is 20% higher than the celestial minimum. It was chosen as a benchmark because it is a stressing case for stray light. The backgrounds are expressed as equivalent units of uniform sky radiance (megaJanskys per steradian, or MJy/sr) at the JWST focal planes. Figure 1 shows that, in general, in-field zodiacal emission and scattered light are the main sources of background at wavelengths less than 4 µm; in-field zodiacal emission dominates from 4 to 15 µm, and thermal self-emission dominates at wavelengths longward of 15 µm.

Stray light, which is out-of-field emission scattered into the field of view, is primarily due to the zodiacal cloud and the Milky Way. In the example shown in Figure 1, this stray light is less than but comparable to the in-field zodiacal emission from 1 to 4 µm. The amount of stray light depends on ecliptic latitude (pointings toward the ecliptic poles will have lower stray light), and the orientation of the Milky Way with respect to JWST. Since the benchmark pointing used in Figure 1 was chosen to be a stressing case for stray light, most extragalactic deep fields should have a lower level of stray light. As one example, the stray light level in the Hubble UltraDeep Field (HUDF) should be about half that of the benchmark pointing.

Figure 1. Contributions to JWST background emission, expressed in equivalent units of uniform sky radiance (MJy/SR) at the JWST focal planes

JWST Observation Planning



This example is for the benchmark pointing (ecliptic Long, Lat = 266.3°, -50.0°, RA, Dec (J2000) $=17^{h}26^{m}44^{s}$ -73°19'56"), chosen to have a zodiacal emission that is 20% higher than the celestial minimum, and to be a stressing case for stray light. In this example, in-field emission from the zodiacal cloud and the Milky Way (blue curve) dominates the background for most wavelengths below 15 µm. At longer wavelengths, thermal emission from JWST itself (red curve) is the dominant source of background. Stray light (yellow curve) results from zodiacal and Milky Way emission scattered into the field of view, and is a significant fraction of the total background, particularly at 1 to 4 µm. The sum of all these emission sources is the total background (black curve). Download the background file used in this plot (FITS format) .

At wavelengths greater than 15 µm, the background seen by JWST is expected to be dominated by thermal emission from JWST itself. Figure 2 shows the expected spectrum of this thermal self-emission, and the major components that produce it. This thermal emission dominates the background at wavelengths longer than 15 µm. As Figure 2 shows, emission from the primary mirror is expected to dominate at wavelengths greater than 21 µm, and that scattered thermal emission from the sunshield will dominate from 15 to 21 µm. As discussed above and shown in Figure 1, at wavelengths shorter than 15 µm, the in-field zodiacal background dominates over thermal emission at the benchmark pointing. The thermal curve plotted in Figure 2 is a conservative estimate of likely on-orbit performance; it is incorporated into the JWST Exposure Time Calculator

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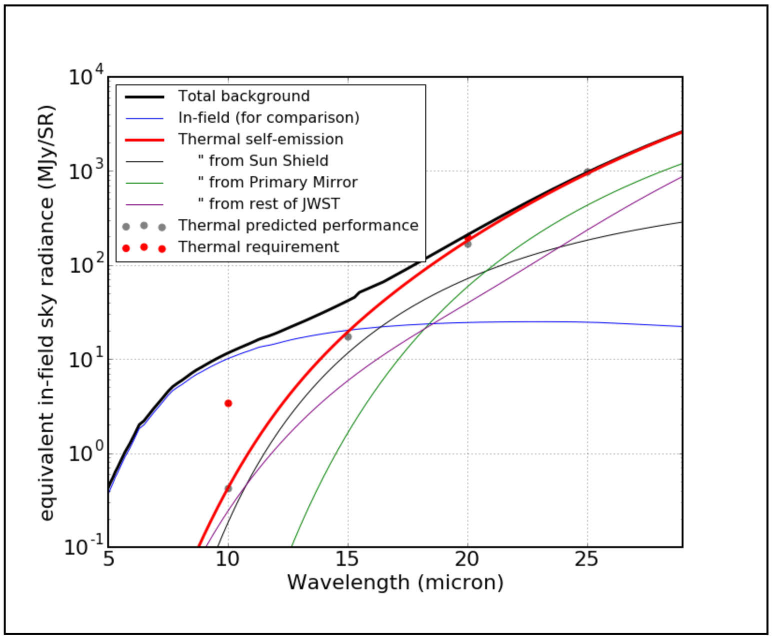
(ETC) and the JWST scheduling system, and is included in the example background file (FITS format).

Figure 2. Expected thermal self-emission from JWST



Extensive thermal modeling has predicted the temperatures and emissivities of JWST components. This was combined with scattering models to predict the level of background from thermal sources. The 2 components that contribute most to thermal self-emission are the primary mirror and the sunshield. At wavelengths greater than 21 µm, thermal emission from the primary mirror (green line) should dominate the background. From 15 to 21 µm, the background should be dominated by thermal emission from the sunshield (thin black line), which is scattered into the field of view by budgeted levels of dust on the primary and secondary mirrors. Thermal emission from the rest of JWST (purple line) is also shown. The total thermal self-emission (red line) is a conservative estimate of expected performance; it is what is assumed by the JWST ETC and Astronomers Proposal Tool (APT). Also shown (red dots) are the JWST design requirements for thermal performance (3.4 MJy/sr at 10 µm, and 200 MJy/sr at 20 µm), as well as modeled thermal performance at these design wavelengths (grey dots). For comparison, the total background (thick black line) and the in-field backgrounds (blue line) from Figure 1 are also shown.

Spatial and temporal variability of background emission

The thermal self-emission of JWST will be characterized on-orbit; APT, the ETC, and the JWST scheduling system currently assume that the thermal self-emission is constant with time and pointing.

Spatial variation of in-field emission

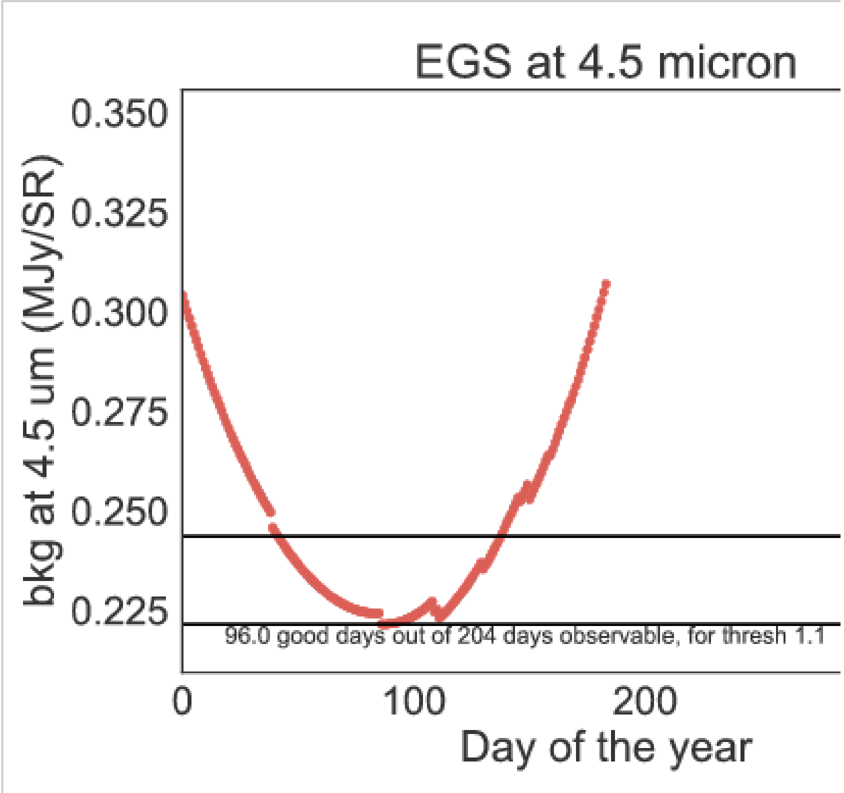
The in-field zodiacal emission depends on ecliptic latitude. The in-field Galactic emission strongly depends on Galactic latitude.

Temporal variation of in-field emission

JWST can observe a specified location on the sky for at least 100 days per year. The length of the visibility window increases with increasing ecliptic latitude.

Within a visibility window, the in-field Galactic background will be constant, while the in-field zodiacal background will vary predictably with date as JWST looks through different path lengths of dust, with different temperatures, in our Solar System. Figure 3 shows an example of the temporal variability of the background over one year.

Figure 3. Temporal variability of the background



The total background versus day of the year, for an example target, the Extended Growth Strip, which is an extragalactic deep field. This example is for a wavelength of 4.5 μm. Two horizontal lines show the minimum background level, and 10% above that minimum. This target is observable for 204 days per year; 96 of those days have a background level <10% above the minimum background. Users can add the "Background Noise" special requirement in APT to specify that a background-limited observation be scheduled when the background is relatively low.

Spatial and temporal variation of stray light

The amount of stray light depends on the pointing and the roll angle. Models predict a correlation of stray light level with the in-field zodiacal and Galactic background level, since much of the susceptibility to stray light occurs within tens of degrees of the boresight.

However, JWST is also susceptible to stray light from sources located far from the boresight. Susceptibility maps predict the susceptibility of JWST to stray light, given material properties and budgeted levels of dust contamination. The JWST Exposure Time Calculator (ETC) uses these susceptibility maps. For a given celestial position and date (which determines the roll angle), the ETC projects the susceptibility maps onto the astronomical sky, to predict the amount of stray light at the instrument focal planes. Users should be aware that JWST is subject to stray light, and they should use the ETC to understand the degree to which stray light affects the signal-to-noise estimates for their planned observations.

How to request low background for background-limited observations

The JWST proposal planning system (PPS) calculates these background levels for both planning and scheduling purposes.

Scheduling

Users can ask the JWST scheduling system to schedule background-limited observations during periods when the background is predicted to be relatively low. The user must opt-in, by specifying, via the "Background Noise" special requirement in APT, that an observation is background-limited. The user must also specify the maximum acceptable background level, relative to the minimum background for those celestial coordinates; the default is ≤10% above the minimum. This functionality will be available by APT 25.4, to be released in Nov. 2017.

In general, background-limited observations should use the background noise special requirement, with the default level of 10%; this will optimize the signal-to-noise ratio. The exception is if other constraints are more important to the science goals than the signal-to-noise ratio. For example, if an observation must have a particular position angle, or if multiple epochs are desired of a time-variable source, then these constraints may conflict with the background noise special requirement, causing the observation to be unschedulable. In such cases, the user may select a higher acceptable background level, or omit the special requirement entirely.

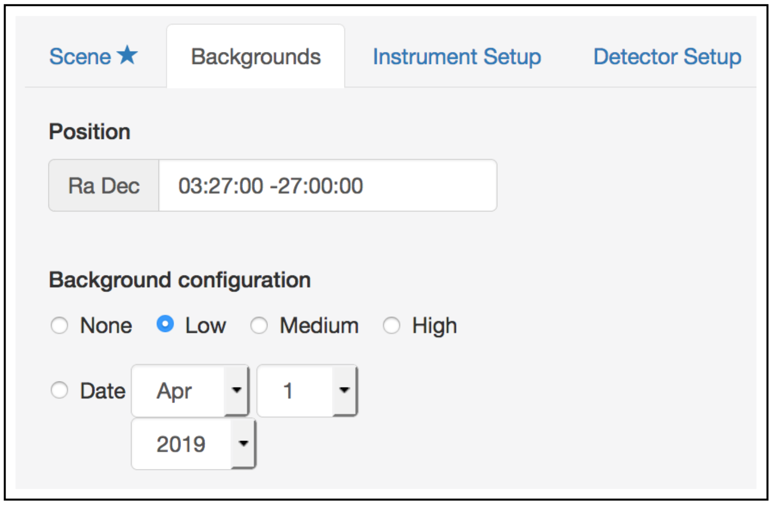
Figure 3 shows an example of how the "Background Noise" special requirement can impact scheduling. In Figure 3, for the default level of ≤10% above the minimum background, of the 204 days per year that the target is observable, 96 days meet the background noise special requirement.

Observations that are not background limited should not use the background noise special requirement. When the noise is dominated by factors other than the background (for example, target shot noise, or detector read noise), then the requirement would decrease schedulability but negligibly improve the signal-to-noise ratio.

Background levels in the ETC

The JWST Exposure Time Calculator (ETC) will calculate these backgrounds for a given celestial position. If the user specifies a date, the ETC will give the background on that date. Otherwise, the user can choose a low background (10th percentile), a medium background (50th percentile), or high background (90th percentile), all calculated for that celestial position over the period of visibility. Figure 4 shows how to input this background information into the ETC. The computed background spectrum can be downloaded as a FITS file, as described in the JWST ETC Outputs Overview page.

Figure 4. ETC screenshot of the Backgrounds tab



An ETC screenshot of the **Backgrounds** tab, selecting the background for a given position, and the 10th percentile best background ("Low").

Uncertainty in background levels

The ETC calculates the in-field zodiacal and Galactic backgrounds using a model based on Cosmic Background Explorer (COBE) data (Kelsall et al. 1998; Reach et al. 1997), that was developed and used operationally for the Spitzer Space Telescope, with the Galactic stellar contribution refined using data from the Wide Field Infrared Survey Explorer (WISE) survey. This model agrees with the Spitzer Infrared Array Camera (IRAC) measurements at the few percent level (Krick et al. 2002). As such, the in-field backgrounds predicted by the ETC should be very reliable.

By contrast, the predicted levels of stray light and of thermal self-emission carry considerable uncertainties. These estimates depend on extensive modeling of the scattering properties of observatory materials, estimates of the amount and properties of contaminating dust particles, knowledge of the deployed observatory configuration, and thermal models incorporating material emissivities which result in temperature estimates of all surfaces which can act as sources of thermal background.

The stray light estimates are thought to have uncertainties of order $^{+30\%}_{-20\%}$. Proposers should use the ETC to understand the extent to which stray light contributes to the total background of their observations, and bear in mind these uncertainties on the stray light predictions.

The thermal background curve (thermal self-emission in Figures 1 and 2) is a conservative best estimate based on detailed thermal modeling. It is neither a worst nor best case, and is uncertain at the $^{+30\%}_{-20\%}$ level. Users are cautioned that, for cycle 1, exposure time estimates will be highly uncertain for background-limited observations at wavelengths longer than 15 µm.

Both the thermal and stray light backgrounds will be measured during the commissioning of JWST; results will be disseminated to users prior to the cycle 2 proposal deadline.

Related links

JWST Exposure Time Calculator Overview
JWST Acronyms and Abbreviations

References

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JWST Background Model Generator