Contrast Considerations for JWST High-Contrast Imaging

In JWST high-contrast imaging (HCI), the term "contrast" means the companion-to-host flux ratio.

Parent article: JWST High-Contrast Imaging
Main articles: MIRI Coronagraphic Imaging, NIRCam Coronagraphic Imaging, NIRISS Aperture Masking Interferometry

When developing an HCI investigation, the user's scientific goal is represented by an "operating point," (s, C_{flux}), where

- s is the expected apparent separation between the companion and host, and
- $C_{flux} = flux_{companion}/flux_{host}$ is the flux contrast between the companion and host.

This operating point is estimated to be feasible if $C_{flux} > C_{limit}(s)$, where $C_{limit}(s)$ is the "limiting contrast."

$C_{limit}(s)$ is a function of many interrelated factors, and is, therefore, a challenge to estimate. In particular, $C_{limit}(s)$ depends on the instrumental configuration, the observing strategy, and the post-observation processing calibrations and processes. $C_{limit}(s)$ is especially sensitive to the step where a scaled reference PSF is subtracted from a science image. PSF subtraction is relied upon to extend the grasp of the investigation deep into the systematic noise (see Soummer et al.) . In the absence of data, it is hard to say how well PSF subtraction will perform for JWST.

To be valid, the feasibility test $C_{flux} > C_{limit}(s)$ assumes that the planned observation has the same technical and procedural factors that produced the calibration of $C_{limit}(s)$.

To gain a better understanding of $C_{limit}(s)$, look more closely at the term "contrast" (C). Although C been widely adopted as a metric of HCI performance, its meaning is sometimes ambiguous in the context of where it appears . Therefore, the various possible meanings of "contrast" are disambiguated as follows:

1. C_{flux} is the term for the companion-to-host flux ratio. C_{flux} is a property of nature, independent of any instrumental or observational details or considerations.

2. $C_{PSF}(s)$ is the ratio of the PSF at separation s to its central value: $C_{PSF}(s) = PSF(s)/PSF(0)$. Here are other useful PSF ratios:
   a. $C_{JWST\_PSF}(s)$, the PSF ratio using the telescope PSF.
   b. $C_{centered\_PSF}(s)$, the PSF ratio using the instrument PSF. The numerator is the PSF when it is centered on the occulting mask and is evaluated at input values s > IWA.

c. $C_{offset\_PSF}(s',s)$, which is the PSF ratio with the numerator equal to the PSF when it is offset from the center of the occulting mask by separation *s'*, and the PSF is evaluated at an input value of *s*.

3. $C_{raw}(s) = C_{offset\_PSF}(0)/C_{centered\_PSF}(s)$ is the raw contrast, which is an intrinsic property of the instrument, independent of any natural or observational details or considerations, including noise and integration time.

4. $C_{limit}(s)$ is limiting contrast, defined as the value of C_{flux}, for the minimum detectable companion. $C_{limit}(s)$ affirmatively *does* take into account any and all relevant technical and procedural factors , such as observational strategy, pointing and instrumental errors, detection threshold, and post-observation processing (especially the PSF-subtraction strategy). The detection threshold is related to the false alarm probability under the assumption that the residual errors after PSF subtraction are normally distributed.

5. $C_{ideal}(s)$ is a floor for the limiting contrast $C_{limit}(s)$, because it makes certain optimistic, simplifying assumptions. For example, $C_{ideal}(s)$ may assume that pointing errors are zero or that photometric noise is ideal, with photon-counting noise dominating.

6. $G_{contrast}(s) = C_{ideal}(s)/C_{raw}(s)$ is the "contrast gain." $G_{contrast}(s)$ is the factor by which the instrument and procedures of HCI must suppress the telescope PSF.

$Q(s) = C_{flux} \times C_{raw}(s)$ is an auxiliary metric sometimes used to gauge the systematic errors in $C_{raw}(s)$ due to aberrations and their speckles. *Q(s)* is the wing-to-center surface-brightness ratio of the host-companion pair of sources, which has been called the "instantaneous signal-to-noise ratio." *Q* depends only on the instrument and on nature, but not on any observational factors, such as exposure time or strategy for PSF subtraction.

At the current time, few treatments of $C_{limit}(s)$ are available for the JWST HCI modes. For now, users must extrapolate $C_{limit}(s)$ from published treatments of $C_{limit}(s)$:

- NIRCam-Specific Treatment of Limiting Contrast
- NIRISS AMI-Specific Treatment of Limiting Contrast
- MIRI-Specific Treatment of Limiting Contrast

References

Beichman, C. A., et al. 2010, PASP, 122:162
Imaging Young Giant Planets from Ground and Space

Boccaletti, A., et al. 2015, PASP, 127, 633
The Mid-Infrared Instrument for the James Webb Space Telescope, V: Predicted Performance of the MIRI Coronagraphs

Greenbaum, A.Z., Pueyo, L., Sivaramakrishnan et al. 2015, ApJ, 798, 68
An Image-Plane Algorithm for JWST's Non-Redundant Aperture Mask Data

Soummer, R., Pueyo, L., and Larkin, J., 2012, ApJ 755 , L28
Detection and Characterization of Exoplanets and Disks Using Projections on Karhunen-Loeve Eigenimages