WebbPSF for JWST and WFIRST

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WebbPSF simulates point spread functions (PSFs) via physical optics calculations in Python.

WebbPSF simulates PSFs for the James Webb Space Telescope (JWST), serving a similar role as the TinyTim package serves for the Hubble Space Telescope.
The latest version of WebbPSF includes:

- Updated models for the JWST instruments based on optical testing results for the flight hardware during the ISIM cryovac test campaign. *(see at right)*
- Updated models for WFIRST Wide Field Instrument based on the Cycle 6 design. *(see lower middle)*
- A new preliminary model for the WFIRST Coronagraph Instrument. *(see lower right)*

WebbPSF and its underlying physical optics library, POPPY, are open-source Python packages, available through the Python Package Index or AstroConda and developed in the open on GitHub.

Feedback from the community is very welcome. Let us know what you need from a PSF simulation tool at **jlong@stsci.edu** or **mperrin@stsci.edu**, or by opening a GitHub issue.

What do WebbPSF simulations include?

WebbPSF calculations include:

- Instrument configuration options such as choice of detector pixel position, bandpass filters, elements such as coronagraph masks, grisms, spectrograph slits, etc.
- Mirror surface maps of high spatial frequency aberrations.
  - For JWST, measured segment surface figures.
  - For WFIRST, approximate high-spatial frequency content based on the Hubble primary mirror.
- Mid and low spatial frequency aberrations, represented as a linear combination of Zernike polynomials based on instrument test data and/or optical modeling.
- Configurable field of view and oversampling factors.
- Convolution with line-of-sight pointing jitter kernel.
- Outputs binned to the correct detector pixel scale for the instrument configuration.

Users should mix in their own:

- Detector effects (interpixel capacitance, read noise, etc.).
- Photon noise and absolute flux scaling.
- Spectral dispersion models for spectrograph modes.

The new JWST Exposure Time Calculator uses WebbPSF outputs and adds these detector effects and more:

http://jwst.etc.stsci.edu

References

Aronstein *et al.* (2016) "Wavefront Error Performance Characterization for the JWST ISIM SIs", Proc. SPIE 9904.

Spergel *et al.* (2015) *WFIRST-AFTA 2015 Report.*

Perrin *et al.* (2014) "Updated point spread function simulations for JWST with WebbPSF", Proc. SPIE. 9143.

Perrin *et al.* (2012) "Simulating point spread functions for the James Webb Space Telescope with WebbPSF", Proc. SPIE 8842.

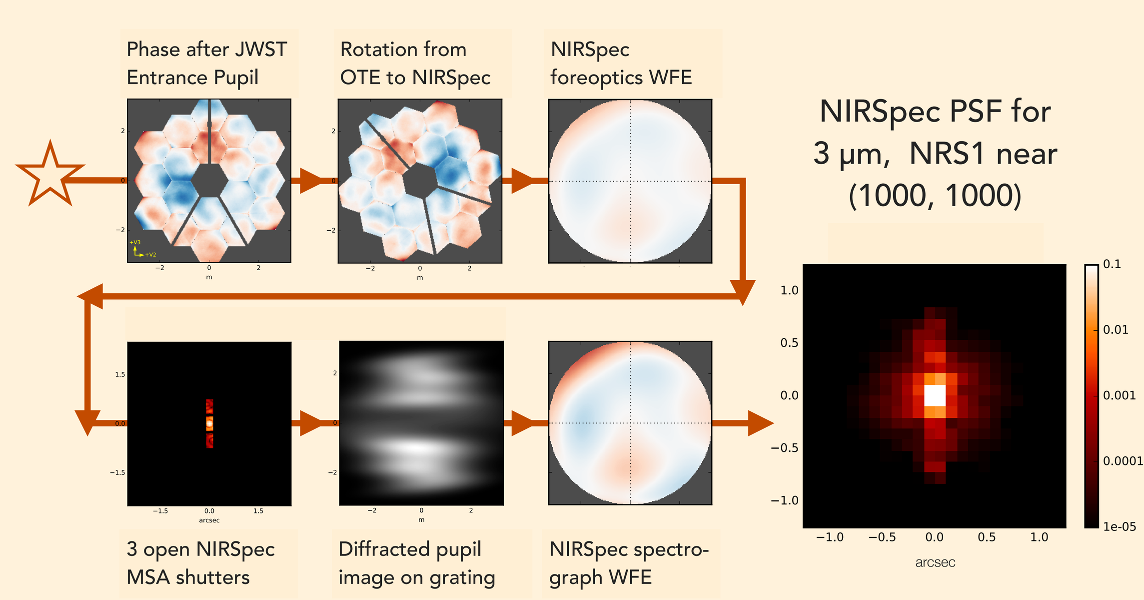
Perrin. (2011) "Improved PSF Simulations for JWST: Methods, Algorithms, and Validation", JWST Technical Report JWST-STScI-002469.

For JWST, WebbPSF now uses measured wavefront error data for the instruments and telescope optics, along with the updated optical budgets for in-flight performance.

To provide predicted PSFs based on the best currently available optical metrology, WebbPSF now includes:

- **Measured internal wavefront errors for all flight instruments**, obtained at several field points each during ISIM CV3 tests. See Aronstein *et al.* 2016 for test methods & analyses.
- **Updated models for instrument specifics**, such as a slight wavelength-dependent focus within NIRCam, and division of NIRSpec WFE between fore- and spectrograph optics.
- **Measured OTE segment surface figures** and secondary, tertiary, and fine steering mirror surface figures. See Knight *et al.* 2012.
- **Simulated OTE mirror alignments**, OTE-to-ISIM alignments, dynamical and thermal effects, and other observatory budget terms according to the latest "Revision W" optical budget. This is provided at two levels of overall wavefront error, a 50% "best prediction" level and a somewhat higher "requirements" level; the latter is the default option since it is more conservative.

Below: WebbPSF calculation stages (optical planes) for a NIRSpec PSF at 3 µm through 3 open MSA shutters.



WebbPSF combines Zernike models for the SI internal WFE and simulated OTE budget terms with the measured high frequency surface figures to derive the overall wavefront error for any particular simulation. **Overall predicted performance levels with these updates are generally near the better end of the range of OPD files distributed with prior versions of WebbPSF.** SI internal variations are typically 10s of nm across the field.

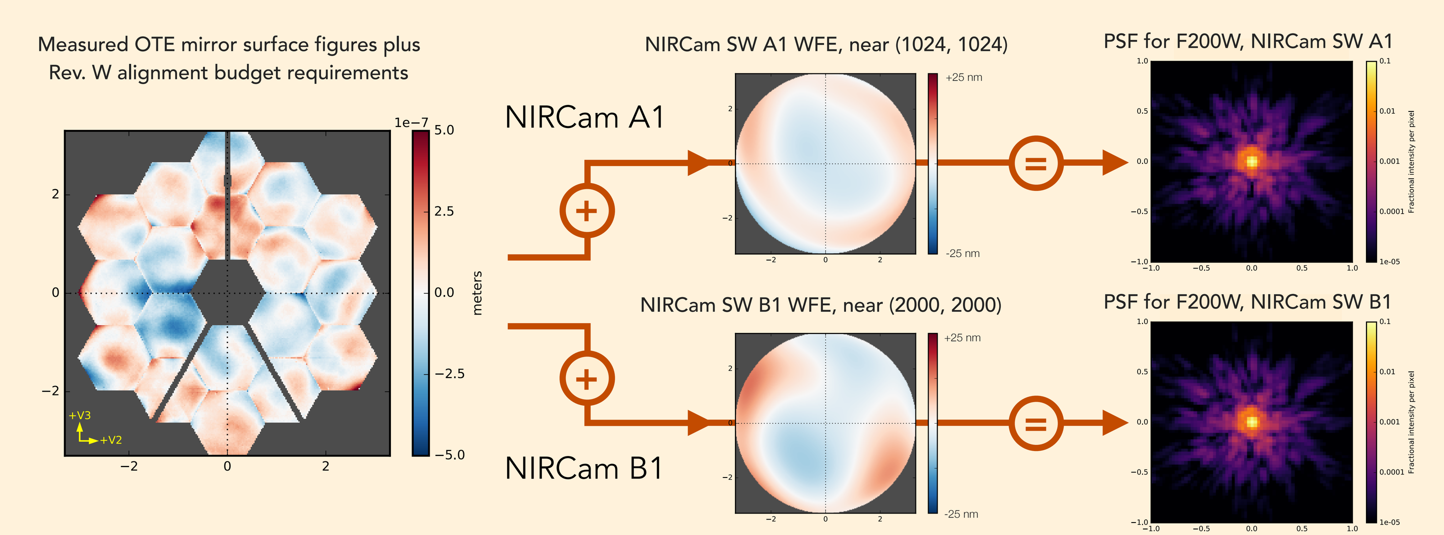
We are currently double-checking and validating these model outputs, for instance via cross-checks against measured PSFs using OSIM during CV3, and expect to complete a technical report this spring. We will continue to make any necessary updates based on these tests and feedback from the instrument teams, but do not expect major additional changes in optical models prior to launch.

Instrument	Internal WFE (nm RMS)	Field points measured	Requirements WFE (nm RMS)	Predicted WFE (nm RMS)	Predicted overall (nm RMS)	Previous WebbPSF (Rev V, nm RMS)
NIRCam SW	40 ± 10	26	117 ± 11	90 ± 8	~100	115 – 155
NIRCam LW *	107 ± 15	26	117 ±11	90 ± 8	~140	115 – 155
NIRSpec	91 ± 30	7	188 ± 14	163 ± 15	~185	125 – 240
NIRISS	47 ± 10	10	145 ± 12	108 ± 11	~120	145 – 180
MIRI	90 ± 28	5	250 ± 20	205 ± 16	~225	205 – 420
FGS	55 ± 29	19	150 ± 13	110 ± 11	~125	150 – 180
			OTE Rev. W budget		Combined OTE + Instruments	

Ranges shown for internal WFE are the standard deviation across measured field points; for the OTE the range is statistical uncertainty in model predictions.

** NIRCam LW focus varies with wavelength; the values shown are conservatively at the wavelength with greatest defocus.*

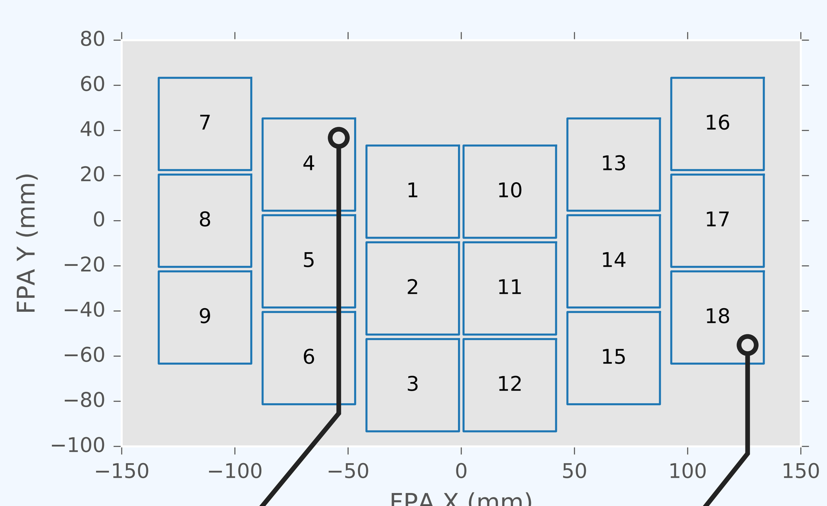
Above: Wavefront error levels for instruments & telescope based on the latest optical metrology & budgets.
Below: Simulated NIRCam PSFs for 2 field points are very slightly different due to a few 10s of nm delta WFE. WebbPSF adds instrument WFE to the OTE OPD to create the overall OPD map.



WebbPSF simulates WFIRST Wide Field Instrument PSFs across its entire FoV.

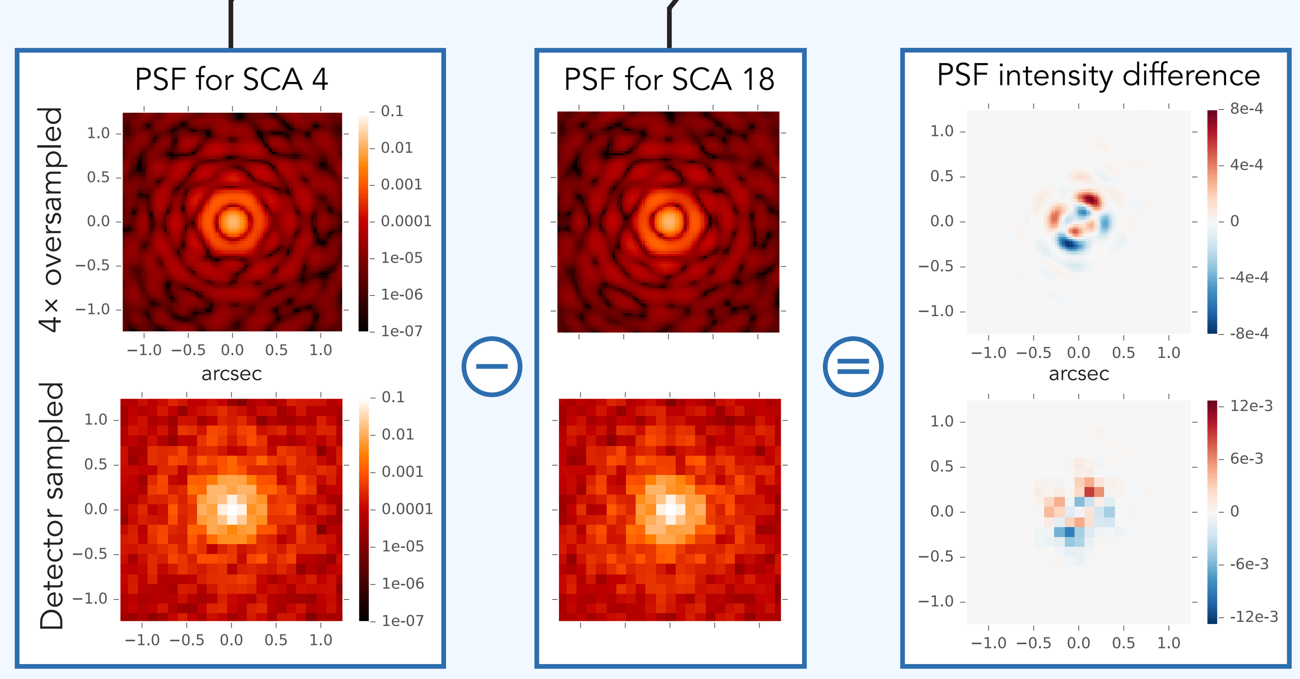
The WFIRST Wide Field Instrument (WFI) model has been updated to provide field- and wavelength-dependent PSFs based on the WFI Cycle 6 design revision. Users can simulate broadband PSFs in the bandpasses given in the WFIRST Science Definition Team report (Z087, Y106, J129, H158, F184, and W149) or at any wavelength from 0.6 to 2.0 µm.

Field-dependent aberrations can be interpolated for any pixel position on the wide-field imaging channel. The WFIRST optics team has calculated Zernike coefficients at five field points on each detector's field-of-view over a range of wavelengths. WebbPSF interpolates spatially and in wavelength to determine the Zernike components of the aberration at each point.



Left: The WFI focal plane array with eighteen 4k × 4k detectors covering 0.281 deg².

Below: Difference between PSFs at two field points (both 4× over-sampled and 0.11″/pixel detector sampled) for a monochromatic source at λ = 2 µm. (PSFs are normalized to total intensity of 1.0.)



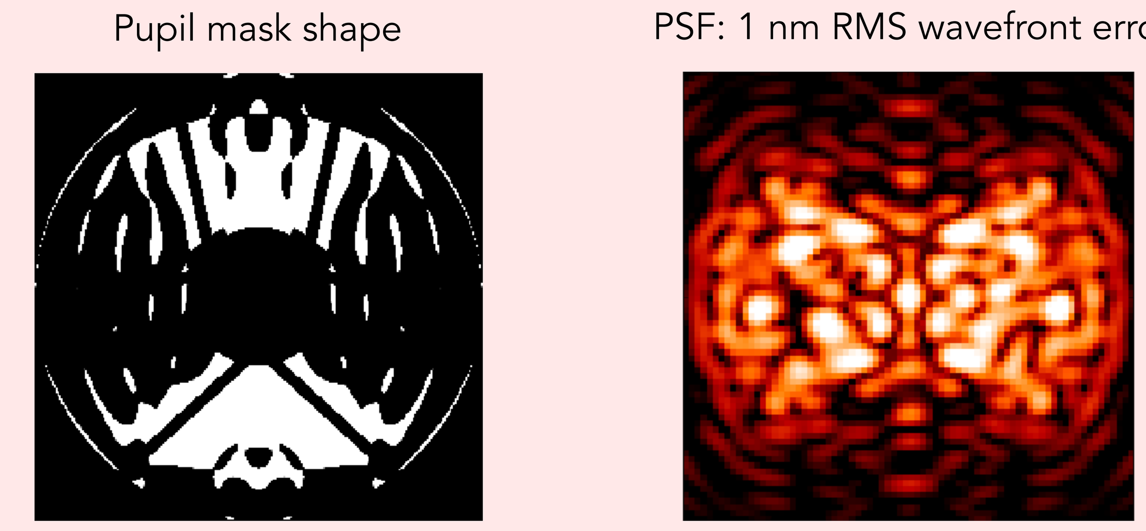
New WFIRST Coronagraphic Instrument simulations include starlight suppression.

We have begun developing a Coronagraph Instrument (CGI) simulation module. Currently we have a prototype implementation available for the shaped pupil coronagraph modes only, for both the CGI imager and IFS. The goal is to provide an open source modeling package for CGI for use by the science centers and science teams, to complement the existing in-house optical modeling capabilities at JPL. Presently we are incorporating realistic aberrations, both static and dynamic, to produce realistic speckle fields. Future releases will add the hybrid Lyot modes.

Shaped pupil coronagraph planet characterization mode

2 × 65° bow-tie field of view, 0.19 arcsec inner working angle, wavelength = 770 nm

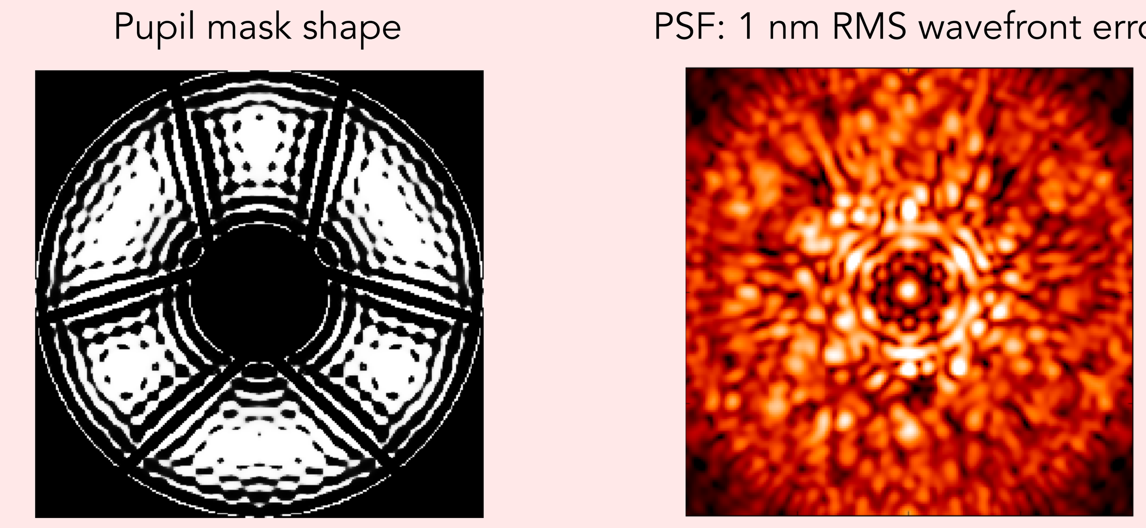
Pupil mask shape | PSF: 1 nm RMS wavefront error



Shaped pupil coronagraph debris disk imaging mode

Annular field of view, 0.31 arcsec inner working angle, wavelength = 565 nm

Pupil mask shape | PSF: 1 nm RMS wavefront error



Install WebbPSF for AstroConda: `(astroconda)$ conda install webbpsf`
Or, install WebbPSF with pip: `$ pip install --upgrade webbpsf`
Read the documentation: https://pythonhosted.org/webbpsf/

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