

Simulating point spread functions for JWST with WebbPSF

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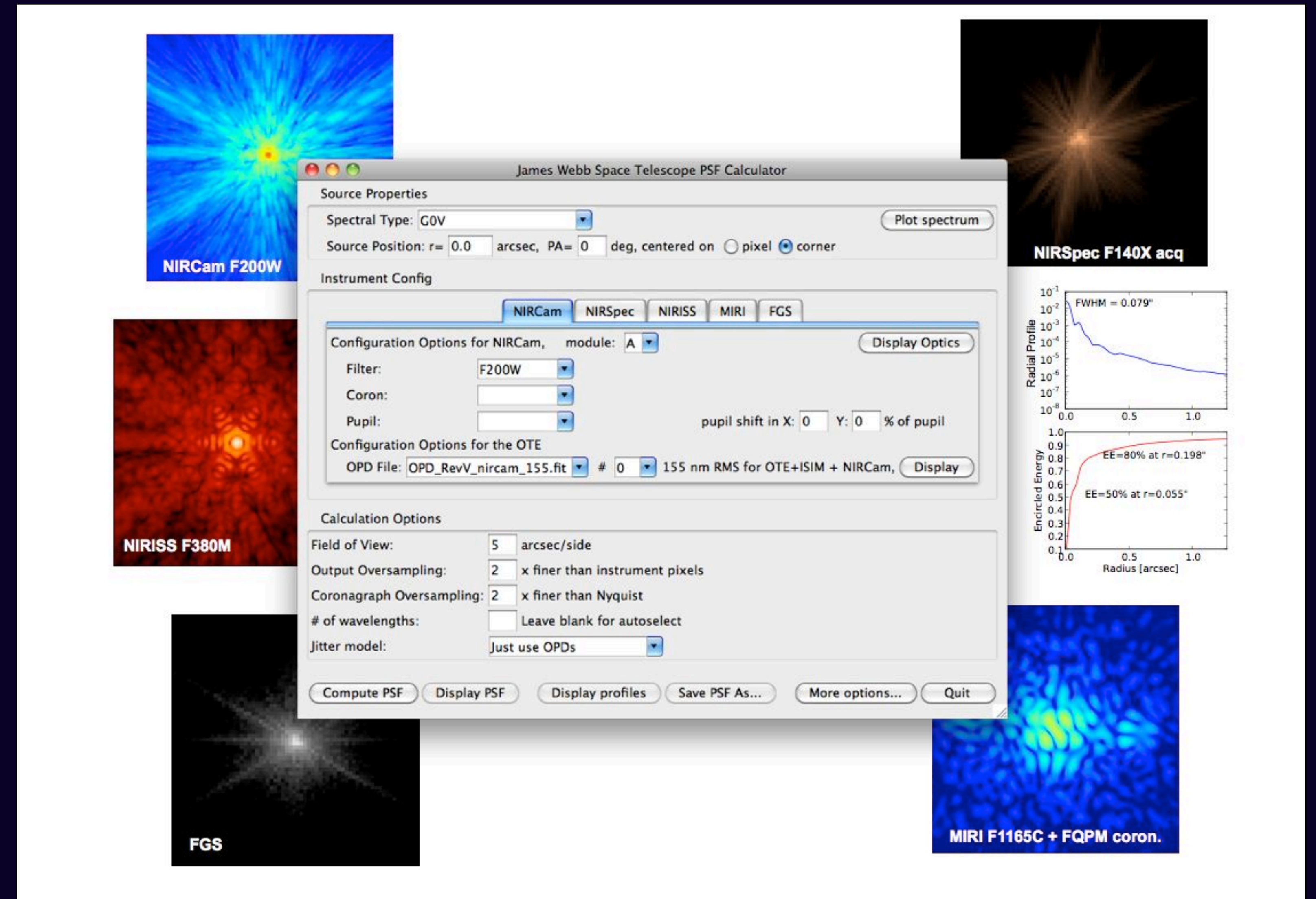
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Summary

WebbPSF is a Python package that computes simulated PSFs for JWST's instruments, based on up-to-date models for telescope wavefront maps. WebbPSF supports all observing modes including direct imaging, coronagraphy, integral field spectroscopy, and aperture masking interferometry.

It is not a full optical model of JWST, but rather a tool for transforming precomputed optical path difference (OPD) maps into the resulting PSFs as observed with JWST's instruments. It is flexible, extensively configurable, and includes both graphical and scripting interfaces. As JWST nears completion, WebbPSF will continue to be updated to enhance its fidelity, and after the observatory is launched it will serve as the basis for an on-orbit PSF modeling capability that tracks temporal variations in the wavefront of the actively-controlled mirror system.

WebbPSF is freely available, with software and extensive documentation available at <http://www.stsci.edu/jwst/software/webbpsf>



Software Design and Capabilities

```
>>> #create a NIRCам instance and calculate a PSF for F210M
>>> nircam = webbpsf.NIRCам()
>>> nircam.filter = 'F210M'
>>> psf210 = nircam.calcPSF(oversample=2)
>>> #display the PSF and plot the encircled energy
>>> subplot(1,2,1)
>>> webbpsf.display_PSF(psf210, colorbar_orientation='horizontal')
>>> axis2 = subplot(1,2,2)
>>> webbpsf.display_EE(psf210, ax=axis2)
>>> psf210.write('nircam_F210M.fits')
>>> savefig('plot_nircam_F210M.pdf')
```

Above: Example WebbPSF scripting code creating and displaying a simple direct imaging PSF for NIRCам and its encircled energy.

A real quote from an actual user: "It is a nice piece of work, and the documentation allows even someone like myself, who am not a Python user, to get images almost immediately."

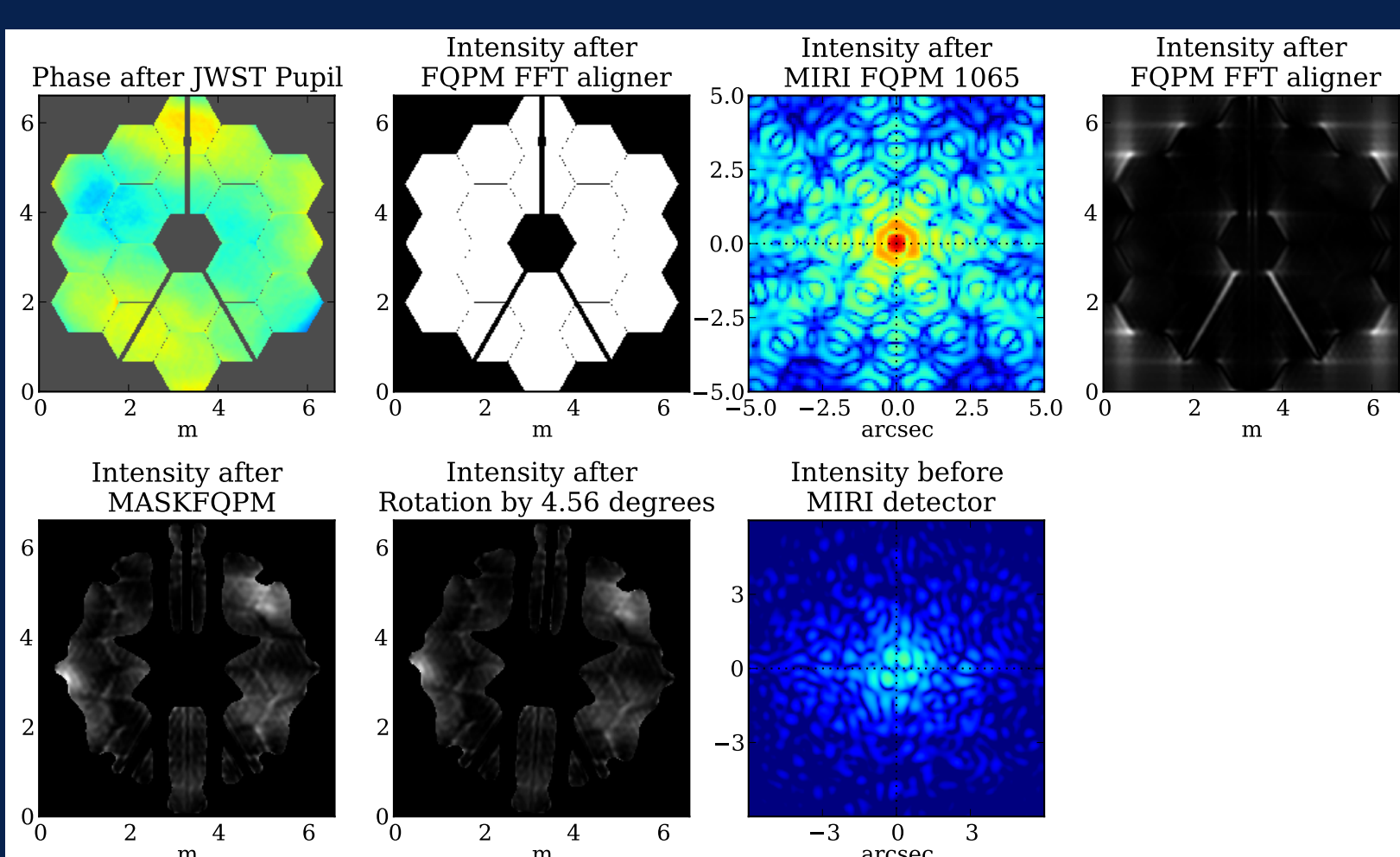
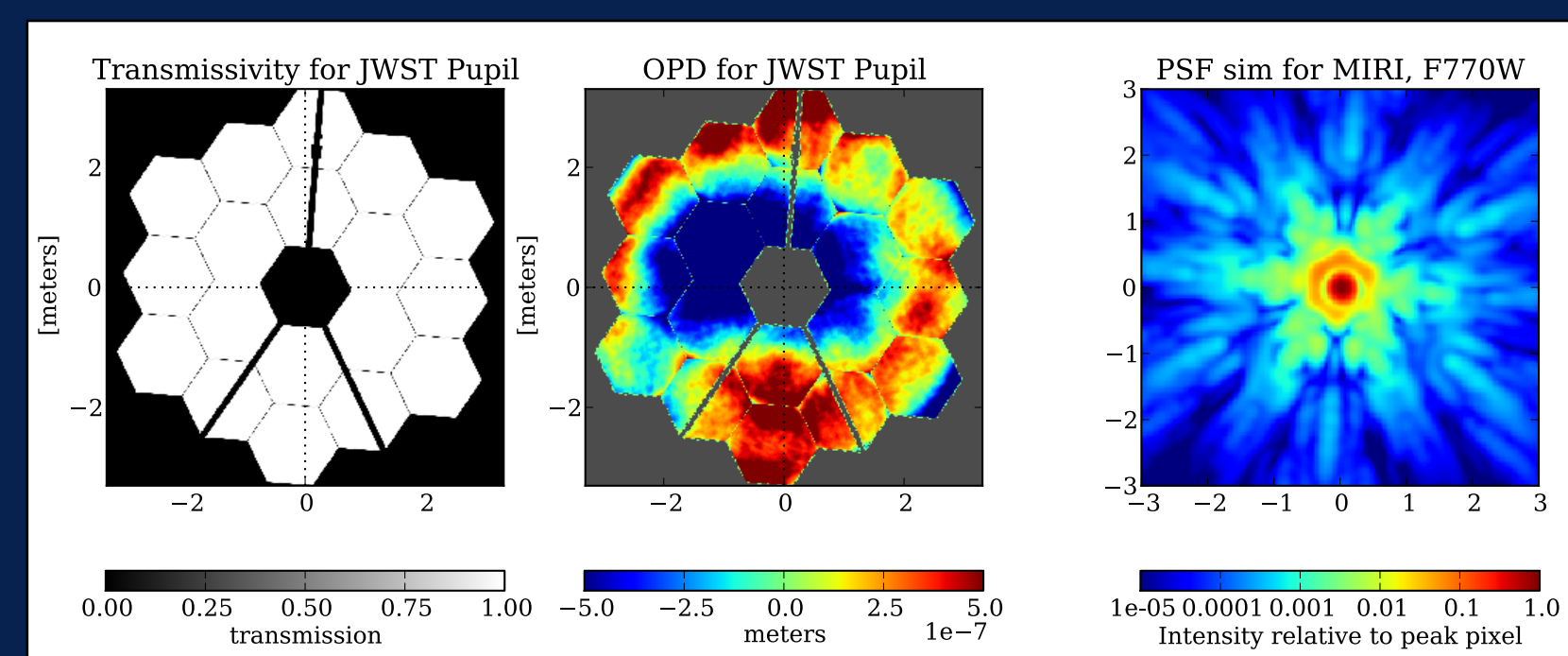
WebbPSF is a lightweight, easy to use astronomer's PSF simulator. It is similar in concept to HST's Tiny Tim (Krist et al. 1992-2011). It provides:

- PSF simulations for direct imaging and coronagraphic modes, and for non-redundant aperture masking mode on NIRISS.
- Up-to-date instrument properties such as normalized spectral responses, detector pixel scales and orientations.
- Arbitrary oversampling of output PSFs
- Quick calculations using optimized matrix Fourier transforms, the fast semi-analytic coronagraphy algorithm, and the FFTW3 library (optional).
- Built-in functions for PSF evaluation such as producing radial profile plots, measuring encircled energy curves, FWHMs, etc.
- An easy-to-use graphical user interface.
- A object-oriented programming interface for sophisticated scripting and automation.

Example Calculations: MIRI Imaging & Coronagraphy

Right: a MIRI direct imaging PSF, calculated for F770W.

Note the 4.5° rotation of the telescope pupil relative to MIRI's detector axes.

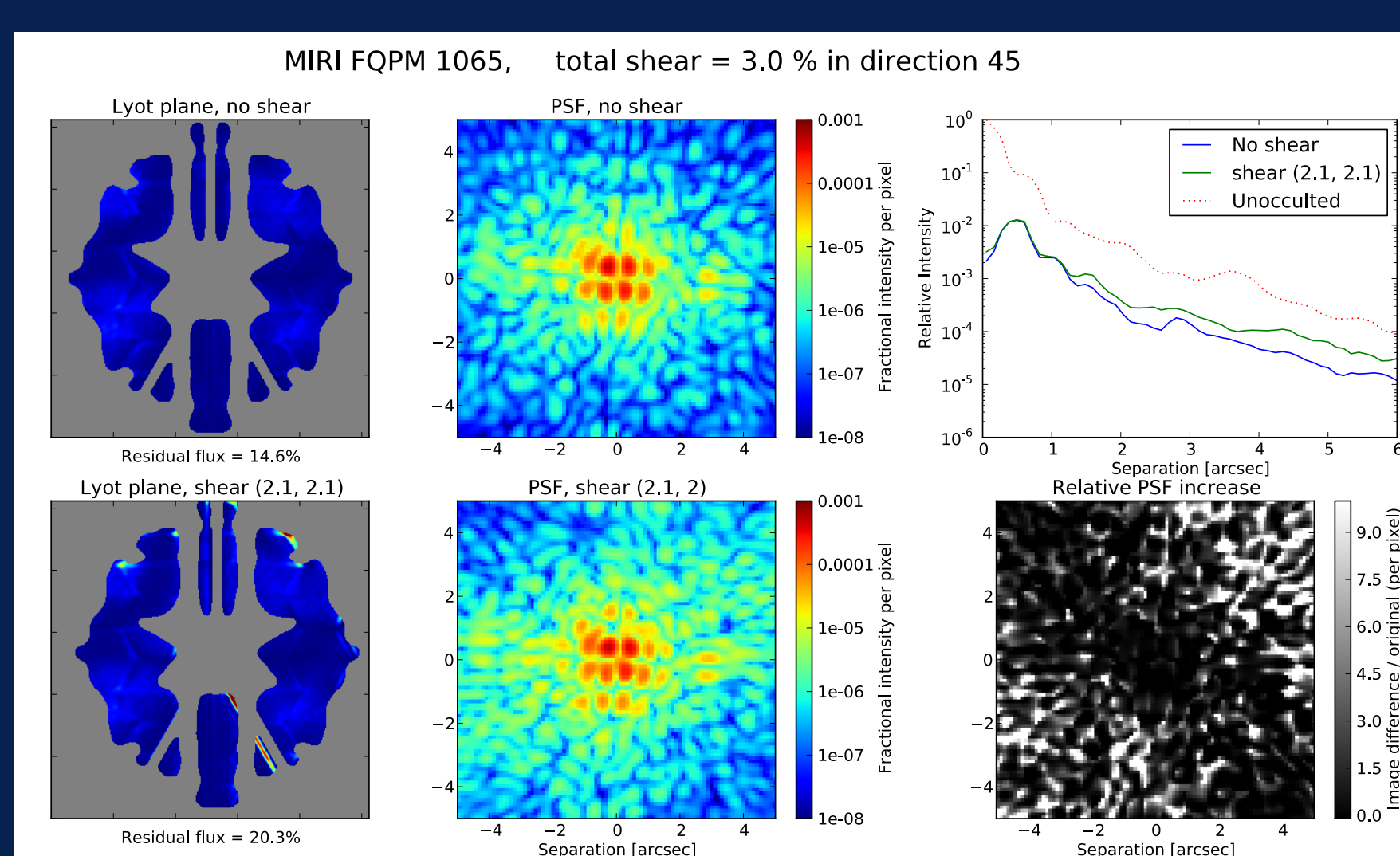


Left: Coronagraphic imaging using the 10.65 μm quadrant phase mask.

From left to right the panels show the model wavefront error, first image plane PSF, pupil intensity prior to the coronagraphic Lyot mask, pupil intensity after the Lyot mask, a rotated version thereof, and the final coronagraphic image plane.

Right: A study of the impact of pupil shear on achieved contrast of MIRI QPM coronagraphy.

This demonstrates the flexibility of WebbPSF for performing *ad hoc* analyses of specific questions that arise during JWST integration and test. These plots demonstrate that a 3% shear would slightly decrease contrast achieved beyond ~ 1.5", but the contrast between 0.4-1.2" is essentially unaffected.



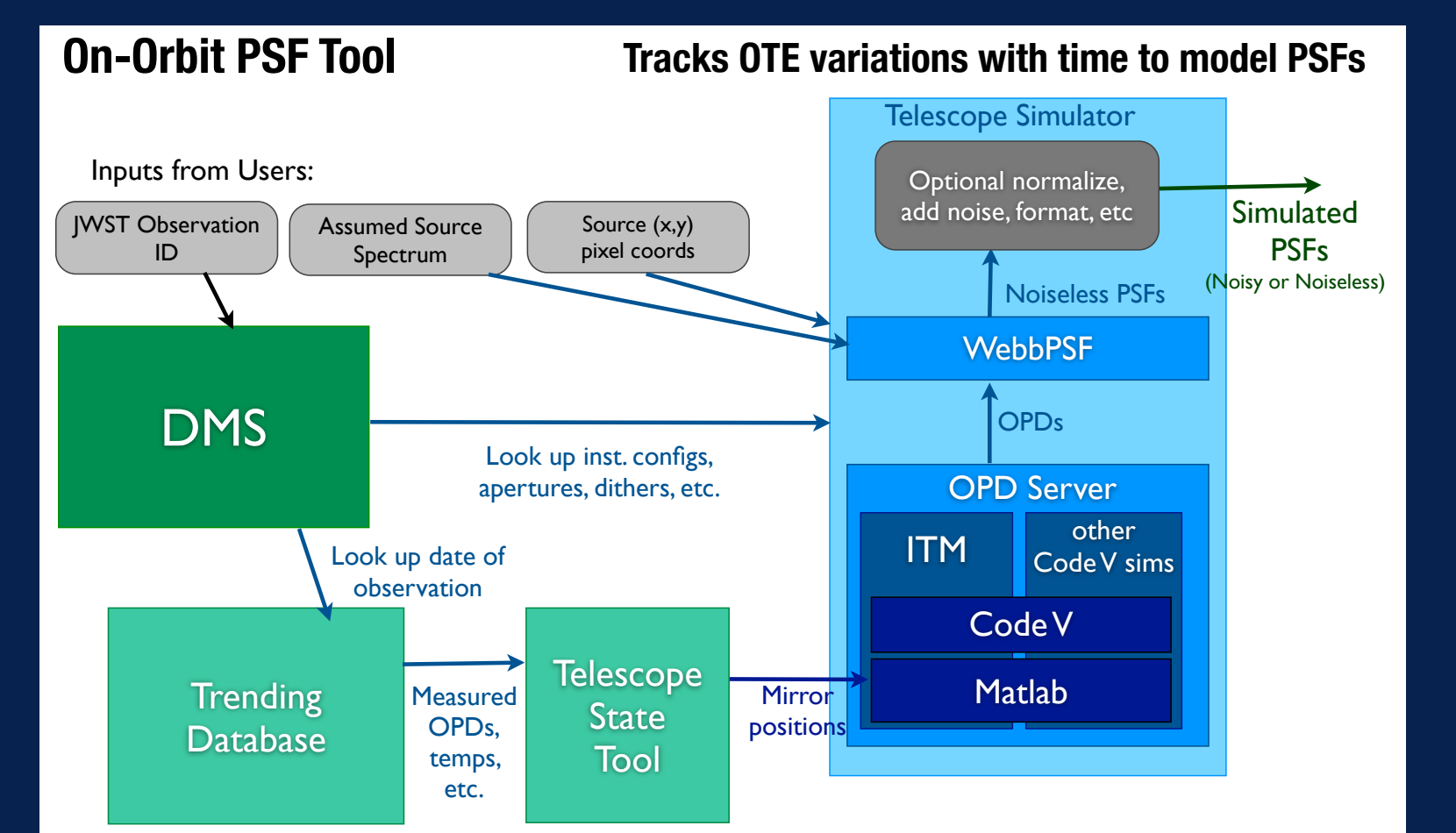
Example Applications

WebbPSF has already been used for many modeling tasks, including:

- Implementing a NIRCам science image simulator, in which it is used to convolve both model and "cloned" galaxies to test detection algorithms that will be used in surveys of very distant galaxies.
- Modeling wide-field slitless spectroscopy with NIRISS, in a project to determine whether one can use the centroids of the zero-order spectra to derive the exact pointing of a dispersed image without having to take a direct image first.
- Creating single-segment and coarse phasing PSFs for use by COMDEV in testing of FGS flight software acquisition, tracking, and guiding algorithms.
- Simulating target acquisition with the MIRI FQPM coronagraphs, to assess and compare multiple possible operations strategies.
- Generating NIRISS PSFs for dithering & target acquisition strategy development, exposure time calculator development, and comparison with measured cryovac test PSFs.
- Generating MIRI PSFs in order to calculate the slit transmission for the MIRI low resolution spectrograph as a function of wavelength and position within the slit.
- Simulating NIRCам defocused weak lens images for testing wavefront sensing and phase retrieval software.
- Simulating coronagraphic observations of the HR 8799 system, to aid in developing exoplanetary science cases and observing plans.
- Assessing the impact on coronagraphy of potential modifications to the telescope pointing jitter requirements.
- Assessing and optimizing coronagraphic performance using the as-built primary mirror segment wavefront maps.

Future Plans: Pre-Launch and On Orbit

The current implementation of WebbPSF relies on a fixed, static set of simulated wavefront maps. During the operational mission, we will need a system for tracking temporal variations in PSFs of the actively controlled telescope. To achieve this, we have developed a software road map for integrating WebbPSF with other software tools to create an **On-Orbit PSF Tool** that will provide accurate model PSFs that track the time evolution of the telescope.



A related variant of this code will be used prior to launch for end-to-end tests of ground system software and commissioning plans. Simulated PSFs with realistic noise added will be processed through the Data Management System and data pipeline, and analyzed with the Wavefront Analysis Software to generate mock mirror move commands, which will be fed back to update the simulated optical state. This mode of operation will incorporate and replicate many of the "Level 4" testing capabilities in Ball's Integrated Telescope Model (ITM) simulator (Knight et al. 2010), with the substantial added benefit of integrating with and exercising the complete Science & Operations Center ground system at STScI. These end-to-end simulations using WebbPSF will be a key element in demonstrating ground system readiness and training personnel in preparation for JWST's launch and commissioning.

References:

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