



**STScI** | SPACE TELESCOPE  
SCIENCE INSTITUTE

**EXPANDING THE FRONTIERS OF SPACE ASTRONOMY**

# HIGH CONTRAST IMAGING (HCI) WITH JWST

ETC Limitations & high(er) fidelity calculations: PanCAKE demo

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Master Class - Level 2 - Nov 19<sup>th</sup> & 20<sup>th</sup> 2019 - STScI



# ETC for Coronagraphy: PSF subtraction from a reference star

Exposure Time Calculator Edit - Expand - Julien Girard - Help -

Today is a nice day!

Simple planet DI case

Calculations Scenes and Sources Uploaded Spectra Coverts and Limitations

MIR MIRCam NIRISS NIRSpec

ID	Plot	Mode	Scene	(s)	SNR	Δ
11	<input checked="" type="checkbox"/>	nircam coronagraphy	2	408.34	98.74	
10	<input checked="" type="checkbox"/>	nircam coronagraphy	2	388.06	93.65	
9	<input checked="" type="checkbox"/>	nircam coronagraphy	2	306.03	87.94	
8	<input checked="" type="checkbox"/>	nircam coronagraphy	2	286.77	81.47	
7	<input checked="" type="checkbox"/>	nircam coronagraphy	2	204.82	73.97	
6	<input checked="" type="checkbox"/>	nircam coronagraphy	2	153.46	65.07	
5	<input checked="" type="checkbox"/>	nircam coronagraphy	2	102.31	53.99	
4	<input checked="" type="checkbox"/>	nircam coronagraphy	2	51.15	38.82	
3	<input checked="" type="checkbox"/>	nircam coronagraphy	2	51.15	38.82	
1	<input checked="" type="checkbox"/>	nircam target_star	2	1.88	37.27	
-	-	-	-	--	--	-

Images

Calculation selected: 10, Mode: nircam coronagraphy

2D SNR Detector Saturation

SNR vs On-Source Time

Instrument Filter/Dispenser: F935W/None

Extraction Aperture Position (arcsec): [1.72, 0.00]

Wavelength of interest used to Calculate Scales Values (micron): 3.35

Size of Extraction Aperture (arcsec): 0.08

Total Time Required for Strategy (seconds): 716.16

Total Exposure Time (seconds): 388.06

Extracted Flux (e-/sec): 76.73

Standard Deviation in Extracted Flux (e-/sec): 0.82

Extracted Signal-to-Noise ratio: 93.65

Input Background Surface Brightness (Mjy/s): 0.14

Total Background Flux in Extraction Aperture (e-/sec): 0.06

Total Sky Background Flux in Extraction Aperture (e-/sec): 1.20

Fraction of Total Background due to Signal From Scene: 0.98

Average Number of Cosmic Rays per Ramp: 4.0e-3

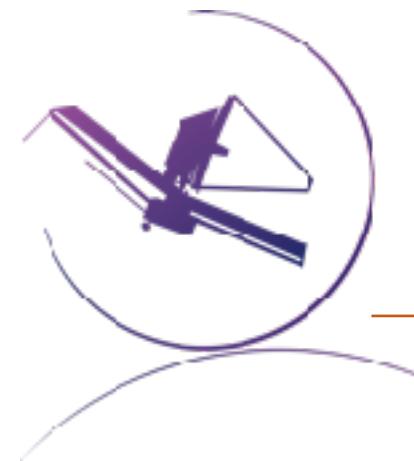
Radius at which Contrast is Measured (arcsec): 1.00

Azimuth at which Contrast is Measured (degrees): 0.0

Contrast: NaN

Example feature:  
Expand SNR  
through filters

The screenshot displays the JWST Exposure Time Calculator (ETC) interface. The top navigation bar includes 'Exposure Time Calculator', 'Edit', 'Expand', 'Julien Girard', and 'Help'. A status message 'Today is a nice day!' is shown. The main area has tabs for 'Calculations', 'Scenes and Sources', 'Uploaded Spectra', and 'Coverts and Limitations'. Under 'Calculations', a table lists various observations (ID 11 to 1, mode: nircam coronagraphy) with columns for Plot, Mode, Scene, (s), SNR, and Δ. The row for ID 10 is highlighted with a yellow background. Below the table are sections for 'Images' (2D SNR, Detector, Saturation) and 'Plots' (SNR vs On-Source Time). The 'SNR vs On-Source Time' plot shows data points for various exposure times (0, 50, 100, 150, 200, 250, 300, 350, 400 seconds) with corresponding SNR values (ranging from ~40 to 100). To the right of the plot is a detailed summary of instrument parameters and performance metrics, including contrast levels and background fluxes. An orange callout box highlights the 'SNR vs On-Source Time' plot with the text 'Example feature: Expand SNR through filters'.



# ETC for Coronagraphy: Limitations for High Contrast Imaging

**Pre-computed PSF library from WebbPSF with a discrete number of angular separations (sparse spatial sampling)**

→ Calculations can be **inaccurate in the speckle limited regime** (close to the coronagraphs, typically at separations  $< 1''$ )

**ETC does not account for spectral mismatch (only photometrically) of the PSF reference star**

**ETC supposes a perfect centering (target acquisition) of all stars**

→ Calculations can be **optimistic**

**PSF calculations “on the fly” are time consuming: can be done in command line with Pandeia engine or with PanCAKE (not yet fully supported)**

- ◆ Custom small grid dithers and positioning
- ◆ Custom spectral sampling
- ◆ Custom field of view

[https://github.com/spacetlescope/  
pandeia-coronagraphy](https://github.com/spacetlescope/pandeia-coronagraphy)

**The ETC PSF subtraction strategies assume the same detector readout parameters for all stars in a workbook**

→ If one wants to use a brighter reference star, several ETC workbooks are needed

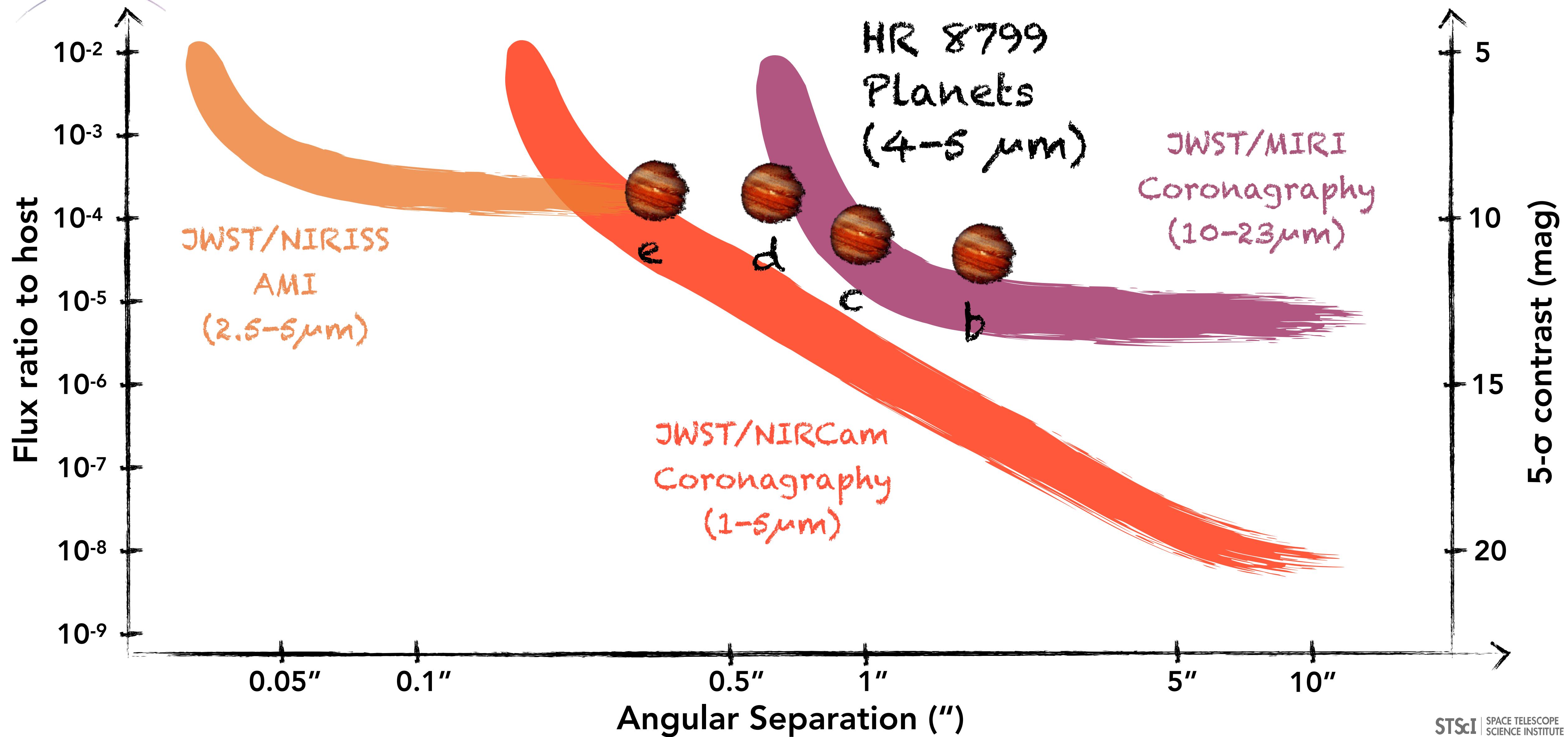
**The ETC cannot inject ring like features or disks**

**Can be done with pyNRC (not supported by STScI)**

<https://pynrc.readthedocs.io>



# NIR to MIR Coronagraphy & Aperture Masking: Ground & Space





# Why do we recommend two rolls plus a PSF calibrator?

## **Factors degrading PSF calibration and subtraction**

Wavefront drifts of the observatory

PSF star color differences

Self-subtraction biases (esp. for disks)

Imperfect target acquisitions

Line-of-sight jitter and dynamic wavefront error

### Optional:

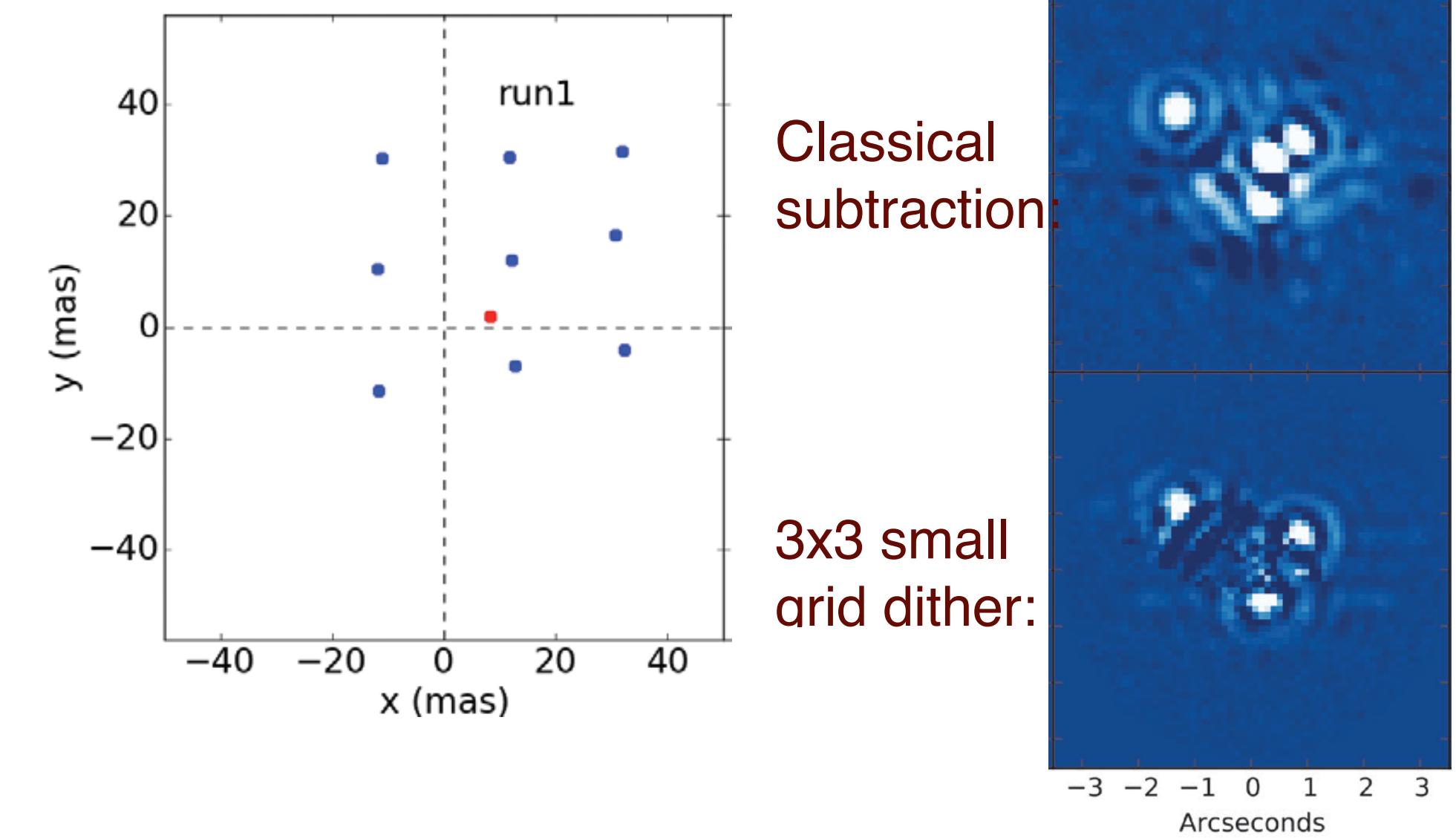
Perform sub pixel dithers of the PSF star to build mini PSF reference library, then synthesize an optimal PSF that matches the target position precisely. “Small Grid Dithers”.

>10x contrast improvement for MIRI,  
3-5x improvement for NIRCam.

Cost: 5-9x longer PSF star exposure times.

Target acq is required for all coronagraphy.  
Expected precision is very good (~ few mas)  
but residuals still matter.

All coronagraphs are sensitive to misalignments;  
MIRI FQPMs more sensitive than NIRCam Lyot corons.



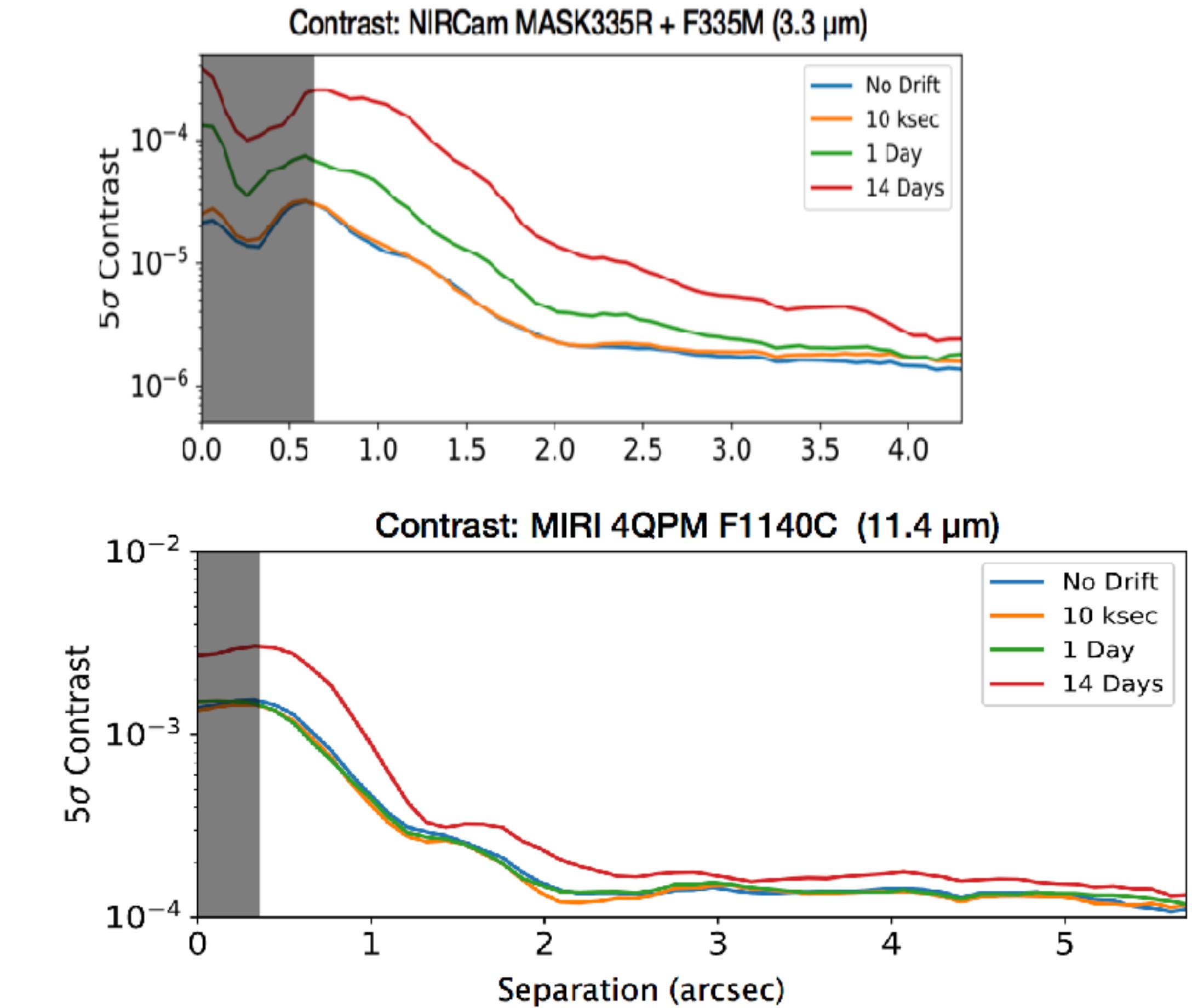
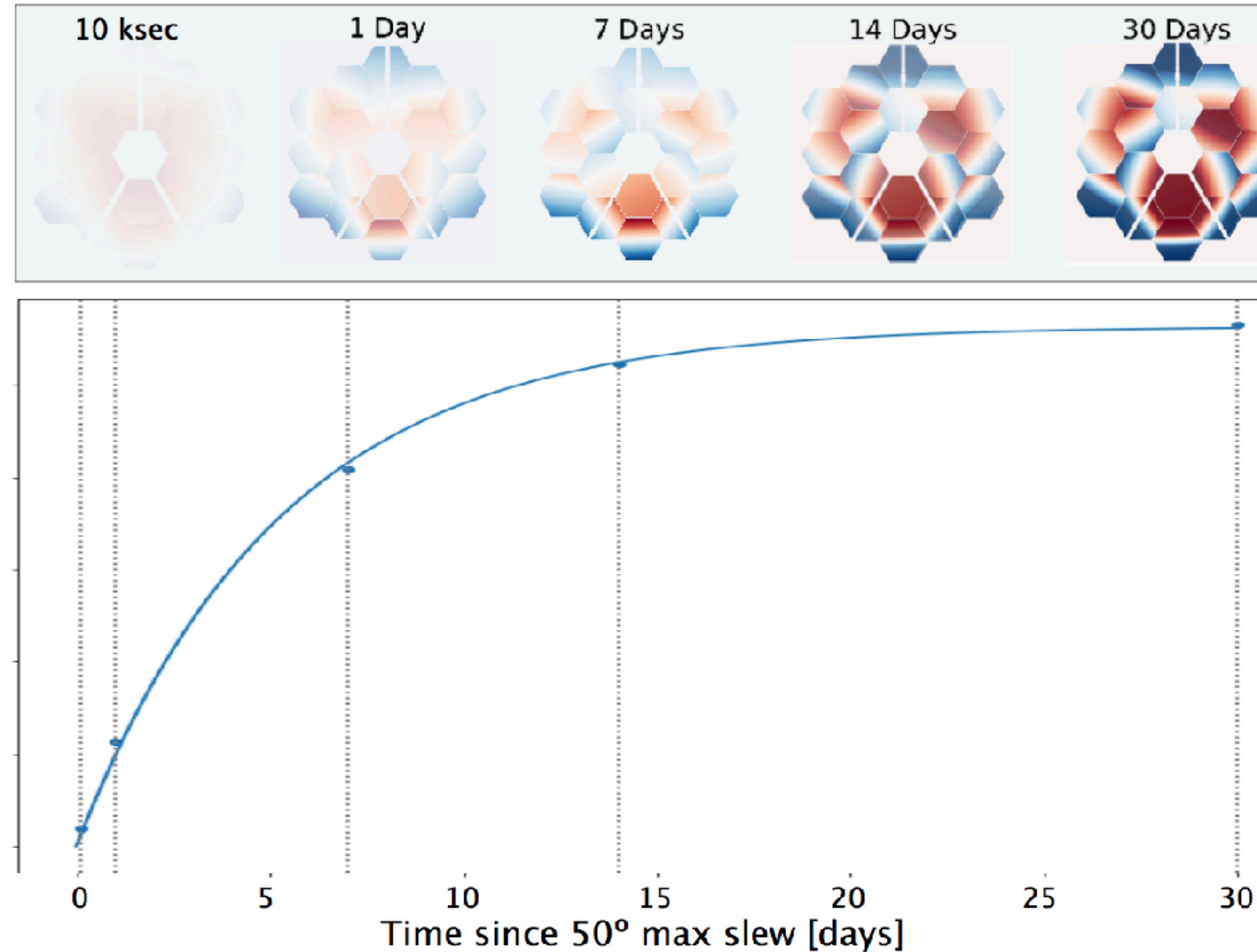
Simulated small grid dither PS subtraction

Lajoie et al. 2106



# Towards the generation of realistic datasets : impact of slew

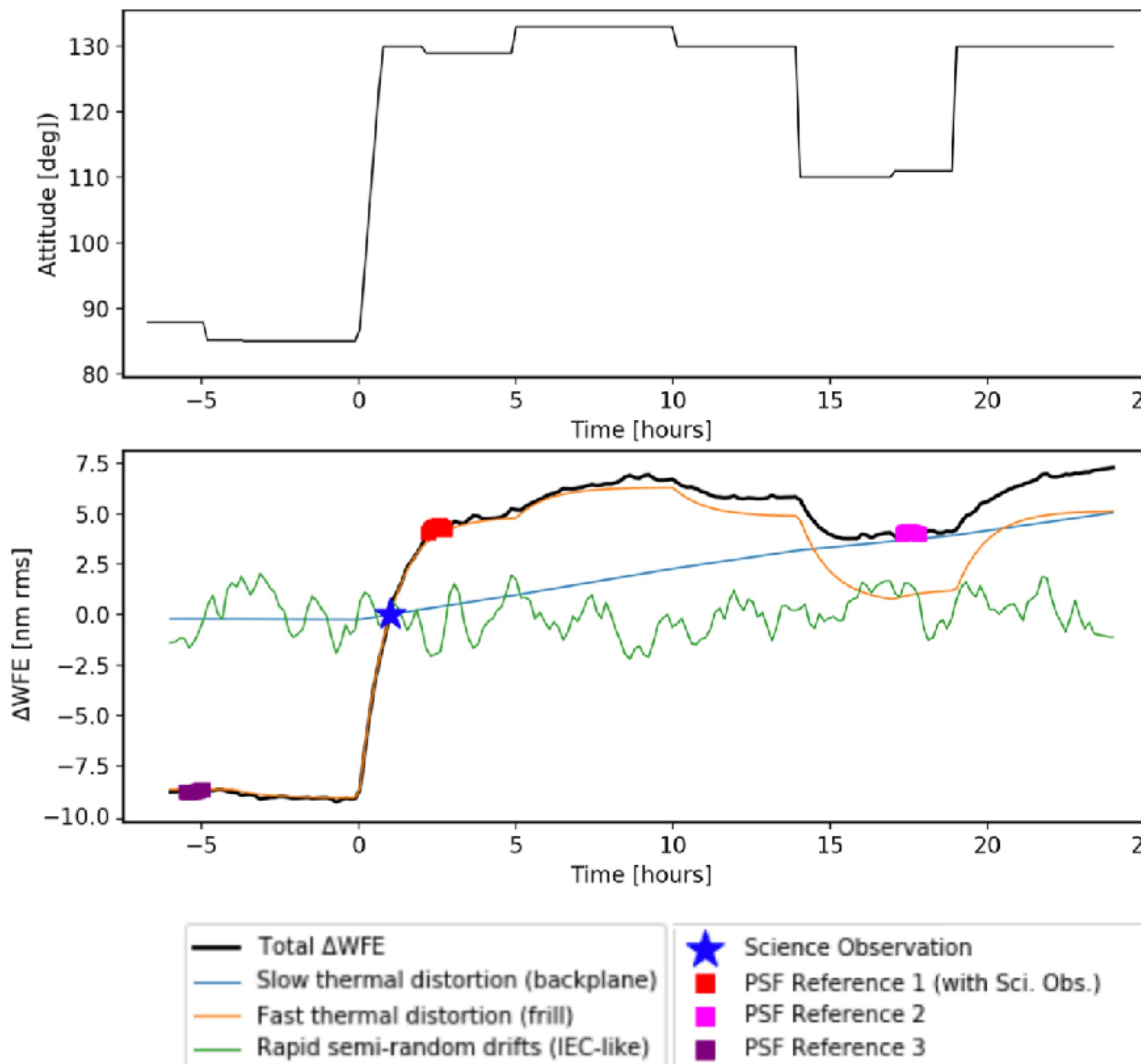
## Model-predicted $\Delta$ WFE from maximum hot-to-cold slew



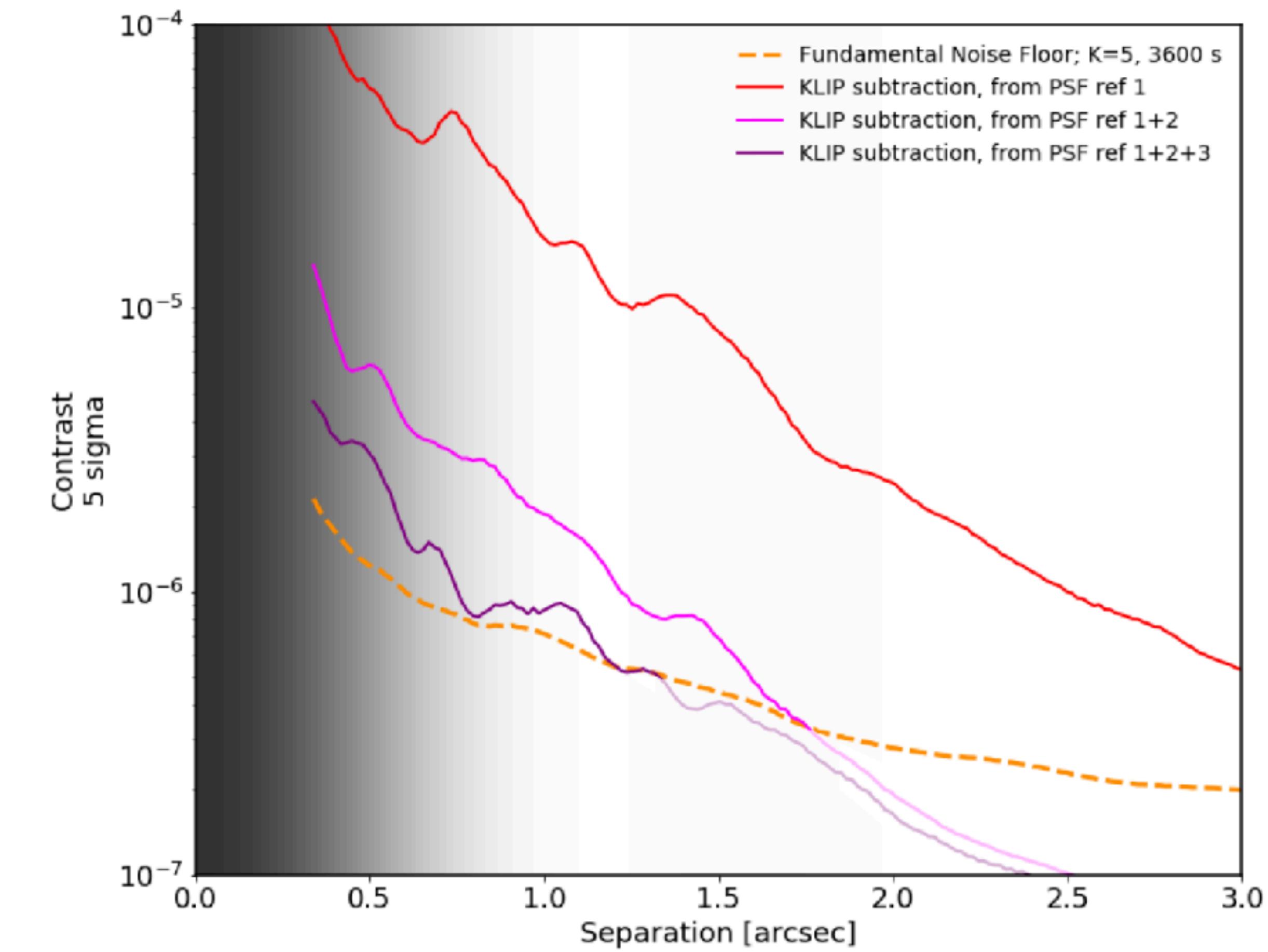


# Towards the generation of realistic datasets : impact of slew

Hypothetical in-flight time series: observatory attitude and  $\Delta\text{WFE}$



Modeled Contrast after KLIP PSF subtraction



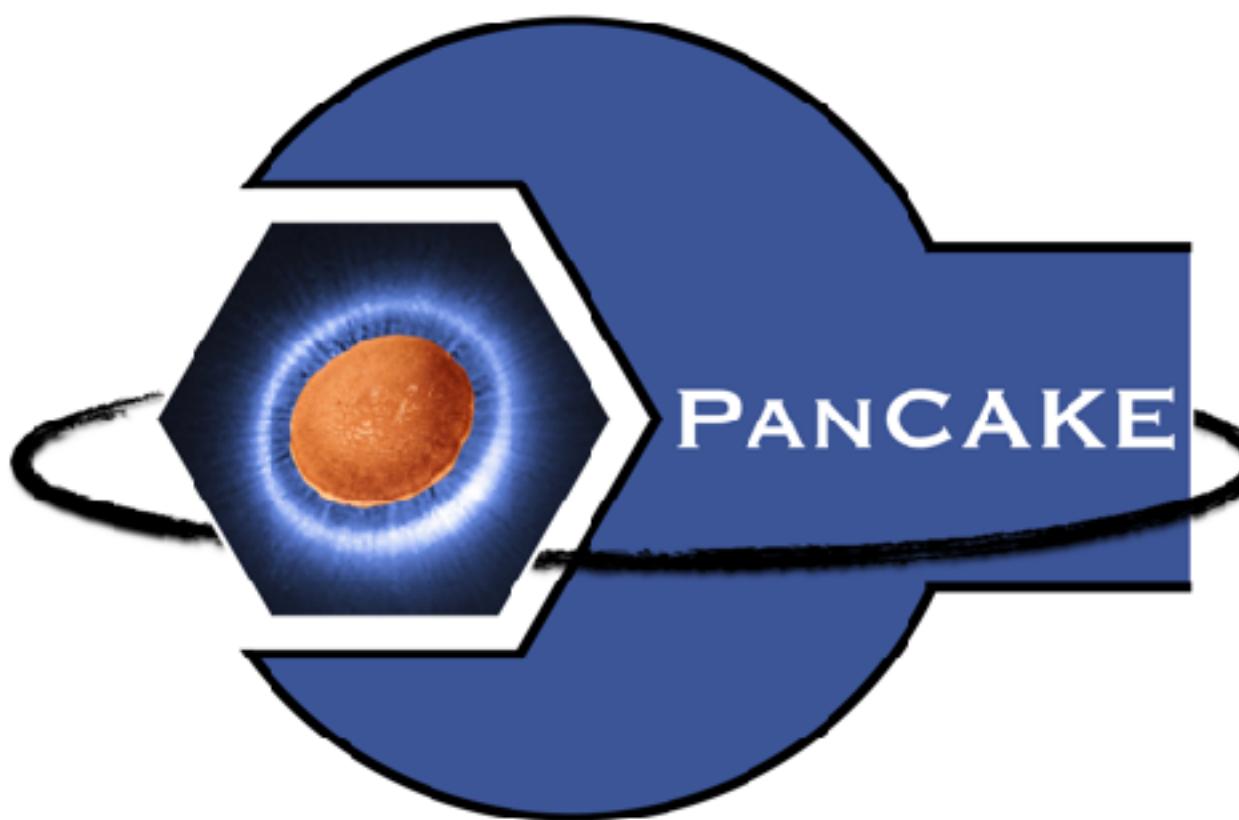
Perrin et al. SPIE 2018

Brooks et al. #AAS233

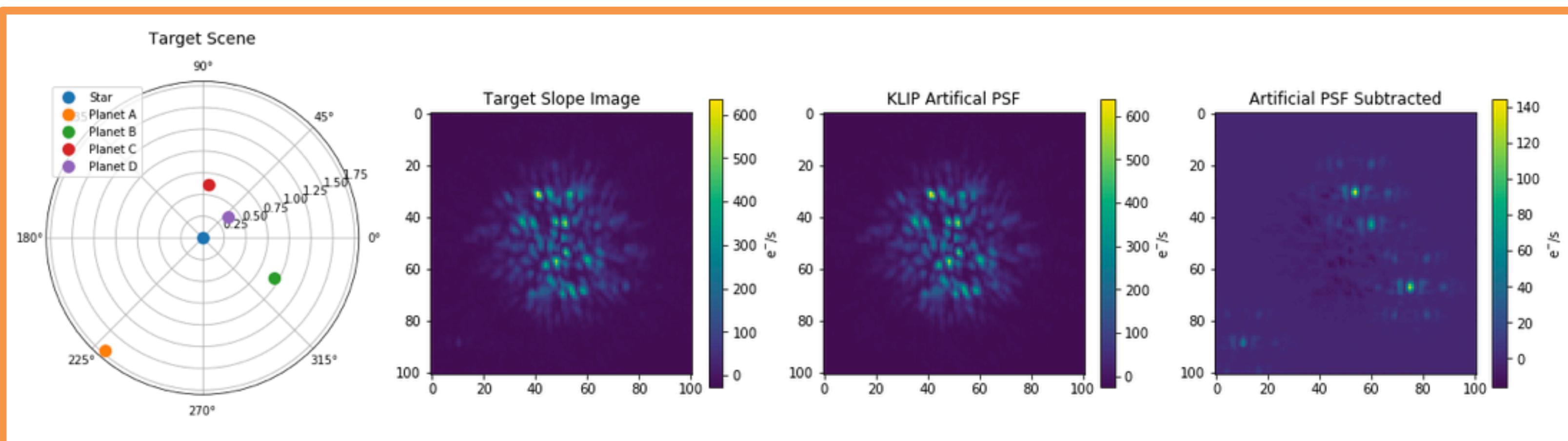


# ETC extensions: PanCAKE (STScI) & pyNRC (NIRCam IDT)

[github.com/spacetelescope/pandeia-coronagraphy](https://github.com/spacetelescope/pandeia-coronagraphy)

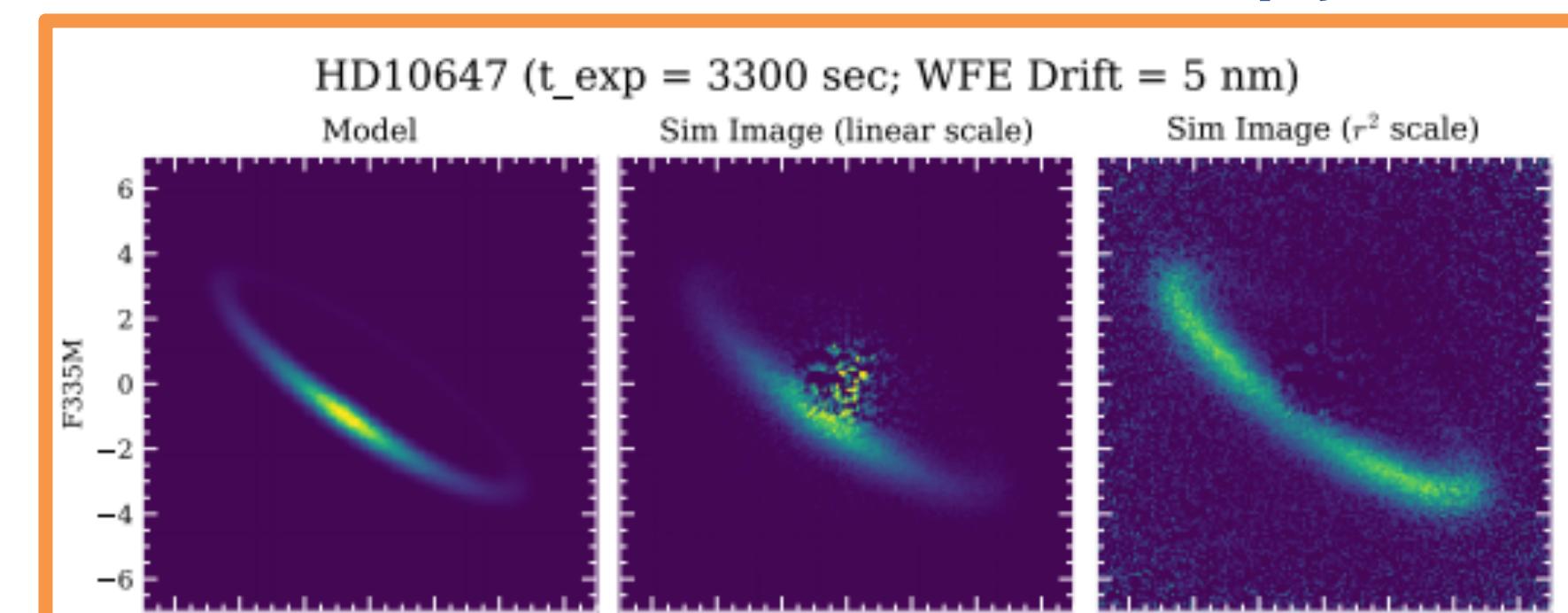


Can call WebbPSF “on the fly”  
custom PSF grids/dithers, FoV, spectral sampling, more precise extractions  
Several coronagraphic specific functions  
Contrast curves  
Currently improving the scene compatibility with ETC UI and outputs



Check also (disks)!

pyNRC





# PanCAKE (formely Pandeia-Coronagraphy)

[spacetelescope / pandeia-coronagraphy](#)

[Unwatch](#) 7   [Unstar](#) 2   [Fork](#) 11

[Code](#)   [Issues 6](#)   [Pull requests 4](#)   [Actions](#)   [Projects 0](#)   [Wiki](#)   [Security](#)   [Insights](#)

Toolkit for adding advanced coronagraph simulations on top of the Pandeia engine

179 commits   3 branches   0 packages   0 releases   4 contributors   View license

Branch: master   New pull request   Create new file   Upload files   Find file   Clone or download

**w polemarkh** Hopefully no longer passing NaN pixels into libraries that don't like... ...   Latest commit 6b30b0b on Jul 10

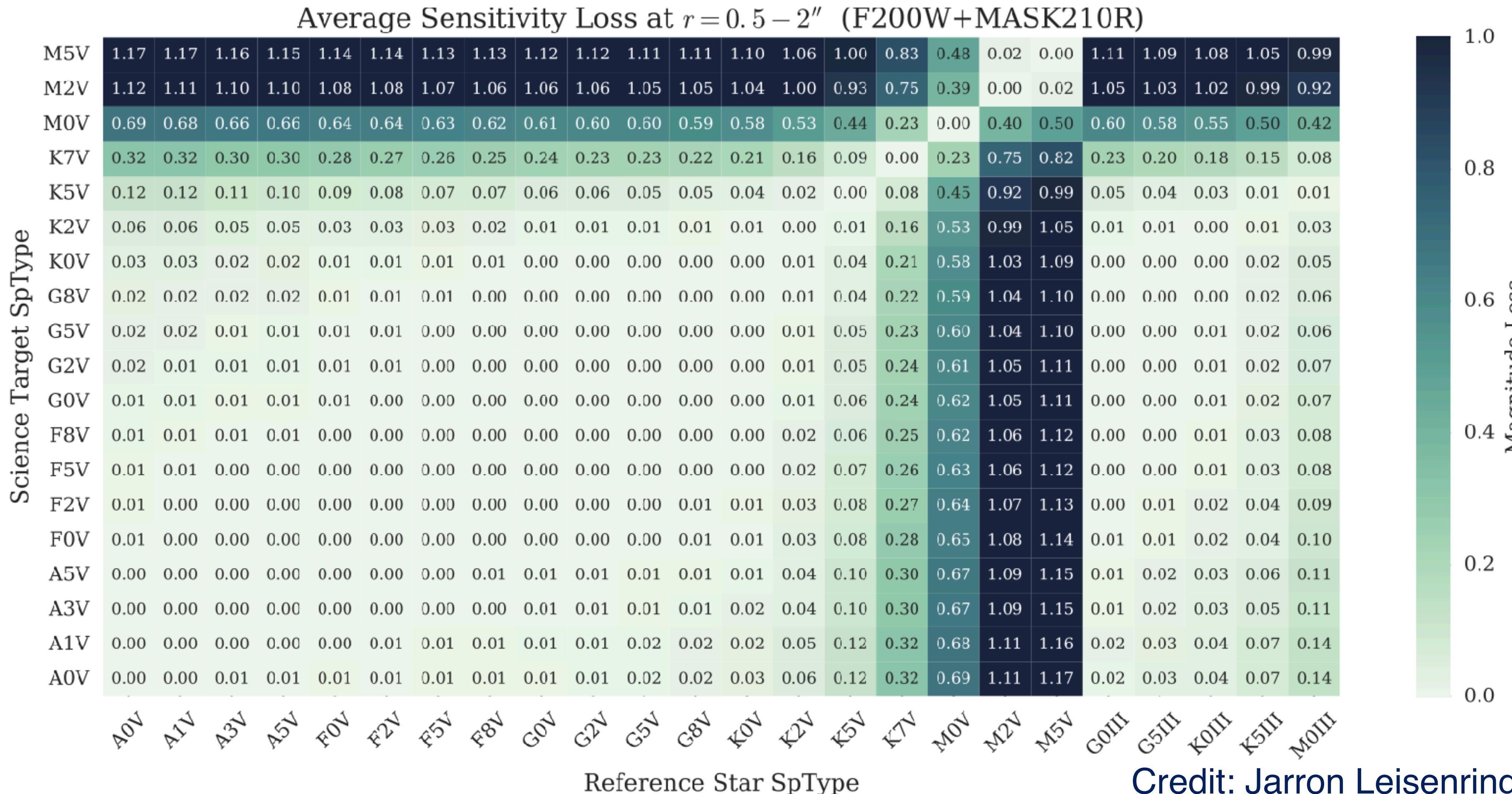
**jwst\_pancake**   Hopefully no longer passing NaN pixels into libraries that don't like...   4 months ago

**notebooks**   Hopefully no longer passing NaN pixels into libraries that don't like...   4 months ago

<https://github.com/spacetelescope/pandeia-coronagraphy>



# Selecting a PSF Reference Star (avoid spectral mismatch)



Credit: Jarron Leisenring (pyNRC)

More critical at shorter wavelengths (NIRCam), not critical for MIRI



# Jupyter Hub Server for the Master Class

<https://jwst-masterclass.science.stsci.edu>

A screenshot of a web browser window titled "JupyterHub". The address bar shows the URL "https://jwst-masterclass.science.stsci.edu/hub/spawn/jgirard@stsci.edu?next=%2Fhub%2F". The main content area is titled "Spawner Options" and contains a single option "JWST Master Class" with a blue radio button next to it. Below this is a large orange button labeled "Spawn".

Spawner Options

JWST Master Class

Spawn

May take a few minutes to load



# Jupyter Hub: Launcher

The screenshot shows the Jupyter Hub Launcher interface. At the top, there's a header bar with a purple background. Below it is a grid of icons representing different kernel environments and tools. A red border highlights the top section of the launcher.

- Python 3**: Standard Python 3 kernel icon.
- Coronagraphic Visibility Tool**: Specialized Python kernel icon.
- desktop**: Python desktop environment icon.
- JWST Mast...**: JWST Mission Control Python kernel icon.
- MIRaGe**: MIRaGe Python kernel icon.

A blue button labeled **>\_ Console** is located below these icons.

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- Python 3**: Standard Python 3 kernel icon.
- Coronagraphic Visibility Tool**: Specialized Python kernel icon.
- JWST Mast...**: JWST Mission Control Python kernel icon.
- MIRaGe**: MIRaGe Python kernel icon.

A section labeled **Other** contains two icons:

- Terminal**: Terminal icon.
- Text File**: Text file icon.

[https://jwst-  
masterclass.science.  
stsci.edu](https://jwst-masterclass.science.stsci.edu)



# Jupyter Hub: “on-the-fly” calculations with PanCAKE

## Pandeia/WebbPSF & Small Grid dithers (SGD)

The screenshot shows a JupyterLab interface with the following details:

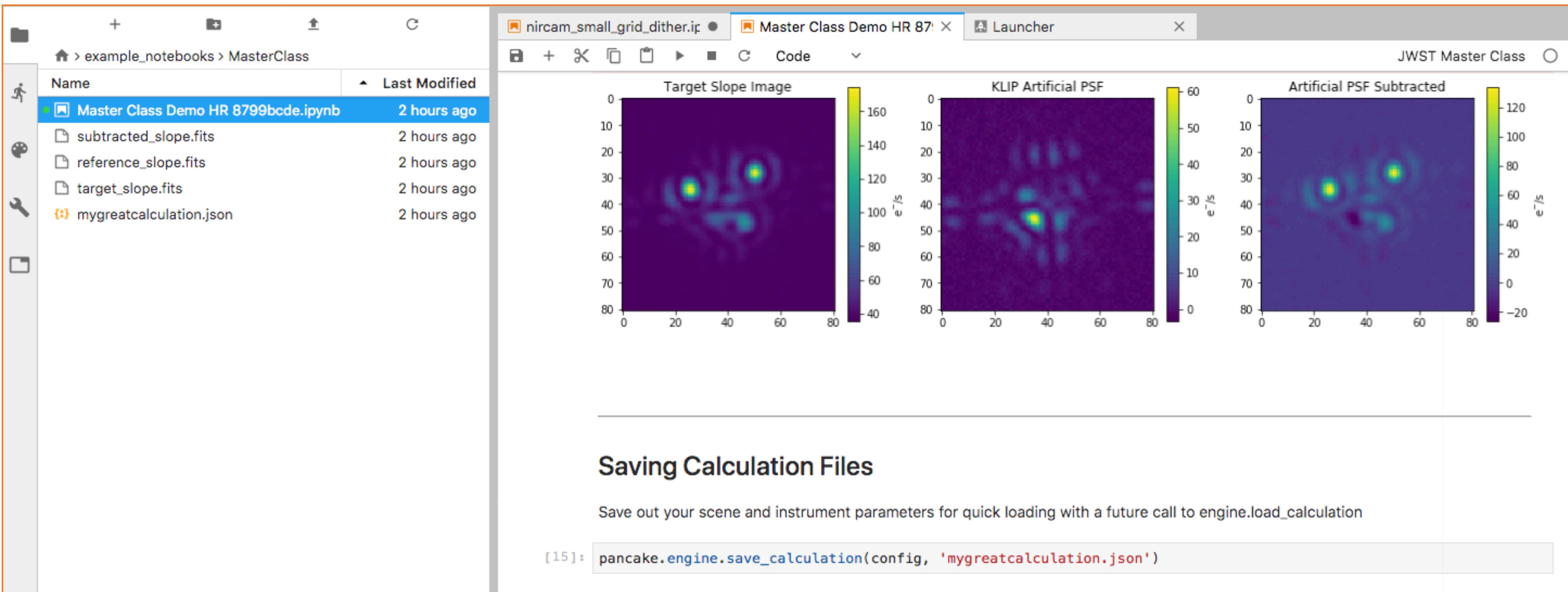
- Header:** JupyterLab, URL: https://jwst-masterclass.science.stsci.edu/user/jgirard@stsci.edu/lab?
- File Menu:** File, Edit, View, Run, Kernel, Hub, Tabs, Settings, Help.
- Launcher Tab:** Shows two open notebooks: "nircam\_pandeia\_pancake.ipynb" and "nircam\_small\_grid\_dither.ipynb".
- Left Sidebar:** Shows a file tree under "example\_notebooks" containing several Jupyter notebooks, with "nircam\_small\_grid\_dither.ipynb" highlighted in blue.
- Right Notebook Content:** Displays two heatmaps side-by-side. The left heatmap is titled "11 Wavelength Bins" and the right one is titled "51 Wavelength Bins". Both plots show a central bright region with a color scale from 0 to 50. The x and y axes for both plots range from 0 to 100.
- Bottom Status Bar:** JWST Master Class.

<https://jwst-masterclass.science.stsci.edu>



# Jupyter Hub: JWST Master Class PanCAKE notebook

## NIRCam and MIRI Coronagraphy of HR 8799 bcde



<https://jwst-masterclass.science.stsci.edu>