



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**

Julien Girard & Bryony Nickson

Master Class - Level 2 - Nov 19th & 20th 2019 - STScI



ETC for Coronagraphy: PSF subtraction from a reference star

Exposure Time Calculator

Simple planet D1 case

Today is a nice day

Calculations Scores and Sources Upload Spectra Constraints and Limitations

ID	Plot	Mode	Scene	(s)	SNR	
11	<input checked="" type="checkbox"/>	nircam coronagraphy	2	408.24	98.74	<input checked="" type="checkbox"/>
10	<input checked="" type="checkbox"/>	nircam coronagraphy	2	268.06	93.65	<input checked="" type="checkbox"/>
9	<input checked="" type="checkbox"/>	nircam coronagraphy	2	306.93	87.94	<input checked="" type="checkbox"/>
8	<input checked="" type="checkbox"/>	nircam coronagraphy	2	266.77	81.47	<input checked="" type="checkbox"/>
7	<input checked="" type="checkbox"/>	nircam coronagraphy	2	204.52	73.97	<input checked="" type="checkbox"/>
6	<input checked="" type="checkbox"/>	nircam coronagraphy	2	153.46	65.07	<input checked="" type="checkbox"/>
5	<input checked="" type="checkbox"/>	nircam coronagraphy	2	102.31	53.99	<input checked="" type="checkbox"/>
4	<input checked="" type="checkbox"/>	nircam coronagraphy	2	51.15	38.82	<input checked="" type="checkbox"/>
3	<input checked="" type="checkbox"/>	nircam coronagraphy	2	51.15	38.82	<input checked="" type="checkbox"/>
1	<input checked="" type="checkbox"/>	nircam target_mask	2	1.88	37.22	<input checked="" type="checkbox"/>

Images

Calculation selected: 10, Mode: nircam coronagraphy

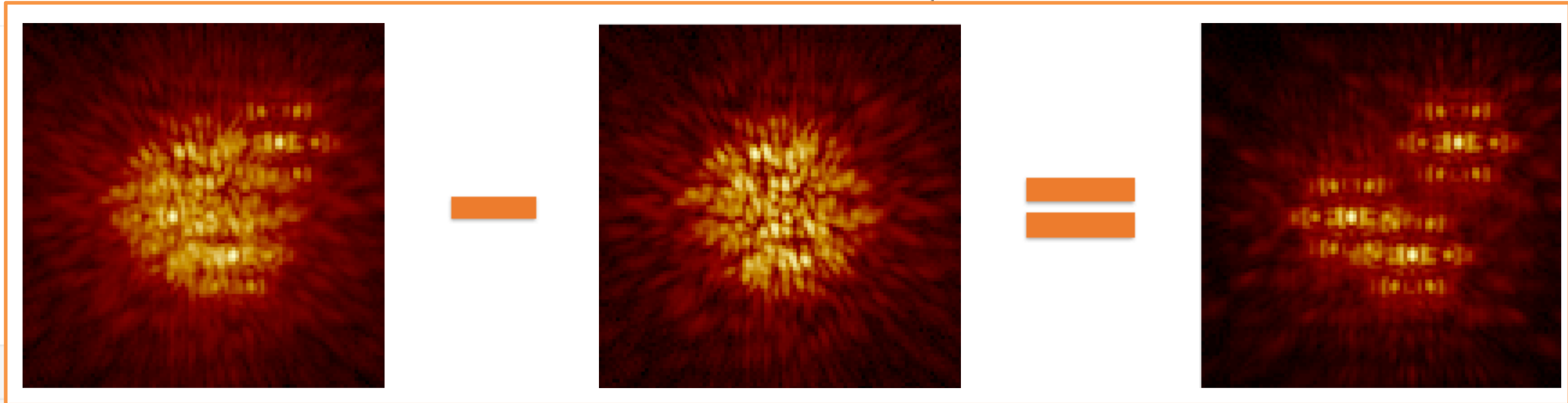
2D SNR Detector Saturation

Plots

ApFlux ApBackground

Seconds	SNR
0	38
50	40
100	55
150	65
200	75
250	82
300	88
350	95
400	100

Instrument Filter/Dispenser: F955m/null
Extraction Aperture Position (arcsec): (1.73, 0.00)
Wavelength of interest used to Calculate Scalar Values (microns): 3.35
Size of Extraction Aperture (arcsec): 0.08
Total Time Required for Strategy (seconds): 716.16
Total Exposure Time (seconds): 358.06
Extracted Flux (e-/sec): 76.73
Standard Deviation in Extracted Flux (e-/sec): 0.82
Extracted Signal-to-Noise ratio: 80.65
Input Background Surface Brightness (MJy/sr): 0.14
Total Background Flux in Extraction Aperture (e-/sec): 60.56
Total Sky Background Flux in Extraction Aperture (e-/sec): 1.20
Fraction of Total Background due to Signal From Scene: 0.86
Average Number of Cosmic Rays per Frame: 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



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/spacetelescope/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

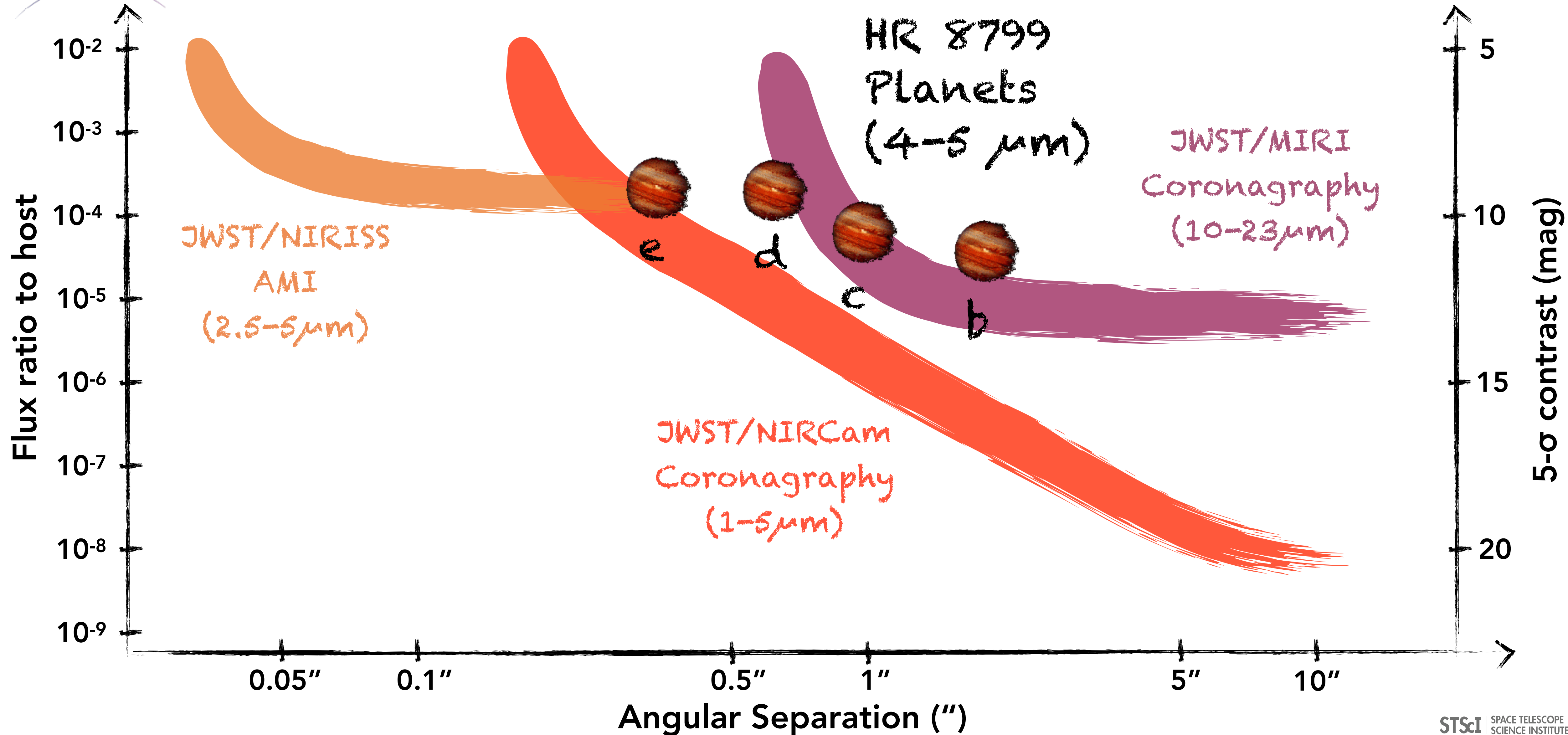
The ETC **cannot inject ring like features** or disks

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:

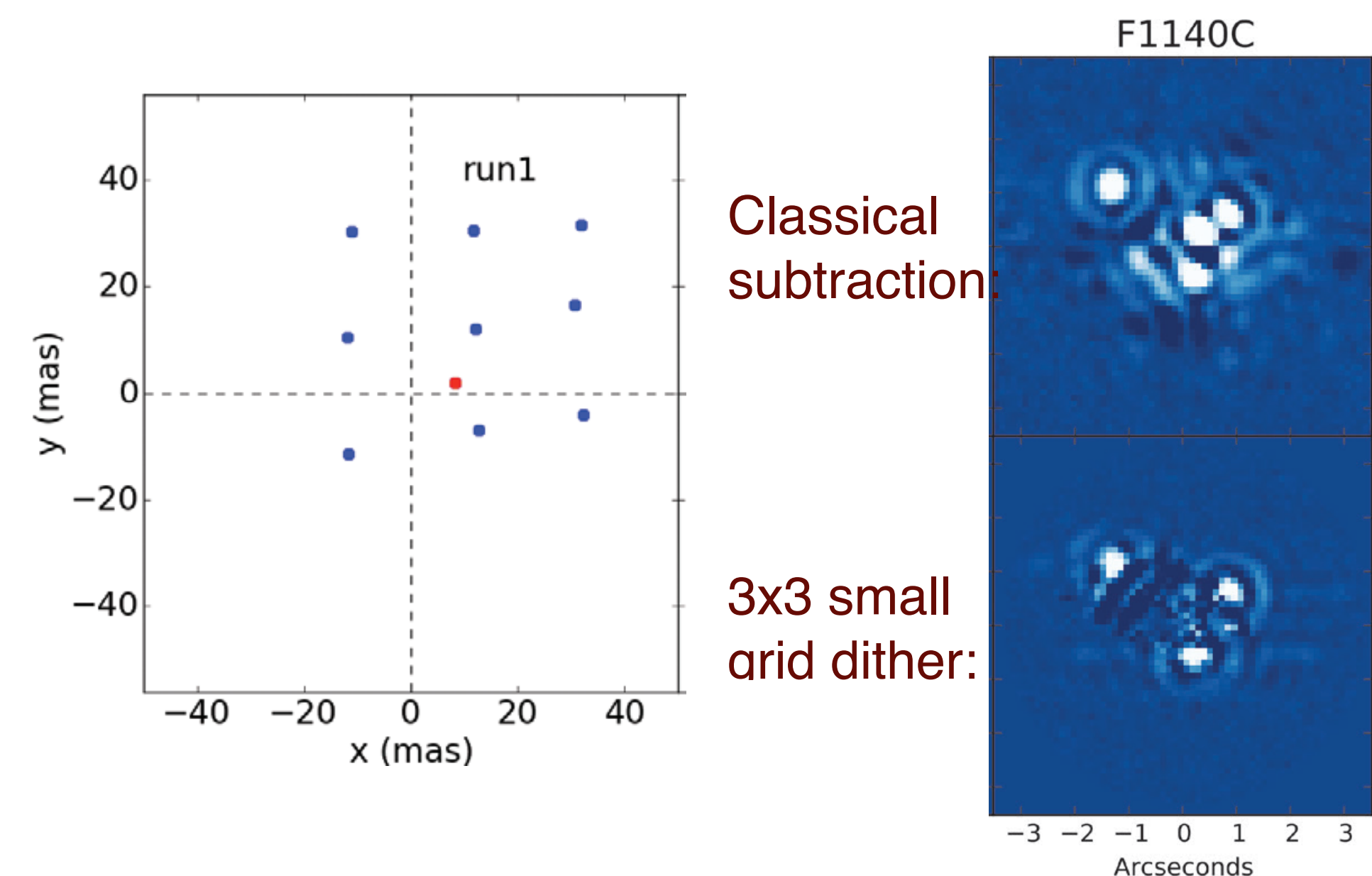
Perform sub pixel dithers of the PSF star to build mini PSF reference library, then synthesize an optimal PSF that matches the target position precisely. “Small Grid Dithers”.

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

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 NIRCcam Lyot coronas.

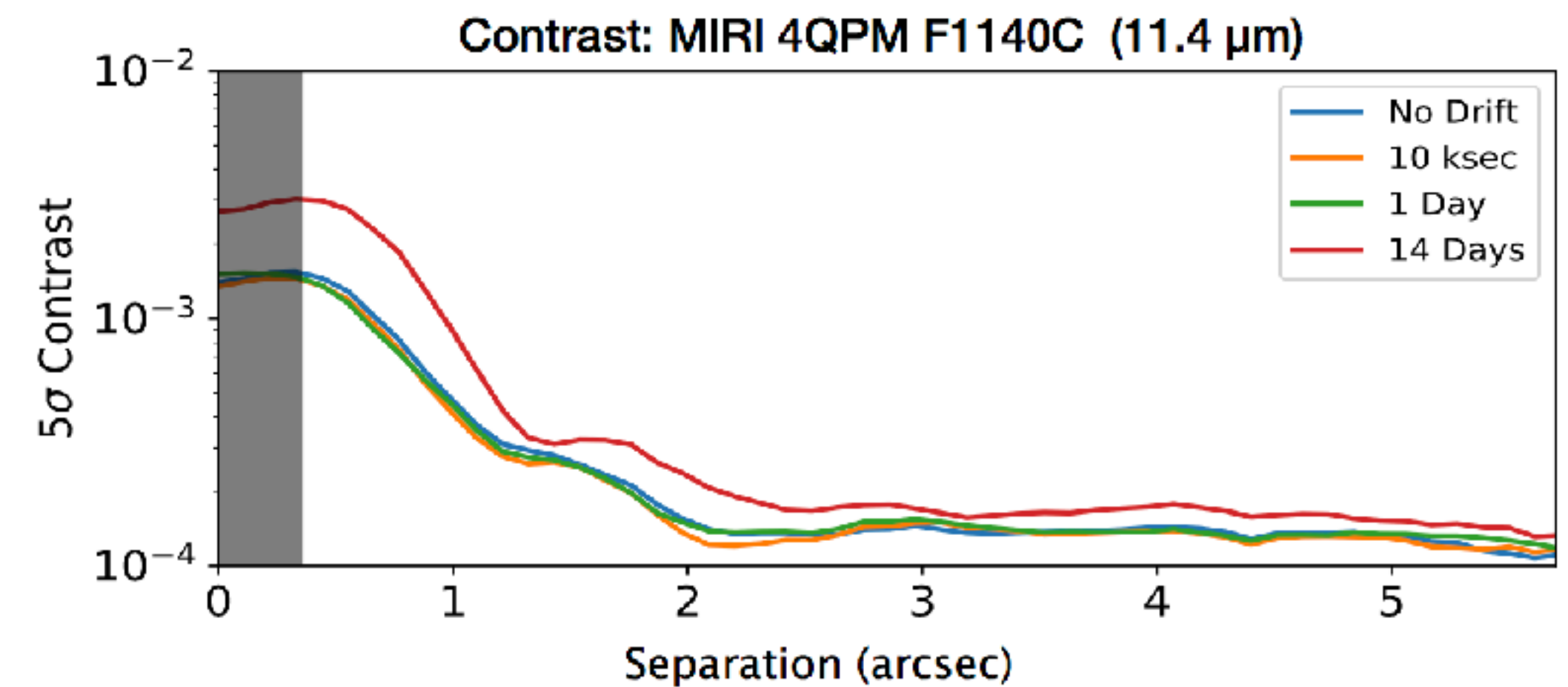
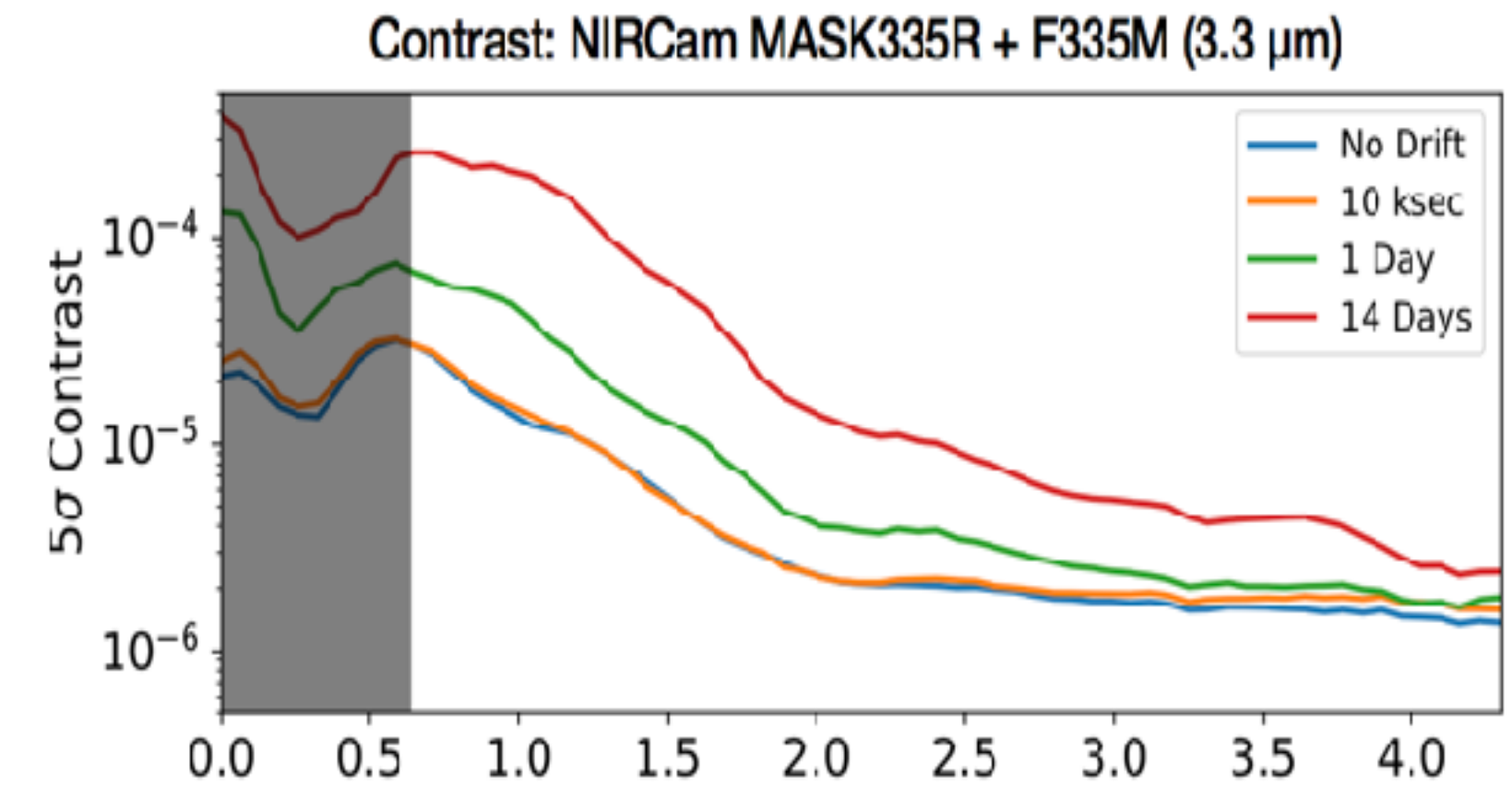
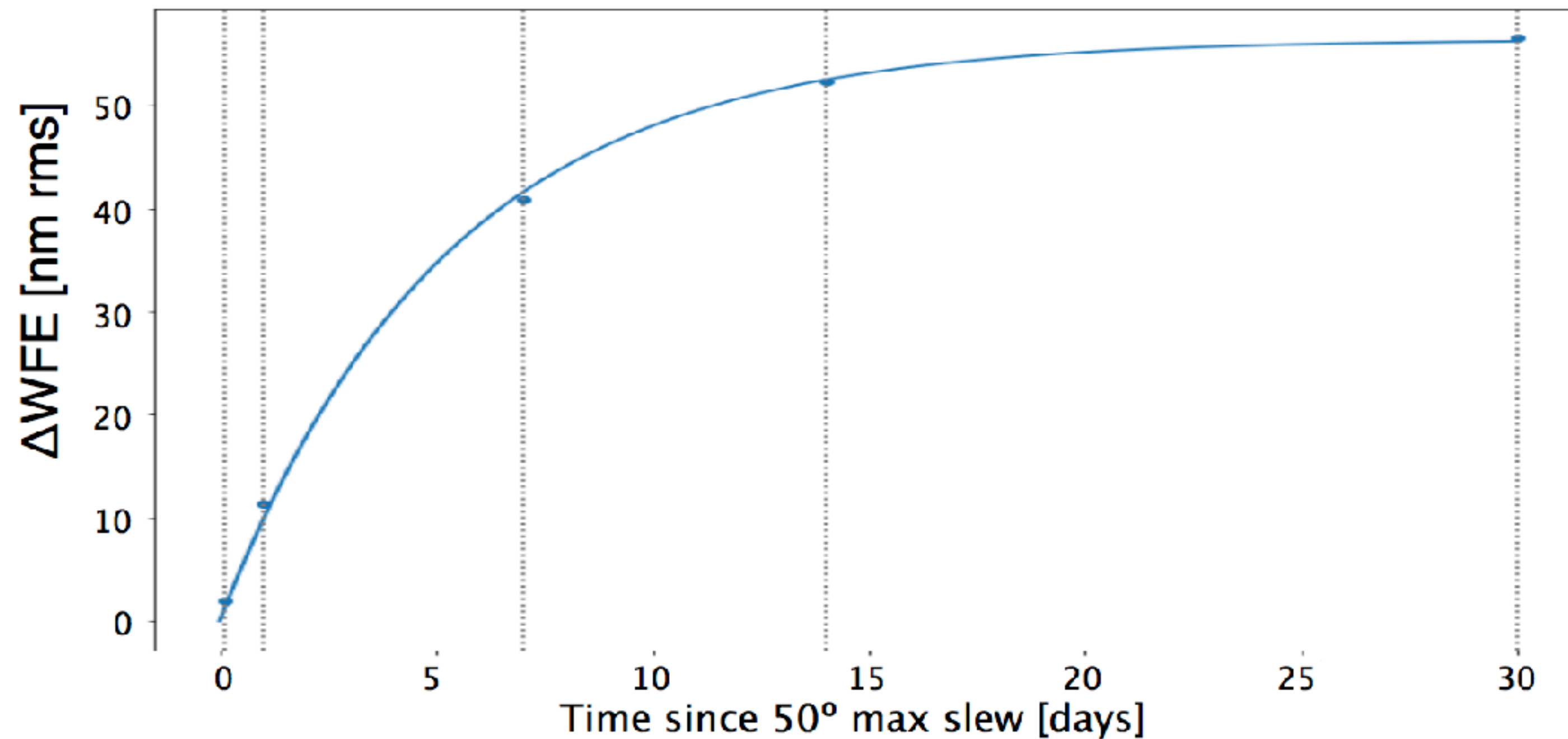


Simulated small grid dither PS subtraction
Lajoie et al. 2106



Towards the generation of realistic datasets : impact of slew

Model-predicted Δ WFE from maximum hot-to-cold slew



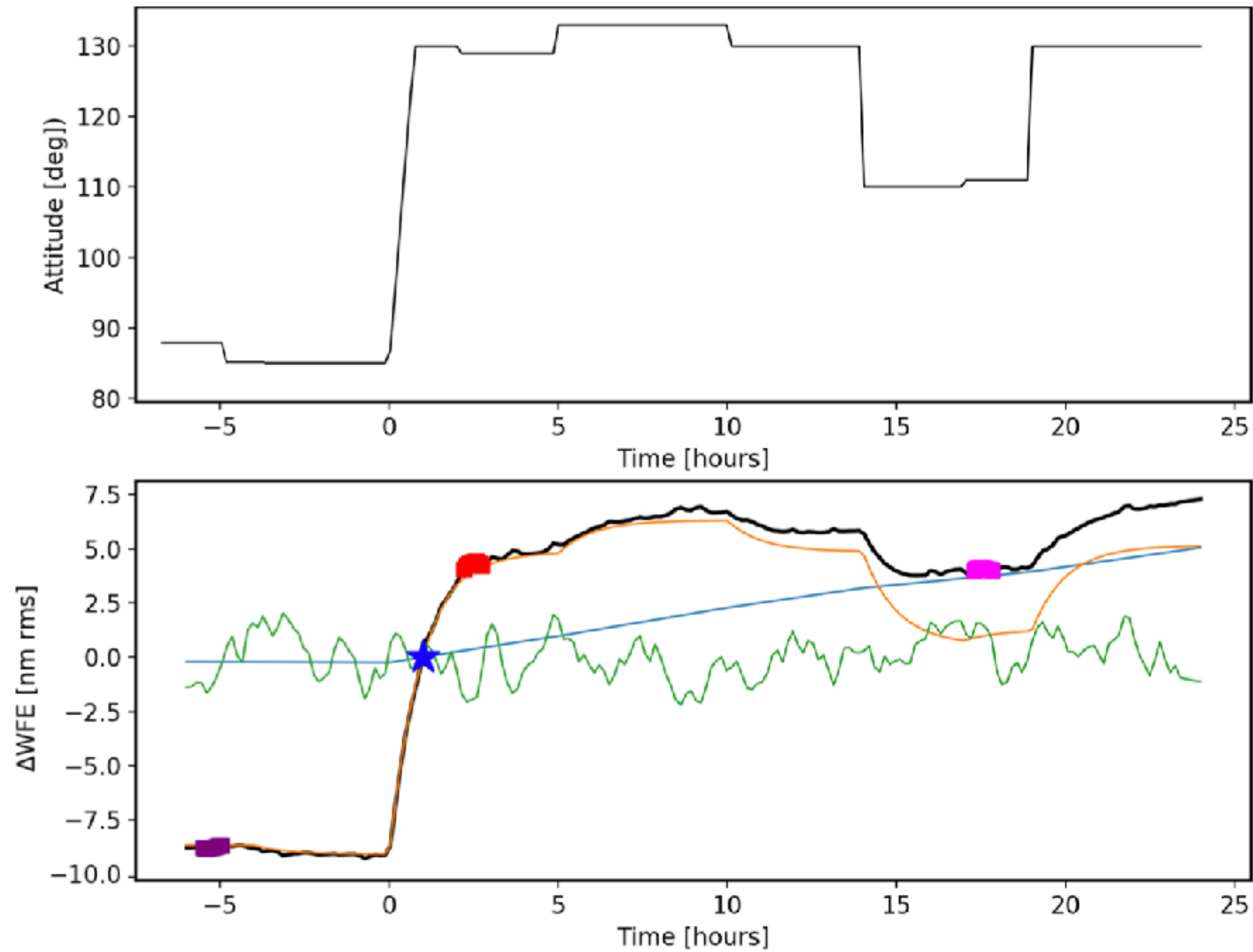
Perrin et al. SPIE 2018

Brooks et al. #AAS233

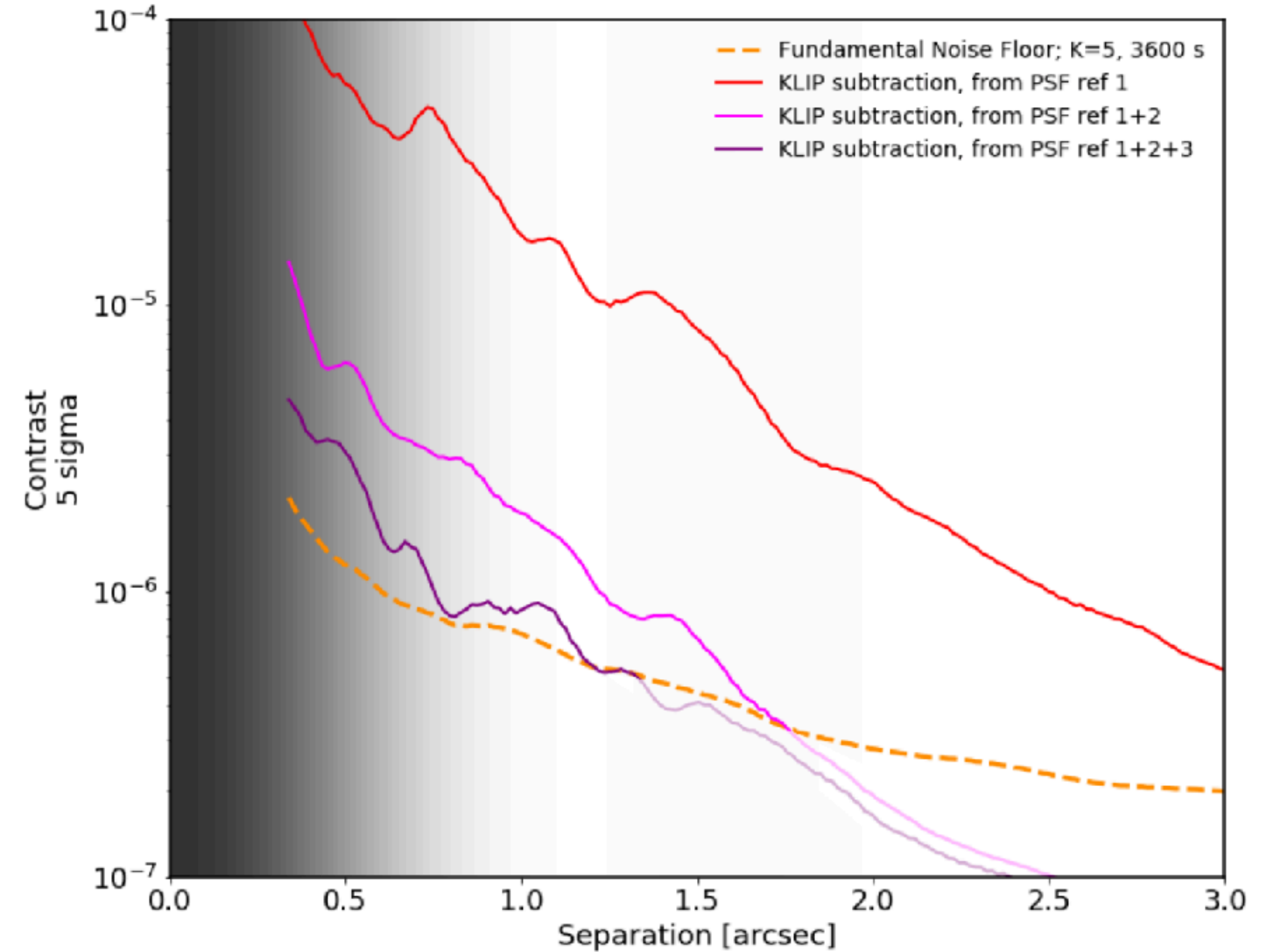


Towards the generation of realistic datasets : impact of slew

Hypothetical in-flight time series: observatory attitude and Δ WFE



Modeled Contrast after KLIP PSF subtraction



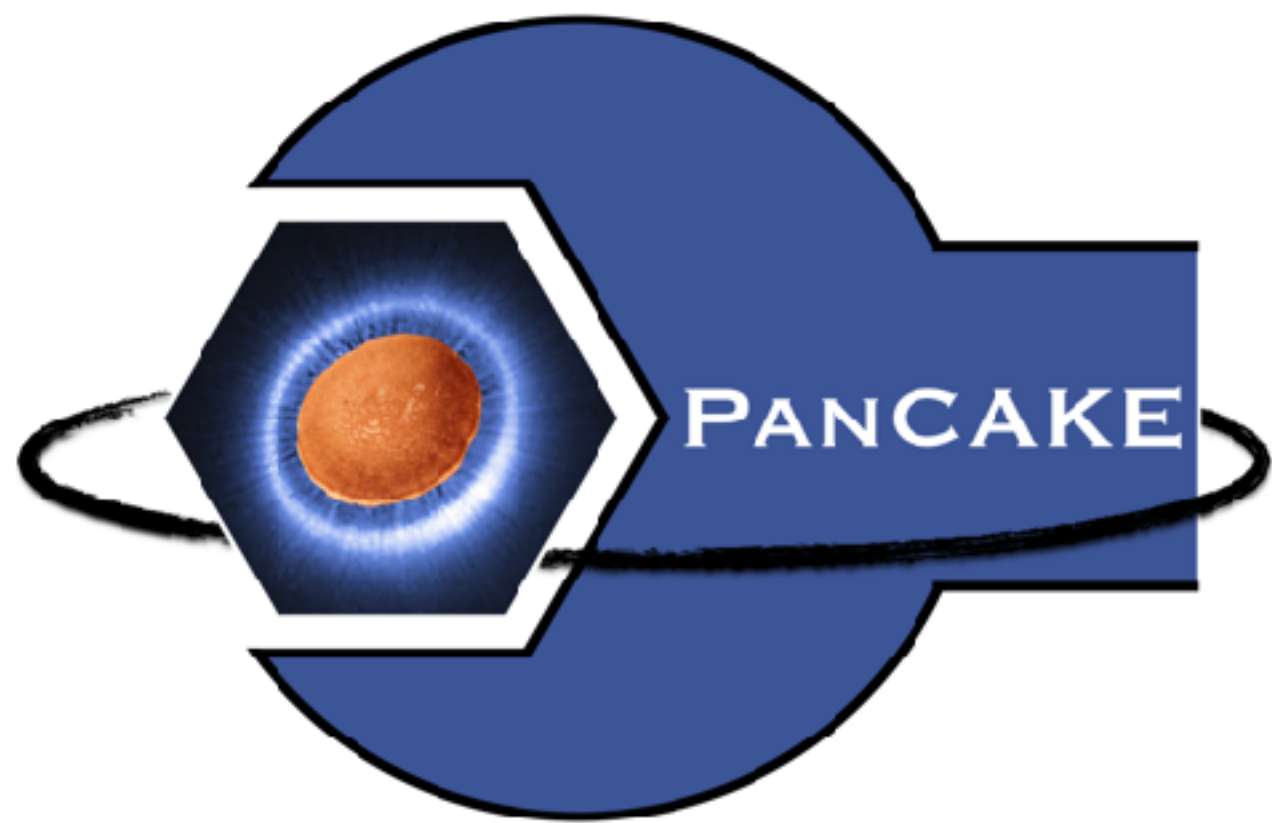
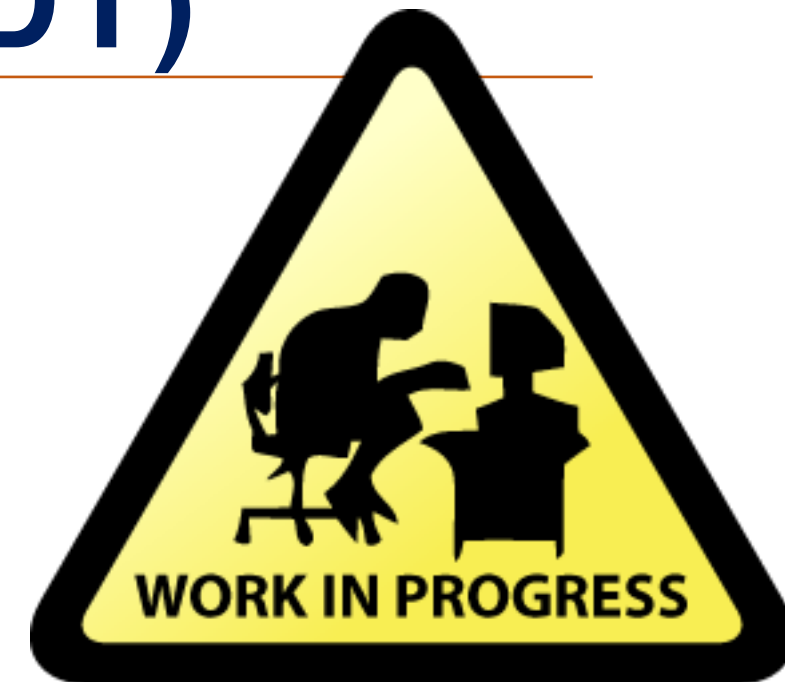
Perrin et al. SPIE 2018

Brooks et al. #AAS233



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

github.com/spacetelescope/pandemia-coronagraphy



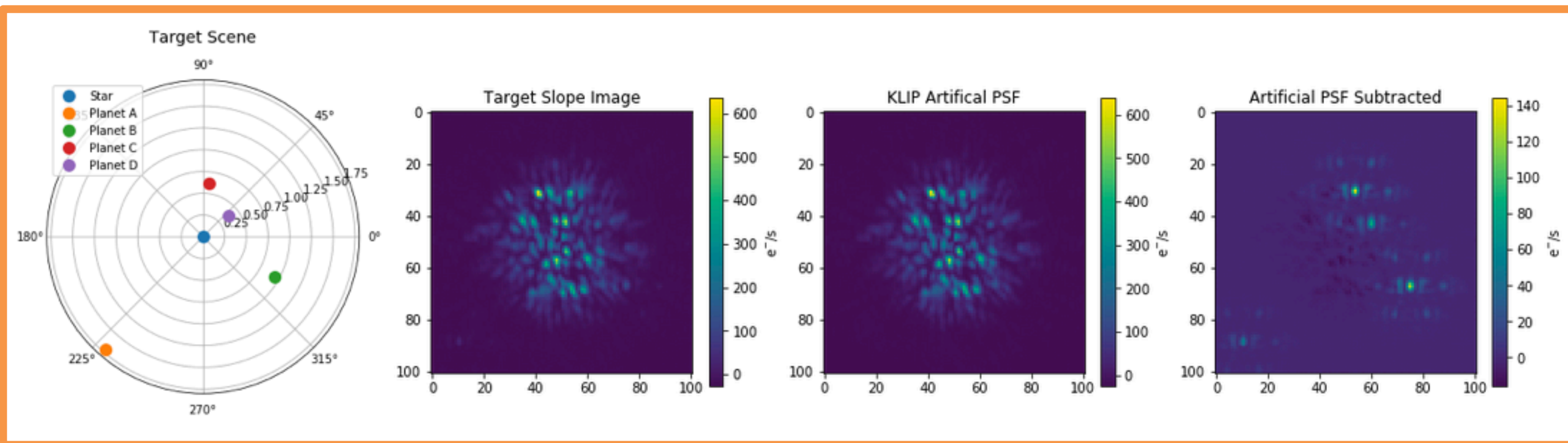
Can call WebbPSF “on the fly”

custom PSF grids/dithers, FoV, spectral sampling, more precise extractions

Several coronagraphic specific functions

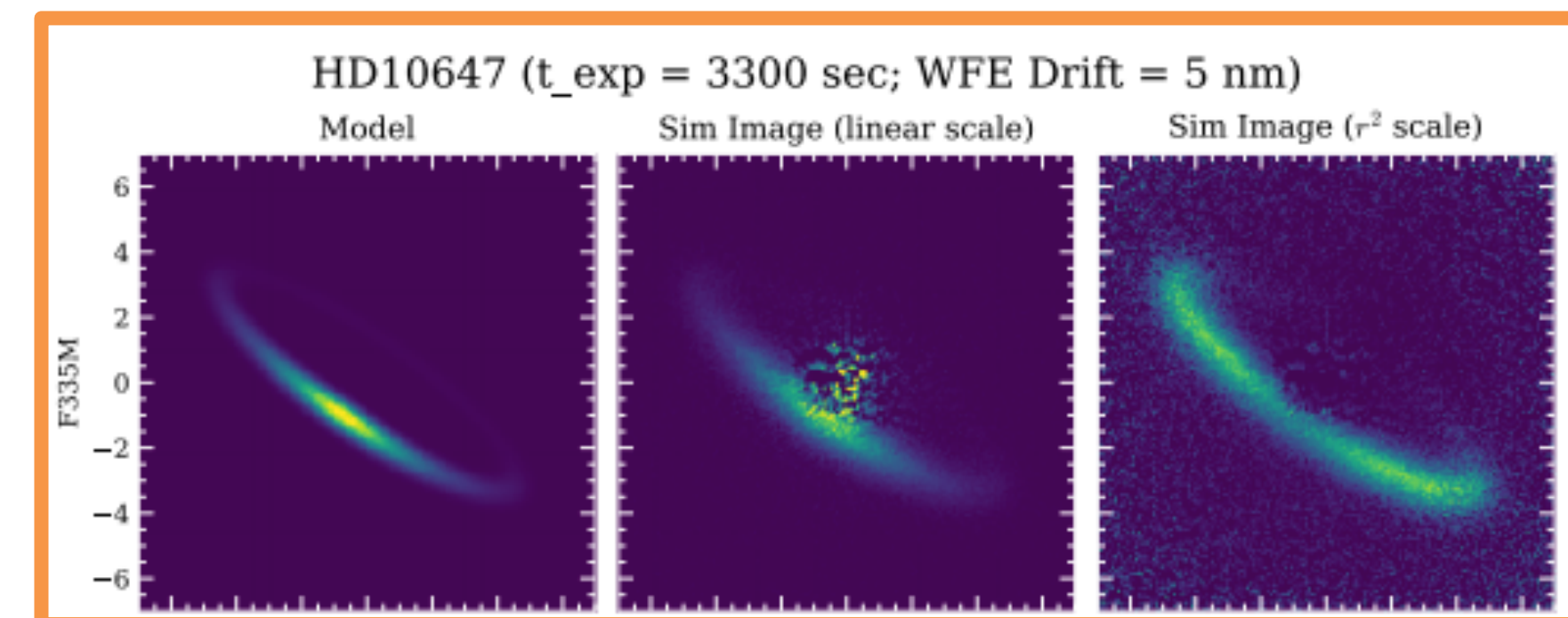
Contrast curves

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

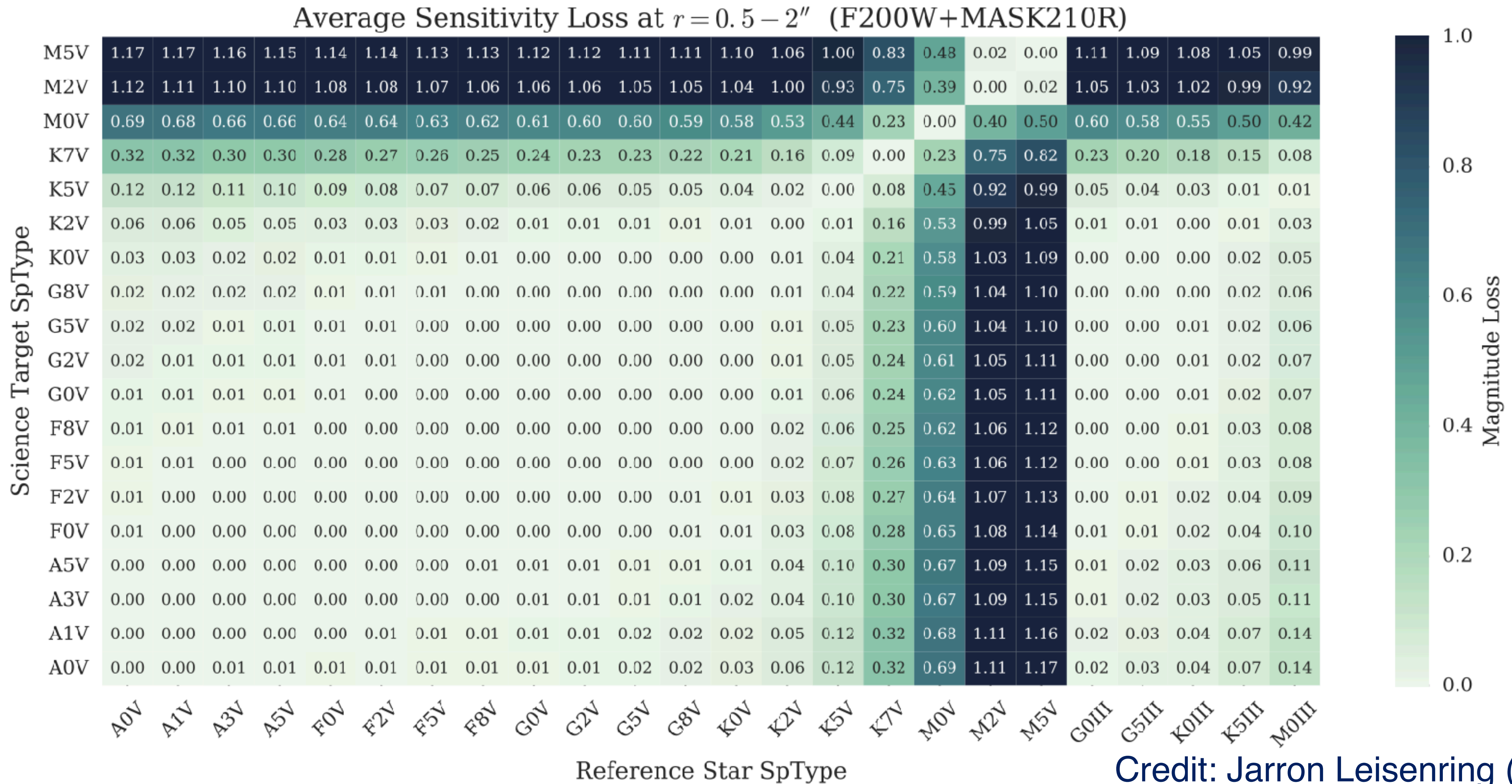
poemarkh Hopefully no longer passing NaN pixels into libraries that don't like... Latest commit 6b30b0b on Jul 10

folder jwst_pancake	Hopefully no longer passing NaN pixels into libraries that don't like...	4 months ago
folder 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)



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 showing the Jupyter Hub interface. The browser's address bar displays the URL: https://jwst-masterclass.science.stsci.edu/hub/spawn/jgirard@stsci.edu?next=%2Fhub%2F. The page title is 'jupyter' and the user is logged in as 'jgirard@stsci.edu'. The main content area is titled 'Spawner Options' and features a single radio button option labeled 'JWST Master Class'. Below this option is a large orange button labeled 'Spawn'. The browser's top bar shows the JupyterHub logo and a plus sign for additional tabs.

May take a few minutes to load



Jupyter Hub: Launcher

The screenshot displays the Jupyter Hub Launcher interface, which is organized into several sections:

- Top Row:** Five icons are shown. From left to right: Python 3 (Python logo), Coronagraphic Visibility Tool (Python logo), desktop (orange 'D'), JWST Mast... (Python logo), and MIRaGe (Python logo). A tooltip for the Coronagraphic Visibility Tool is visible below its icon.
- Console:** A section with a blue terminal icon and the text "Console".
- Middle Row:** Four icons are shown. From left to right: Python 3 (Python logo), Coronagraphic Visibility Tool (Python logo), JWST Mast... (Python logo), and MIRaGe (Python logo).
- Other:** A section with two icons: Terminal (black square with white '\$_') and Text File (teal document icon).

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



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

Pandeia/WebbPSF & Small Grid dithers (SGD)

JupyterLab

https://jwst-masterclass.science.stsci.edu/user/jgirard@stsci.edu/lab?

File Edit View Run Kernel Hub Tabs Settings Help

example_notebooks

Name	Last Modified
covariance_contrast.ipynb	a day ago
miri_pandeia_pancake.ipynb	a day ago
miri_photon_noise_and_contrast...	a day ago
miri_small_grid_dither.ipynb	a day ago
nircam_pandeia_pancake.ipynb	a day ago
nircam_photon_noise_and_contrast...	a day ago
nircam_small_grid_dither.ipynb	a day ago
stsci_pancake_installation.ipynb	a day ago

Launcher

nircam_pandeia_pancake_ X nircam_small_grid_dither.ip X

Markdown

JWST Master Class

11-point On-the-fly result completed in 249.1 seconds
51-point On-the-fly result completed in 165.6 seconds

11 Wavelength Bins

51 Wavelength Bins

e^-/s

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



Jupyter Hub: JWST Master Class PanCAKE notebook

NIRCam and MIRI Coronagraphy of HR 8799 bcde

The screenshot displays a Jupyter Notebook interface. On the left is a file browser showing a directory structure: `example_notebooks > MasterClass`. The files listed are:

Name	Last Modified
Master Class Demo HR 8799bcde.ipynb	2 hours ago
subtracted_slope.fits	2 hours ago
reference_slope.fits	2 hours ago
target_slope.fits	2 hours ago
mygreatcalculation.json	2 hours ago

The main area shows a code cell with three plots and a code snippet:

Target Slope Image: A 2D plot showing intensity in e^-/s (color scale 40 to 160) over a spatial range of 0 to 80 on both axes. It displays a complex pattern of bright spots and structures.

KLIP Artificial PSF: A 2D plot showing intensity in e^-/s (color scale 0 to 60) over a spatial range of 0 to 80 on both axes. It shows a similar pattern to the target slope image but with a different intensity scale.

Artificial PSF Subtracted: A 2D plot showing intensity in e^-/s (color scale -20 to 120) over a spatial range of 0 to 80 on both axes. It shows the result of subtracting the artificial PSF from the target slope image.

Saving Calculation Files

Save out your scene and instrument parameters for quick loading with a future call to `engine.load_calculation`

```
[15]: pancake.engine.save_calculation(config, 'mygreatcalculation.json')
```

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