STScI | SPACE TELESCOPE SCIENCE INSTITUTE

Preparing a JWST coronagraph proposal.

Laurent Pueyo (STScI)
for the JWST Coronagraphs Working Group

Mastering the Science Instruments and the observing modes of JWST. Sept 26 th- 28 th 2016

Overview of a JWST coronagraph program

- Science Use Cases.
- Exposure Time Calculator.
- Target Visibility.
- Standard Coronagraph Sequence.
- Astronomer Proposal Tool.
- After your observations have been taken.

List of Science Use cases and SODRM.

1. Characterization of a known planet.

This use-case corresponds to proposals to observe a previously discovered planet to characterize its atmosphere. Such observations will likely desire multiple filters and potentially both NIRCam and MIRI. Observations may also desire a full-frame imaging capability with the intent to perform astrometry on the planet.

TR JWST-STScI-004140 described two possible configurations of coronagraph sequences for these observations: one with interleaved filters and one in which the target and reference are observed sequentially for each filter.

target_1, MIRI, 4QPM, F1065, -5deg
target_1, MIRI, 4QPM, F1140, -5deg
target_1, MIRI, 4QPM, F1550, -5deg
target_1, MIRI, 4QPM, F1065, 5deg
target_1, MIRI, 4QPM, F1140, 5deg
target_1, MIRI, 4QPM, F1550, 5deg
PSF1, MIRI, 4QPM, F1065
PSF1, MIRI, 4QPM, F1140
PSF1, MIRI, 4QPM, F1550

These programs have been implemented in APT.

2. Characterization of a known disk.

This use-case corresponds to proposals to characterize known circumstellar disks. Observing programs for this use case may require multiple filters and instruments. Additionally, if observing with the NIRCam bar masks or MIRI 4QPMs, users may want to make a second set of observations at a large relative roll angle (~30° or more) to move the mask axes and recover the full astronomical scene. Given JWST's pointing constraints, obtaining relative roll angles ≳10° requires observing on multiple dates. TR JWST-STScI-004140 gives the following example coronagraphic sequence for MIRI:

target_1, MIRI, 4QPM, F1065, -5deg
target_1, MIRI, 4QPM, F1550, -5deg
target_1, MIRI, 4QPM, F1550, +5deg
target_1, MIRI, 4QPM, F1065, +5deg
PSF1, MIRI, 4QPM, F1065
PSF1, MIRI, 4QPM, F1550
--
target_1, MIRI, 4QPM, F1065, 40deg
target_1, MIRI, 4QPM, F1550, 40deg
target_1, MIRI, 4QPM, F1065, 50deg
target_1, MIRI, 4QPM, F1550, 50deg
PSF1, MIRI, 4QPM, F1065
PSF1, MIRI, 4QPM, F1550

Where each 6-observation coronagraphic sequence is non-interruptible, includes a roll dither, and observations at two filters.

List of Science Use cases and SODRM.

1. Characterization of a known planet.

This use-case corresponds to proposals to observe a previously discovered planet to characterize its atmosphere. Such observations will likely desire multiple filters and potentially both NIRCam and MIRI. Observations may also desire a full-frame imaging capability with the intent to perform astrometry on the planet.

TR JWST-STScI-004140 described two possible configurations of coronagraph sequences for these observations: one with interleaved filters and one in which the target and reference are observed sequentially for each filter.

Target	Reference
HR 8799	28-PEG
Fomalhaut	V-V-PSA
Beta Pic	DEL-DOR
GQ Lup	IRAS-15443-3521
2MASSWJ1207334-393254	2MASS-J12505265-2121136
1RXS J160929.1-210524	2MASS-J16014743-2049457
UScoCTIO108	2MASS-J16084744-2235477
CT Cha	V-VW-CHA

These programs have been implemented in APT.

Mastering the Science Instruments and the observing modes of JW

2. Characterization of a known disk.

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target 1, MIRI, 4QPM, F1065, -5deg

Target	Reference
HD 141569	49 Cet
HR 4796A	U Cen
HR 32297	HD 33403
Fomalhaut	Alf Lyr
Beta Pic	Alf Pic
HD 15745	HD 20499
HD 15115	HR 783
HD 181327	HR 7297
HD 139664	HD 99353
HD 10647	Alf Boo
HD 107146	HD 120066
HD 61005	HD 65161
HD 92945	HD 89585
AU Mic	HD 191849

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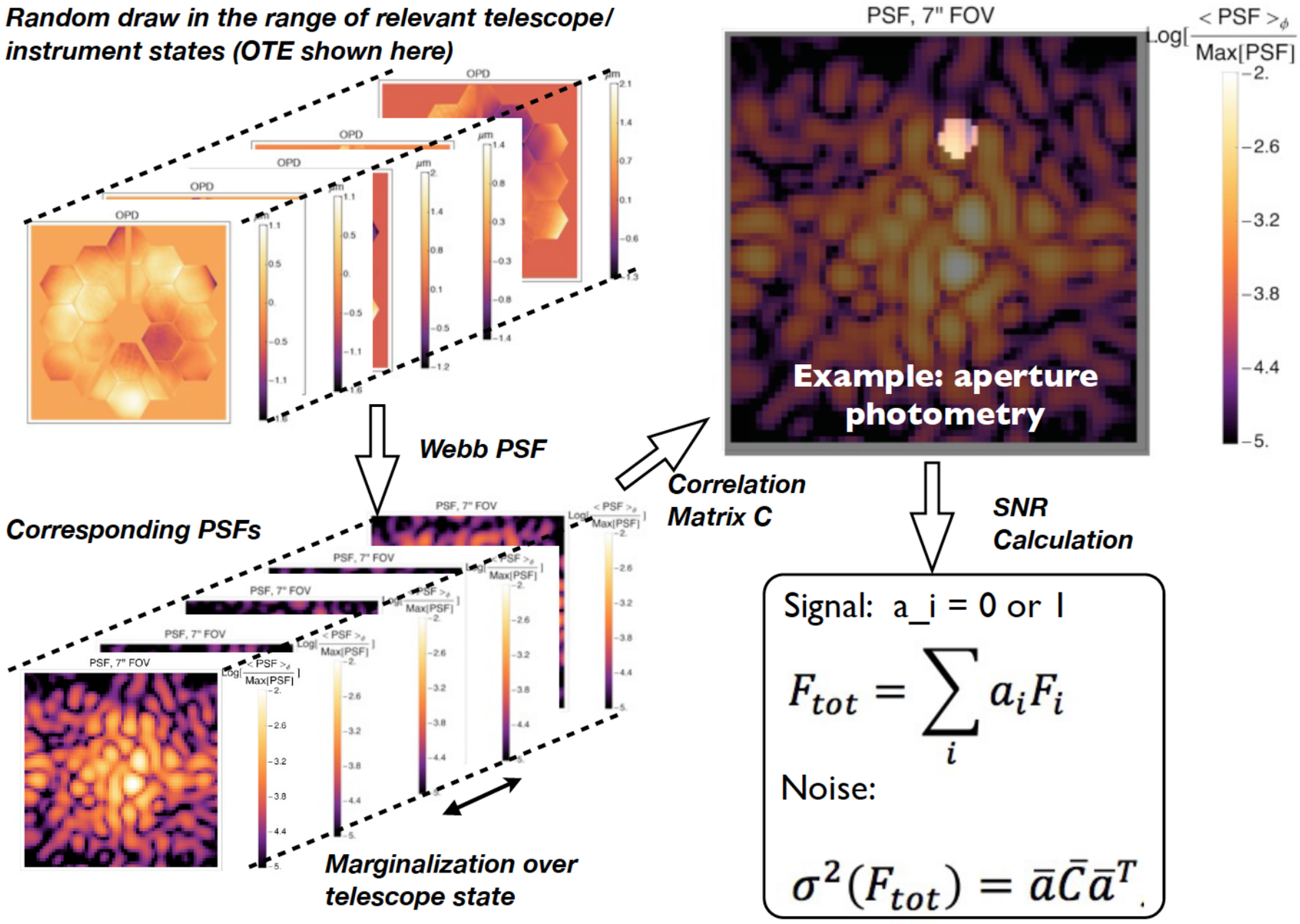
ETC Engine for coronagraphy

Calculation based on multiple realizations of the noise to assemble covariance matrices.



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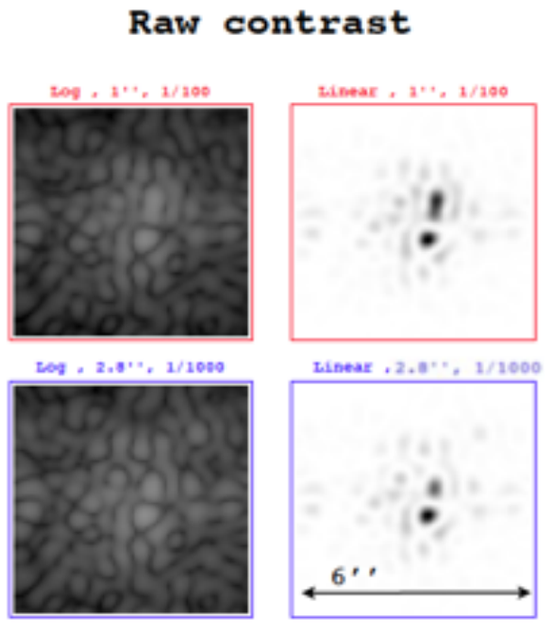
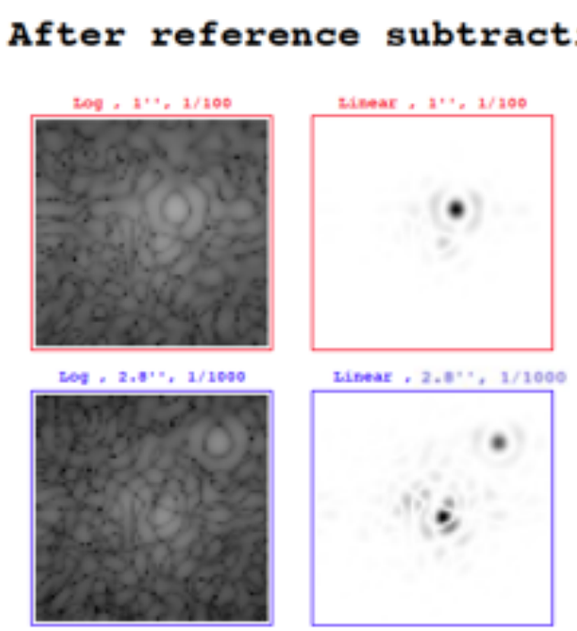
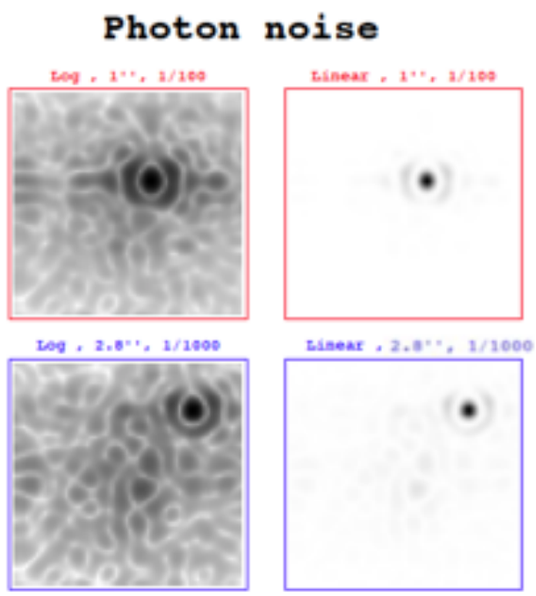
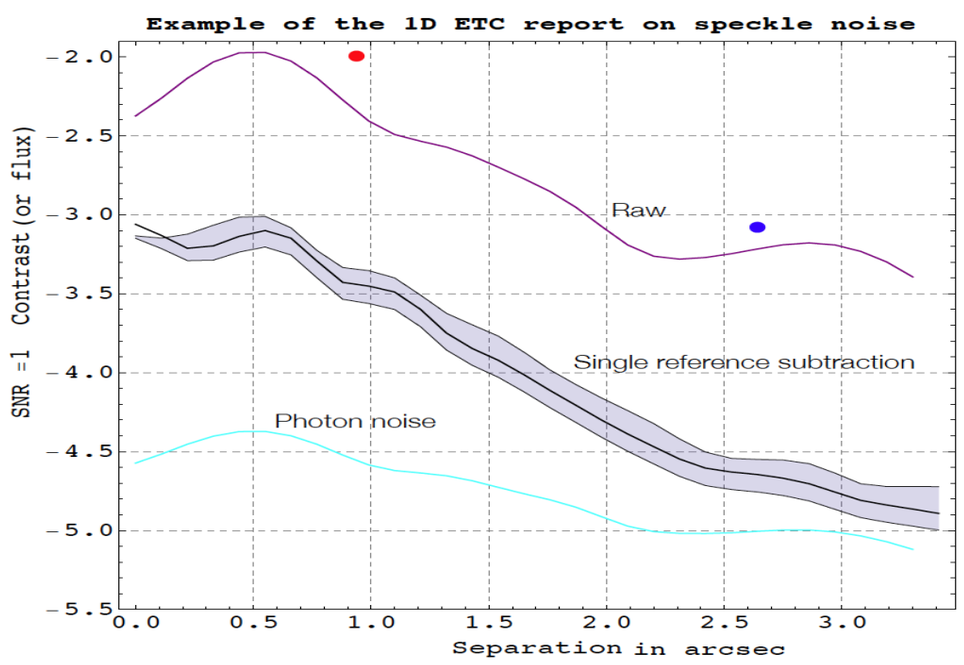
ETC Engine for coronagraphy

ETC will calculate three levels of contrast for a given observation.









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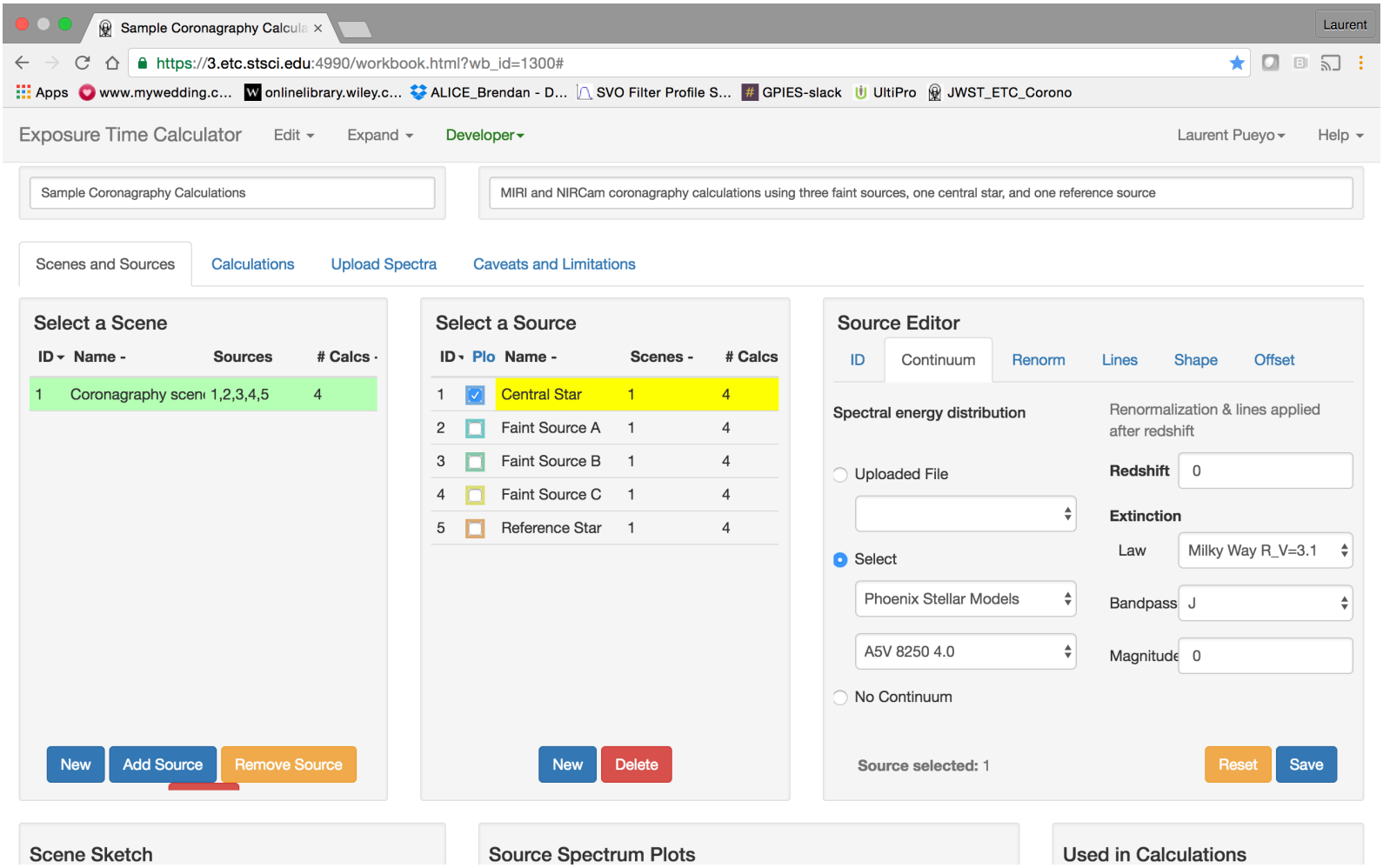
ETC demo

Foreword:

- This is a semi-stable development version of ETC.
- Only "optimal" PSF subtraction is operational so far, however all the machinery is in place for the two other configurations.
- Quantitive verification of ETC for coronagraphy has not occurred yet.


Sample Coronagraphy Calcula
Laurent
https://3.etc.stsci.edu:4990/workbook.html?wb_id=1300#
Apps
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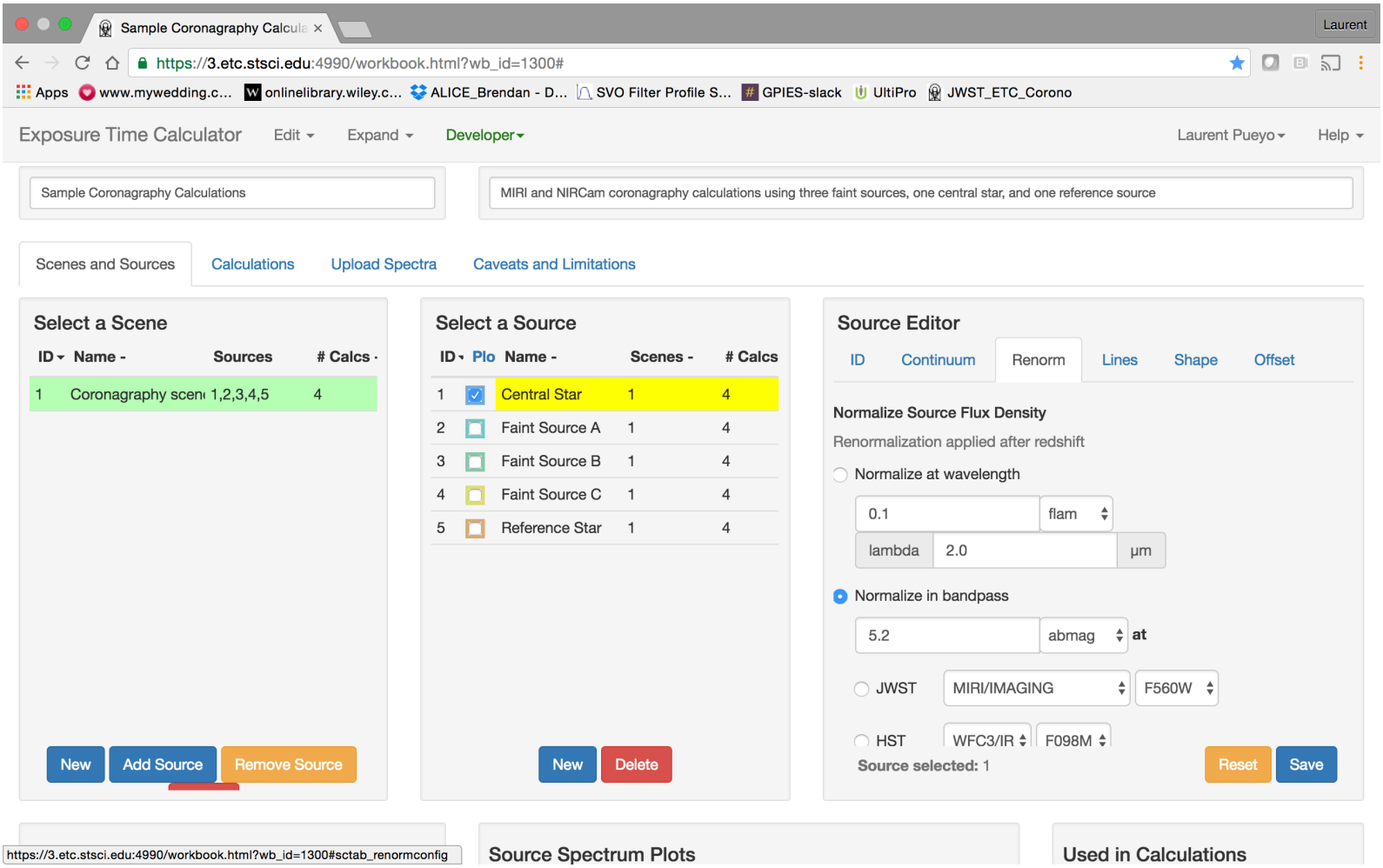
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Source Spectrum Plots
Used in Calculations

Sample Coronagraphy Calcula ×

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Exposure Time Calculator Edit Expand Developer Laurent Pueyo Help

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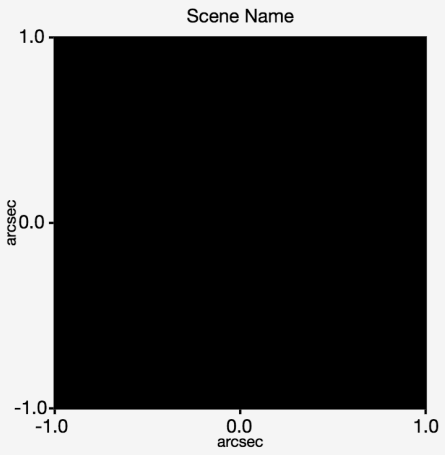
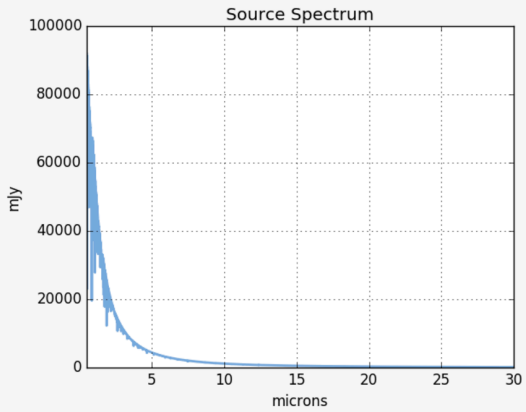
Scene Sketch



Show source outlines

Source Spectrum Plots



Spectra Plot

Bounds/Scale:

X: min max Linear Clear

Y: min max Linear Clear

Used in Calculations

ID	Name	Scene
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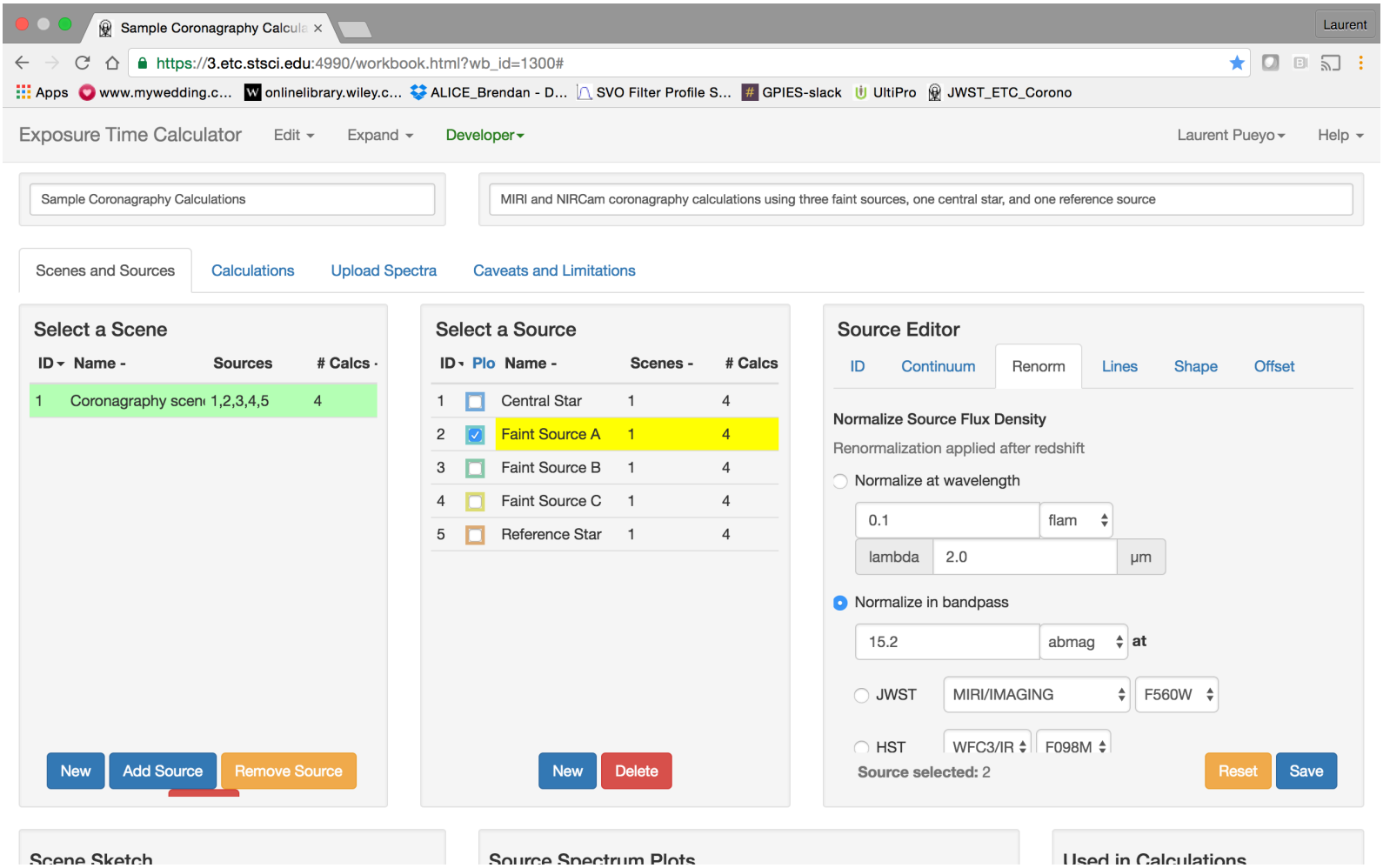
5	nircam_coronagraph	1
6	miri_coronagraphy	1
7	nircam_coronagraph	1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Scenes and Sources | Calculations | Upload Spectra | Caveats and Limitations

MIRI NIRCam NIRISS NIRSpec

ID	Plot	Mode	Scene	(s)	SNR	⚠
7	☐	nircam coronagraphy	1	12.00	14.03	✓
6	☐	miri coronagraphy	1	4.56	161.18	✓
5	☐	nircam coronagraphy	1	32.40	270.25	!
2	☑	miri coronagraphy	1	22.78	732.12	✓
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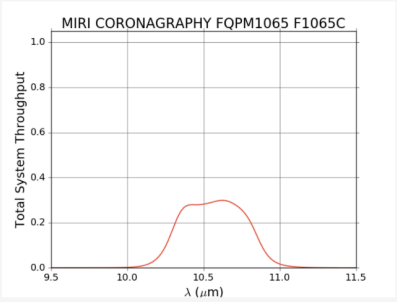
Scene ★ | Backgrounds | Instrument Setup | Detector Setup | Strategy

MIRI Coronagraphy

Coronagraph

FQPM F1065C



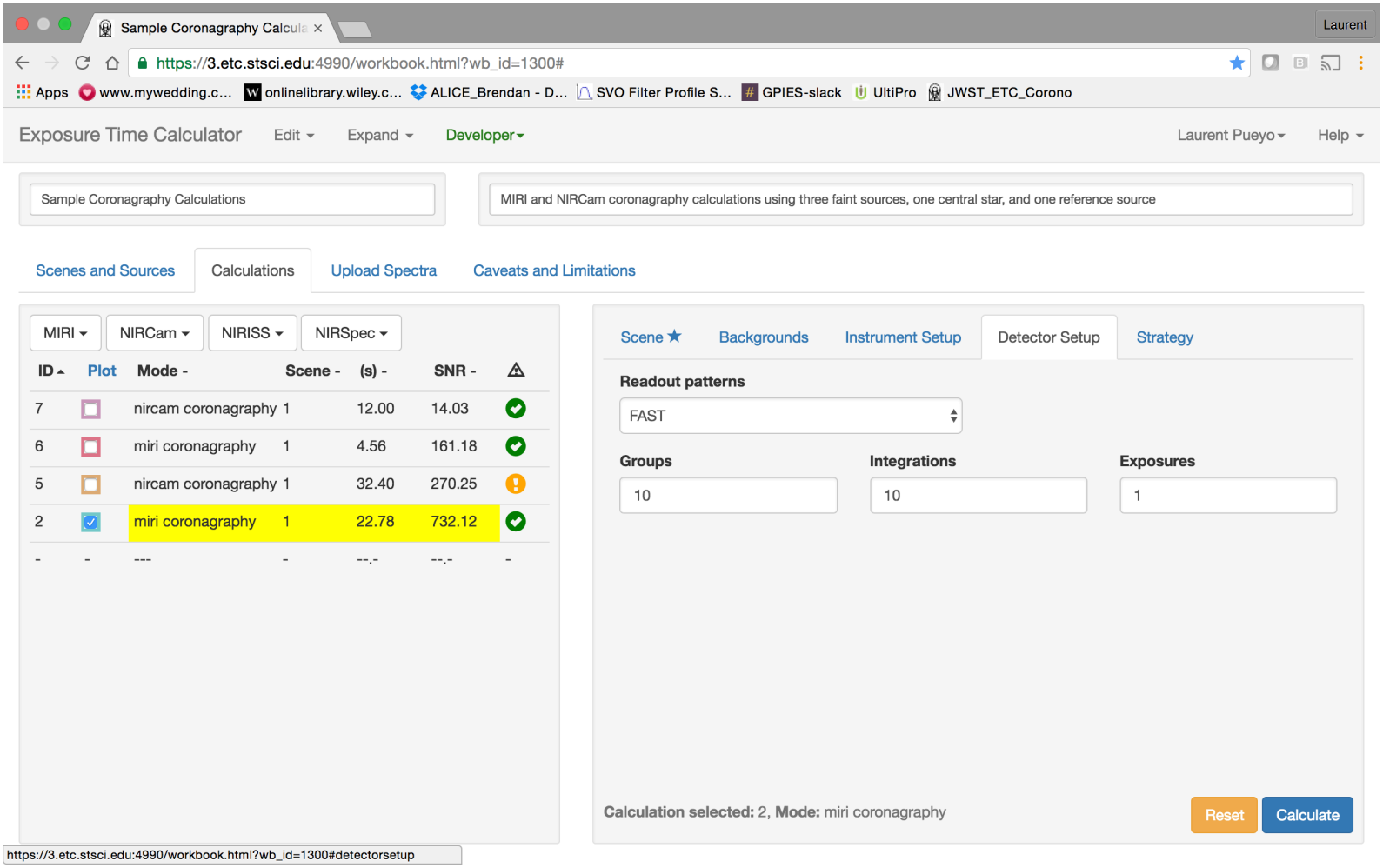
Calculation selected: 2, **Mode:** miri coronagraphy

Reset Calculate

Images

Plots

Reports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Detector Setup
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Sample Coronagraphy Calcula ×

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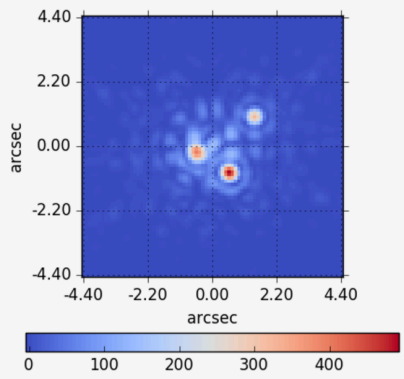
Exposure Time Calculator Edit Expand Developer Laurent Pueyo Help

Reset Calculate

Images

Calculation selected: 2, **Mode:** miri coronagraphy

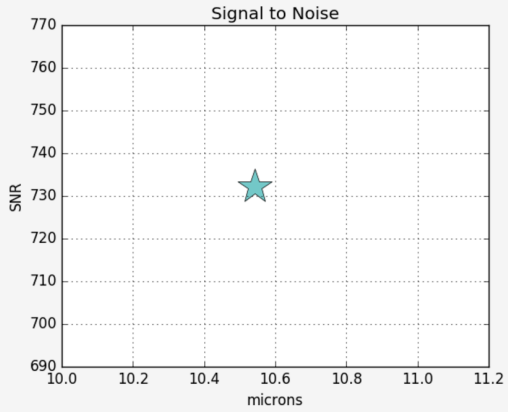
2D SNR | Detector | Saturation



2D SNR Image

Plots

ApFlux | ApBackground | SNR | SNR (time) | Contrast



SNR Line Plot

Bounds/Scale:

X: min max Linear Clear

Reports

Calculation selected: 2, **Mode:** miri coronagraphy

Report | Warnings | Errors

Downloads

Instrument Filter/Disperser:	f1065c/null
Extraction Aperture Position (arcsec):	[1.30, 1.09]
Wavelength of Interest used to Calculate Scalar Values (microns):	10.54
Size of Extraction Aperture (arcsec):	0.3
Total Time Required for Observation (seconds):	68.34
Total On-Source Time (seconds):	22.78
Extracted Flux (e-/sec):	64718.51
Variance in Extracted Flux (e-/sec):	88.40
Extracted Signal-to-Noise	732.12

Sample Coronagraphy Calcula ×

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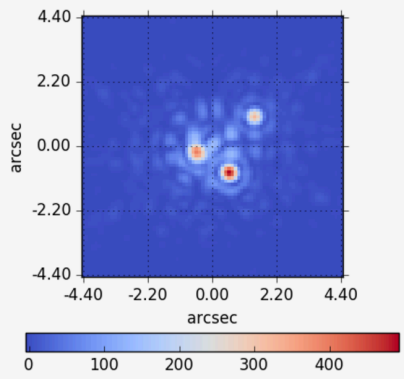
Exposure Time Calculator Edit Expand Developer Laurent Pueyo Help

Reset Calculate

Images

Calculation selected: 2, **Mode:** miri coronagraphy

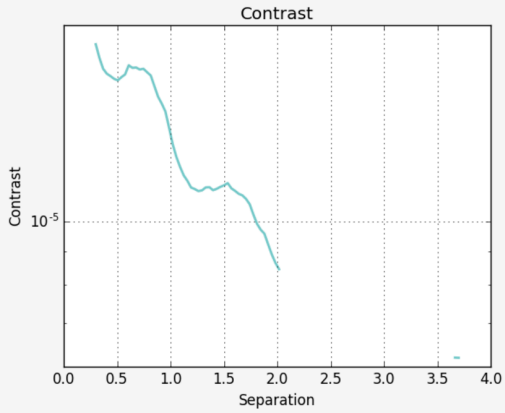
2D SNR | Detector | Saturation



2D SNR Image

Plots

ApFlux | ApBackground | SNR | SNR (time) | Contrast



Contrast

Bounds/Scale:

X: min max Linear Clear

https://3.etc.stsci.edu:4990/workbook.html?wb_id=1300#contrast

Reports

Calculation selected: 2, **Mode:** miri coronagraphy

Report | Warnings | Errors

Downloads

Instrument Filter/Disperser:	f1065c/null
Extraction Aperture Position (arcsec):	[1.30, 1.09]
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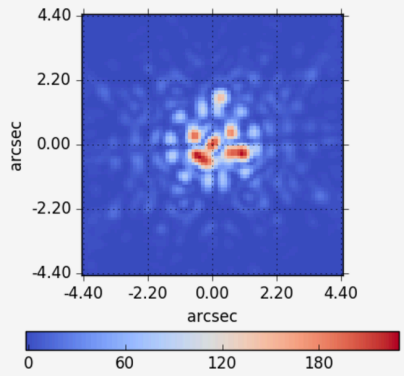
Exposure Time Calculator Edit Expand Developer Laurent Pueyo Help

Images

Calculation selected: 6, **Mode:** miri coronagraphy

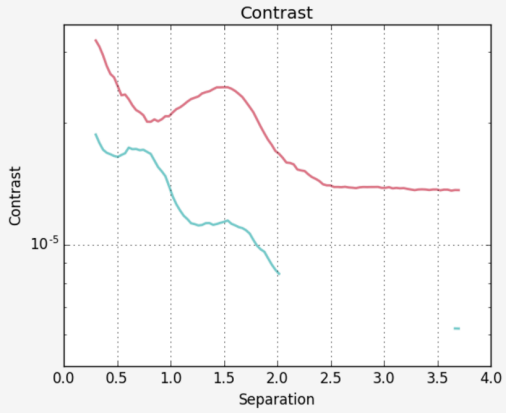
2D SNR | Detector | Saturation



2D SNR Image

Plots

ApFlux | ApBackground | SNR | SNR (time) | Contrast



Contrast

Bounds/Scale:

X: min max Linear Clear

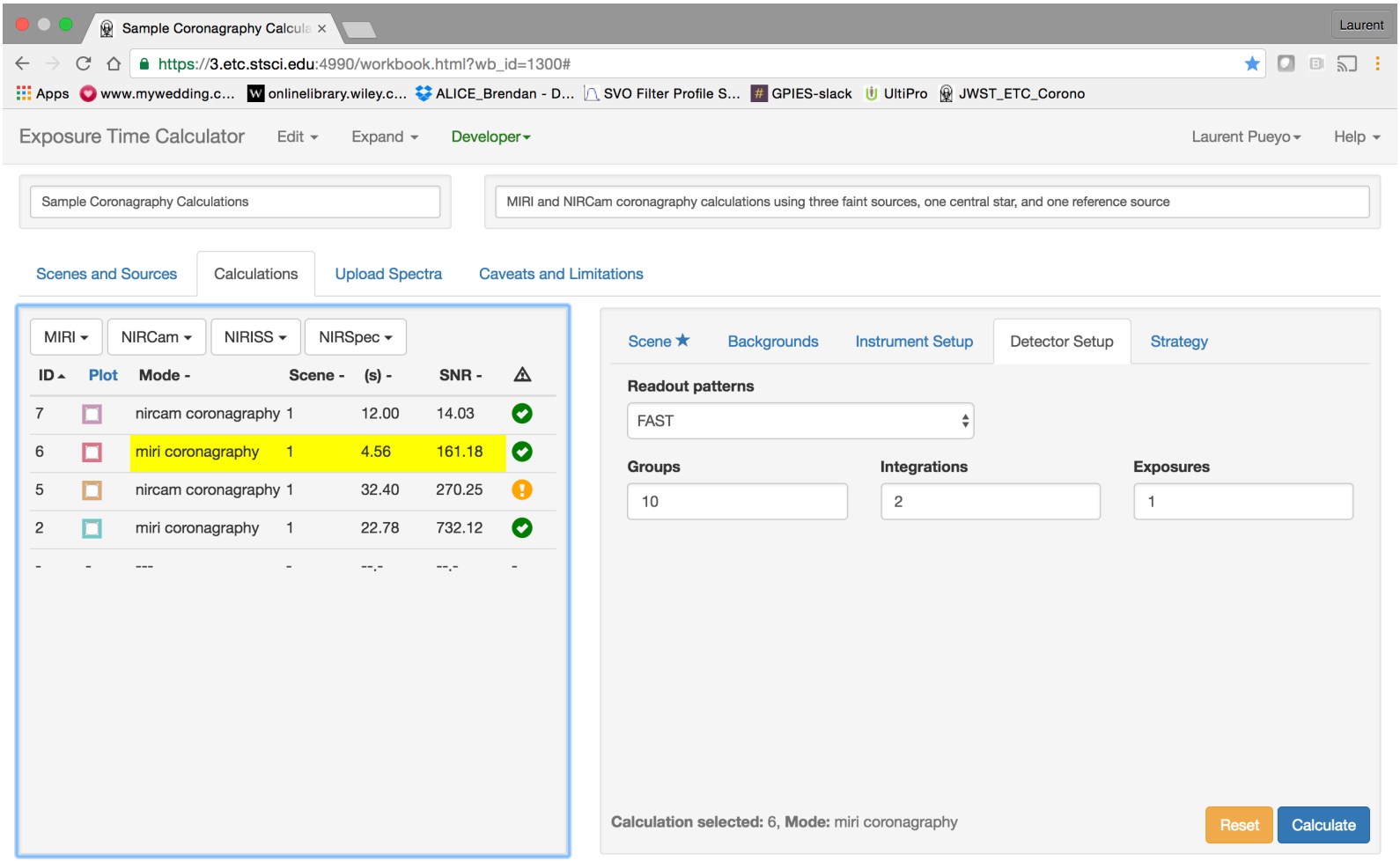
Reports

Calculation selected: 6, **Mode:** miri coronagraphy

Report | Warnings | Errors

Downloads

Instrument Filter/Disperser:	f1065c/null
Extraction Aperture Position (arcsec):	[0.00, 0.00]
Wavelength of Interest used to Calculate Scalar Values (microns):	10.54
Size of Extraction Aperture (arcsec):	0.3
Total Time Required for Observation (seconds):	13.67
Total On-Source Time (seconds):	4.56
Extracted Flux (e-/sec):	48496.46
Variance in Extracted Flux (e-/sec):	300.89
Extracted Signal-to-Noise ratio:	161.18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NIRISS
NIRSpec
ID
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FAST
Groups
10
Integrations
2
Exposures
1
Calculation selected: 6, Mode: miri coronagraphy
Reset
Calculate

Sample Coronagraphy Calcula ×

Laurent

https://3.etc.stsci.edu:4990/workbook.html?wb_id=1300#

Apps www.mywedding.c... onlinelibrary.wiley.c... ALICE_Brendan - D... SVO Filter Profile S... GPIES-slack UltiPro JWST_ETC_Corono

Exposure Time Calculator Edit Expand Developer Laurent Pueyo Help

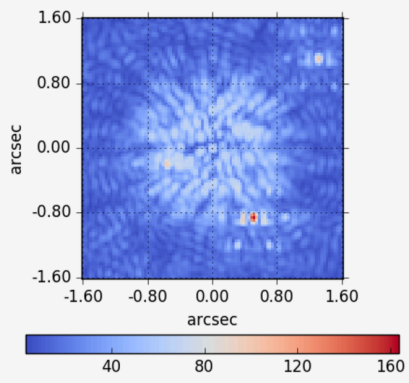
Calculation selected: 5, **Mode:** nircam coronagraphy

Reset Calculate

Images

Calculation selected: 5, **Mode:** nircam coronagraphy

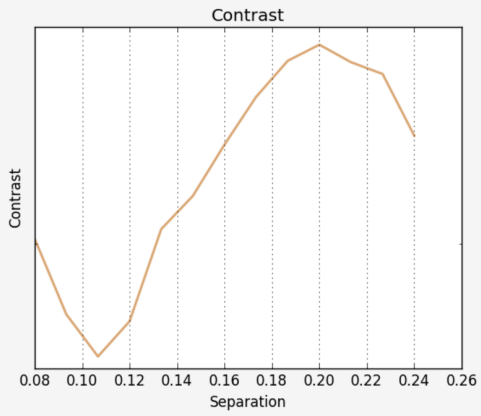
2D SNR | Detector | Saturation



2D SNR Image

Plots

ApFlux | ApBackground | SNR | SNR (time) | Contrast



Contrast

Reports

Calculation selected: 5, **Mode:** nircam coronagraphy

Report | Warnings | Errors

Downloads

Instrument Filter/Disperser:	f210m/null
Extraction Aperture Position (arcsec):	[0.50, -0.87]
Wavelength of Interest used to Calculate Scalar Values (microns):	2.08
Size of Extraction Aperture (arcsec):	0.08
Total Time Required for Observation (seconds):	97.20
Total On-Source Time (seconds):	32.40
Extracted Flux (e-/sec):	7444.00
Variance in Extracted Flux	

Sample Coronagraphy Calcula ×

Laurent

https://3.etc.stsci.edu:4990/workbook.html?wb_id=1300#

Apps www.mywedding.c... onlinelibrary.wiley.c... ALICE_Brendan - D... SVO Filter Profile S... GPIES-slack UltiPro JWST_ETC_Corono

Exposure Time Calculator Edit Expand Developer Laurent Pueyo Help

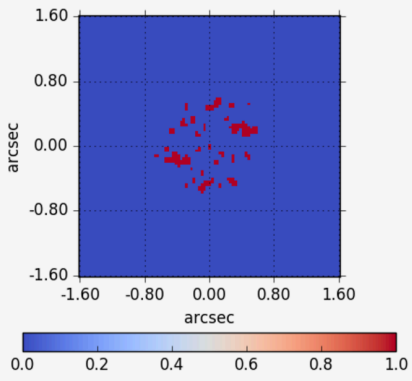
Calculation selected: 5, **Mode:** nircam coronagraphy

Reset Calculate

Images

Calculation selected: 5, **Mode:** nircam coronagraphy

2D SNR | Detector | Saturation

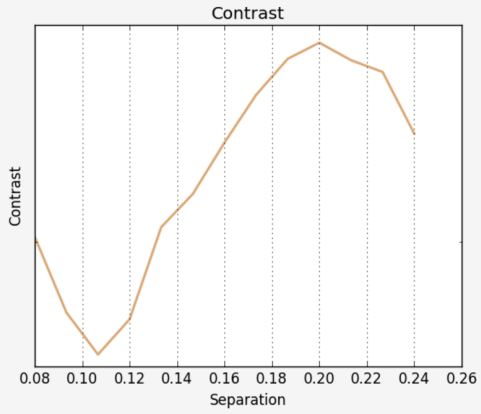


Saturation Image

https://3.etc.stsci.edu:4990/workbook.html?wb_id=1300#saturation

Plots

ApFlux | ApBackground | SNR | SNR (time) | Contrast



Contrast

Reports

Calculation selected: 5, **Mode:** nircam coronagraphy

Report | Warnings | Errors

Downloads

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Extraction Aperture Position (arcsec):	[0.50, -0.87]
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Variance in Extracted Flux	

Sample Coronagraphy Calcula ×

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https://3.etc.stsci.edu:4990/workbook.html?wb_id=1300#

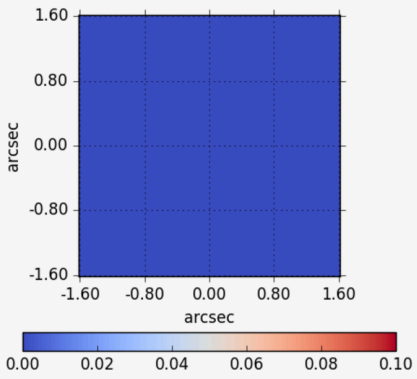
Apps www.mywedding.c... onlinelibrary.wiley.c... ALICE_Brendan - D... SVO Filter Profile S... GPIES-slack UltiPro JWST_ETC_Corono

Exposure Time Calculator Edit Expand Developer Laurent Pueyo Help

Images

Calculation selected: 7, **Mode:** nircam coronagraphy

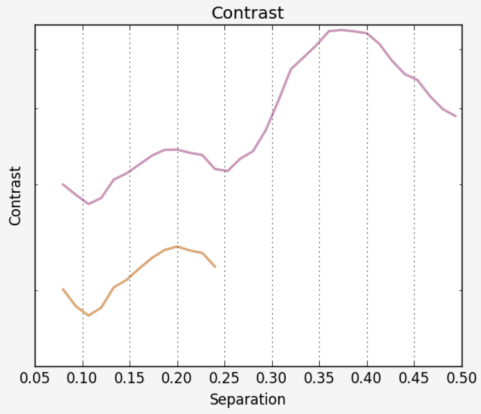
2D SNR | Detector | Saturation



Saturation Image

Plots

ApFlux | ApBackground | SNR | SNR (time) | Contrast



Contrast

Bounds/Scale:

X: min max Linear Clear

Y: min max Linear Clear

Apply

Reports

Calculation selected: 7, **Mode:** nircam coronagraphy

Report | Warnings | Errors

Downloads

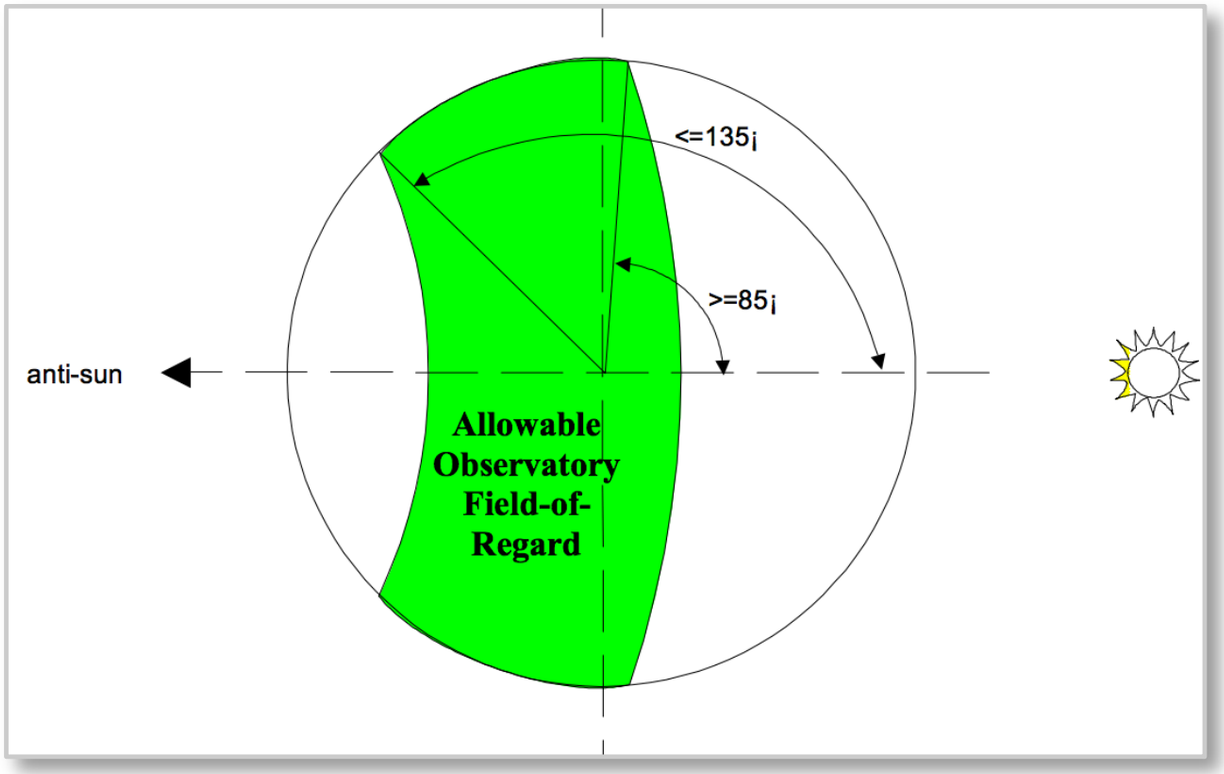
Instrument Filter/Disperser:	f210m/null
Extraction Aperture Position (arcsec):	[0.00, 0.00]
Wavelength of Interest used to Calculate Scalar Values (microns):	2.08
Size of Extraction Aperture (arcsec):	0.08
Total Time Required for Observation (seconds):	36.00
Total On-Source Time (seconds):	12.00
Extracted Flux (e-/sec):	983.35
Variance in Extracted Flux (e-/sec):	70.09
Extracted Signal-to-Noise ratio:	14.03
Input Background Surface	0.28

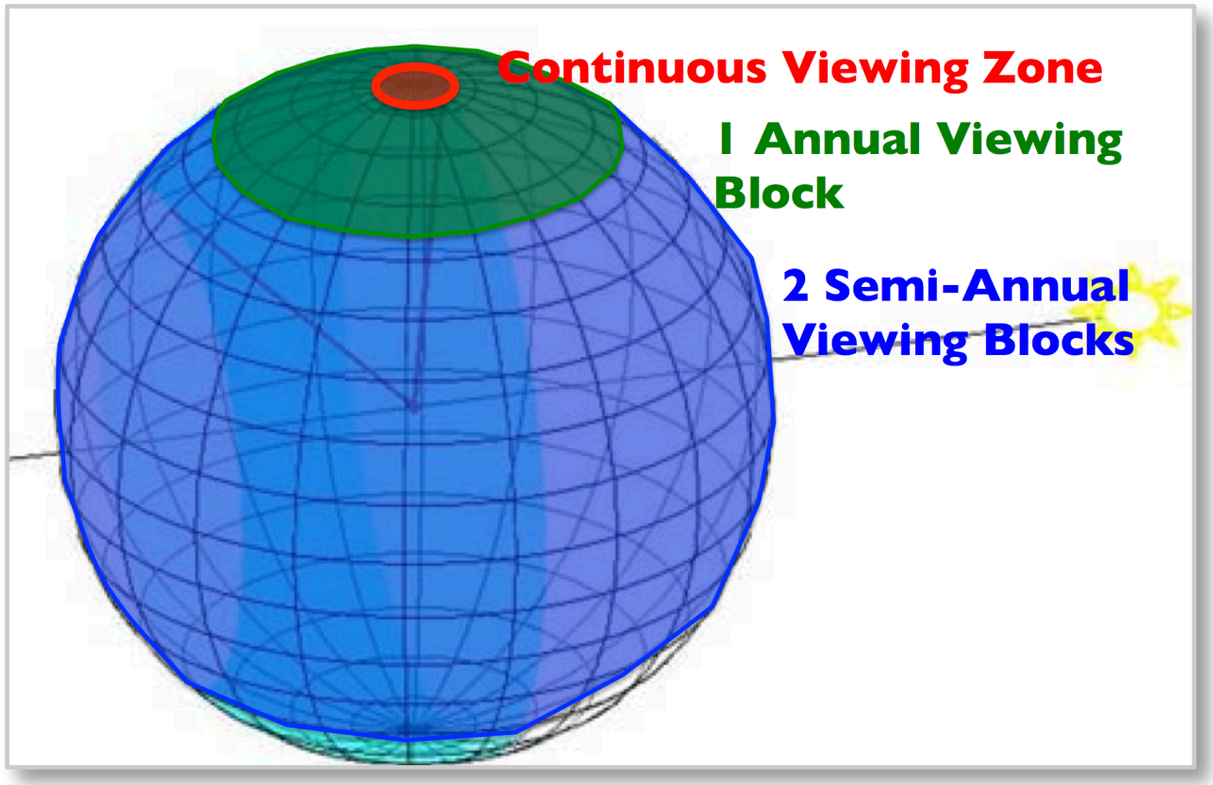
Overview of a JWST coronagraph program

- Science Use Cases.
- Exposure Time Calculator.
- Target Visibility.
- Standard Coronagraph Sequence.
- Astronomer Proposal Tool.
- After your observations have been taken.

Target visibility

Not all sources can be view at any time at any orientation. Main driver is the sun exclusion angle.





Target visibility demo

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Standard Coronagraph Sequence.

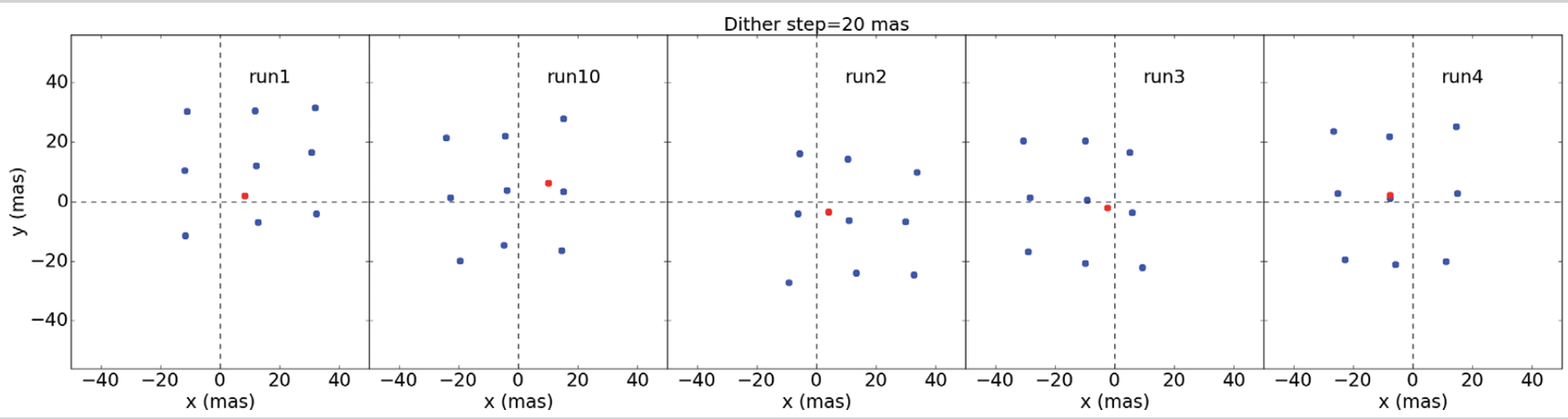
- Roll 1 - Roll 2 - Reference.

- Exceptions will be possible for relevant use cases.

- Reference exposures will be public.

- Overheads will be charged to user. If the science can be done without the two rolls and/or reference then justification is needed.

Small Grid Dithers



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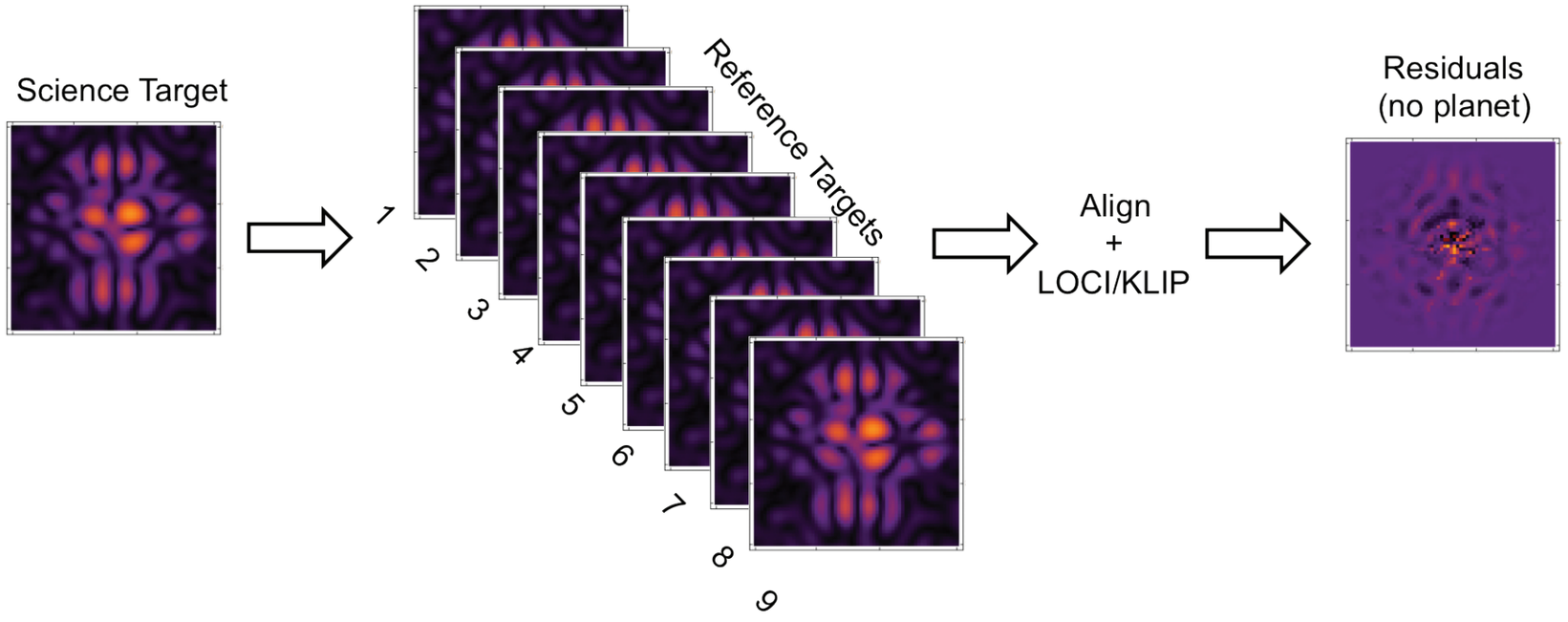

Figure 2: Cartoon illustrating the Small-Grid Dither technique. A science target image is first acquired, followed by a square grid of reference images. Post-processing then aligns the reference PSFs to the target PSF and performs a local optimization to build an improved synthetic PSF, which is used for the final PSF subtraction (e.g., Locally Optimized Combination of Images [LOCI] algorithm or KL Image Projection [KLIP] algorithm; see Lafrenière et al. 2007 and Soummer et al. 2012 respectively).

Small Grid Dithers

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NIRCam

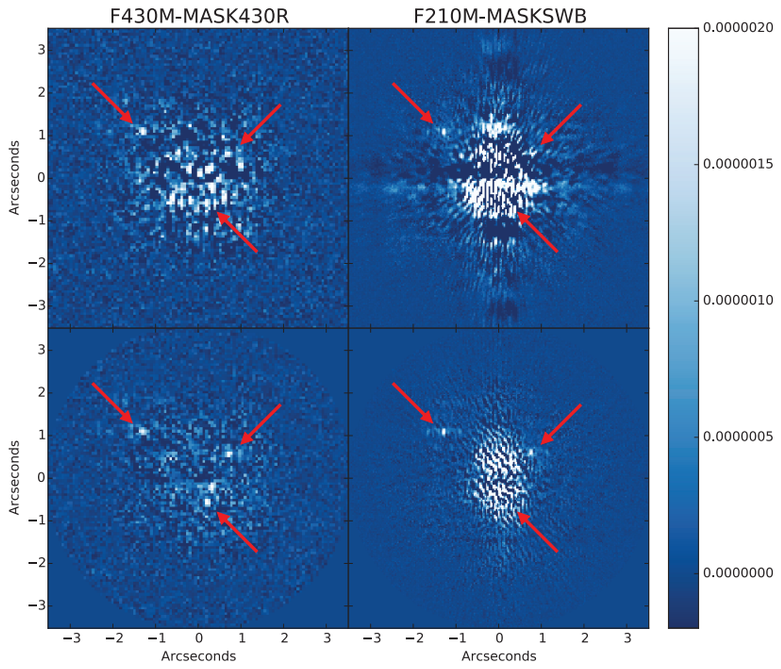

Figure 4: A simulated case showing the relative performance of Classical subtraction (*top row*) and Small-Grid Dithers (*bottom row*) for the NIRCam F430M+MASK430R (*left*) and F210M+MASKSWB (*right*) coronagraphs using fake planets with a large difference in magnitude of 14.

MIRI

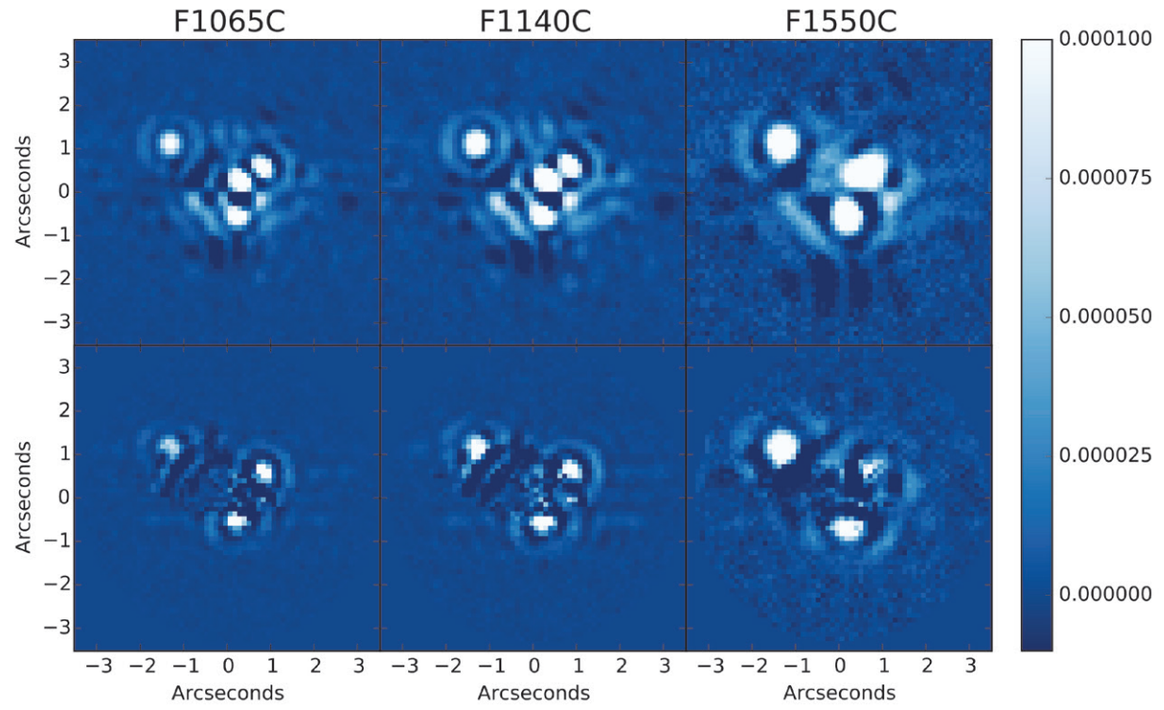

Figure 5: A simulated case showing the relative performance of Classical subtraction (*top row*) and Small-Grid Dithers (*bottom row*) for all three of MIRI's Four-Quadrant Phase Masks using fake planets with differences in magnitude of ~10 (see Boccaletti et al. 2015).

See:

https://blogs.stsci.edu/newsletter/files/2016/01/Lajoie.pdf

http://spie.org/Publications/Proceedings/Paper/10.1117/12.2057190

Standard Coronagraph Sequence: overheads

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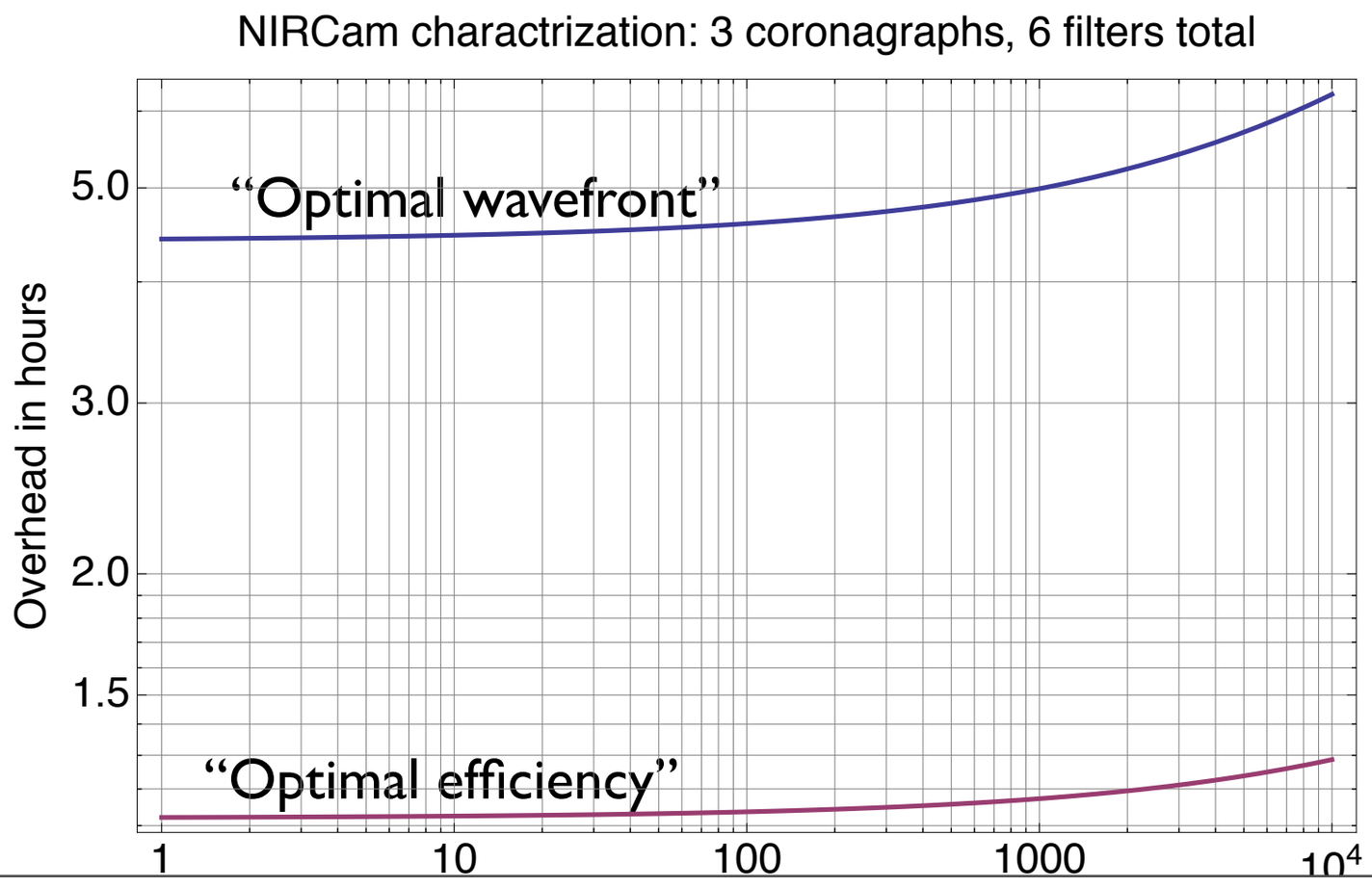
When using multiple filters, two options for coronagraph sequence:

- An "optimal wavefront stability" strategy for which the observations are consecutive in each filter to minimize the chance of any wavefront changes. This strategy increases the number of slews and rolls for the telescope.
- An "optimal efficiency" strategy for which observations for a given target are organized in each filter and coronagraphs to minimize the number of rolls and slews. This strategy increases the time between an observation of a target in a given filter and the corresponding reference PSF star observation in the same filter, which *may* allow increased variations in PSF properties, but which will *not necessarily* do so.



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APT demo

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After your observations have been taken.

- Specific exposures dedicates to astrometric and photometric calibration.
- The possibility to use a PSF library will be enabled.
- Coronagraph pipeline will include optimal image combination algorithms (KLIP/LOCI).
- Automated pipeline will run “conservative” data analyses.
- Python code will be available for custom analysis of the data.

Overview of a JWST coronagraph program

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Thank you.