Planning MOS Observations

JWST Master Class November 18-22, 2019

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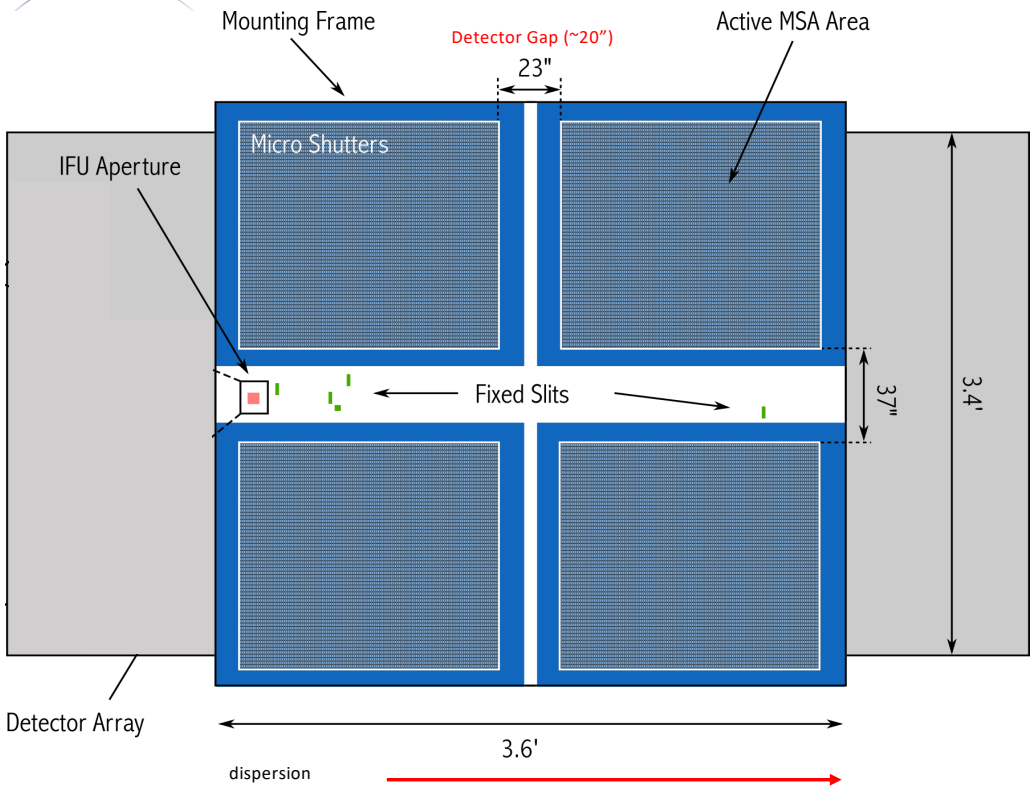
Gary Curtis and the APT team

The NIRSpec Micro-shutter Assembly

NIRSpec MSA for Multi-Object spectroscopy



NIRSpec has 2 detectors. There is gap between them (~20").

Spectra are dispersed from left to right, and in many cases, will fall across the gap

The Micro-Shutter Assembly (**MSA**) is a 4 quadrant array of tiny configurable shutters. The entire array has nearly 250,000 shutters.

The MSA Field of View is ~3.6' x 3.4'


The MOS Observing Process

Multi-Step Process

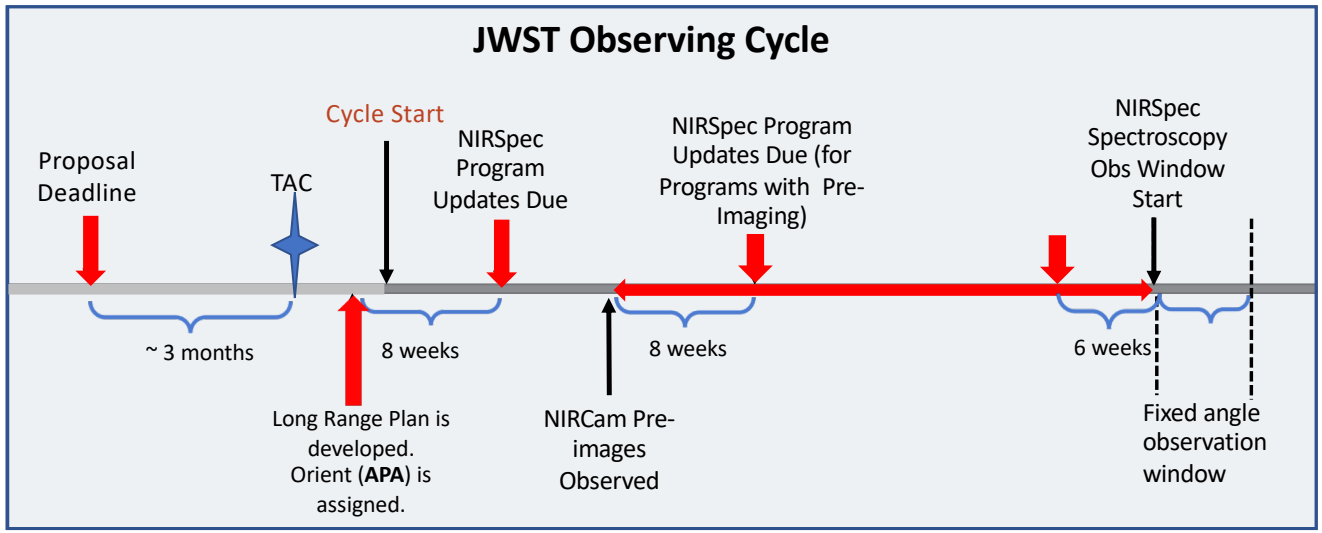
To accurately align science sources within the small MSA shutters, NIRSpec MOS mode observations must be planned and executed at a fixed instrument Aperture Position Angle (APA), assigned by STScI. Hence, a multi-step planning process.

For the Proposal deadline, use MPT to create placeholder visits to accurately estimate the overheads.

After the TAC, an APA will be assigned by STScI.

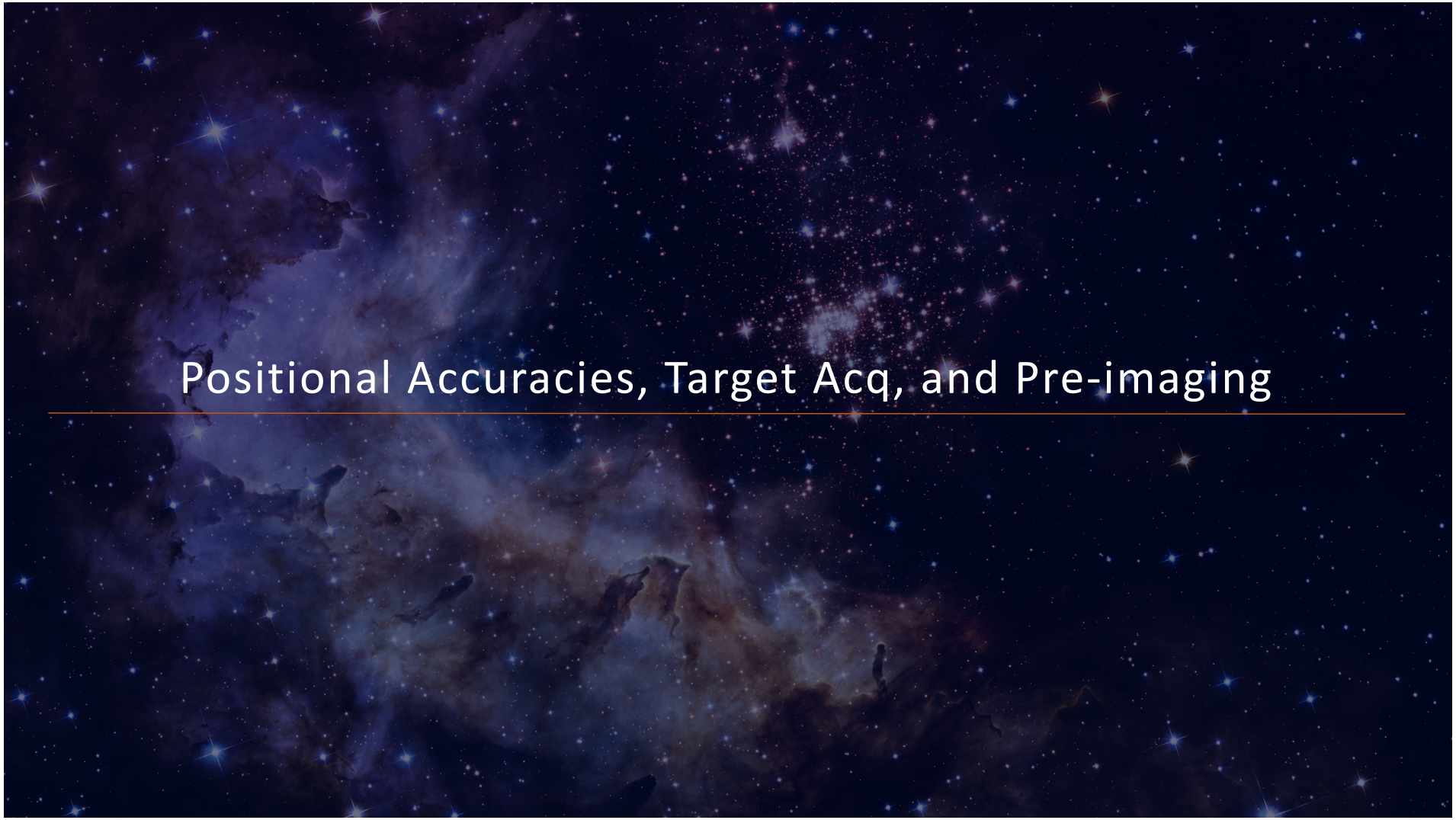
Flight ready programs are due 8 weeks after the APA is assigned (no NIRCam pre-imaging)

Or, 8 weeks after the NIRCam pre-imaging is observed.



For best success, users should place their NIRCam pre-imaging and NIRSpec observations in different visibility windows to have time to reduce and analyze the NIRCam astrometry.

When that's not possible, program updates will be due a min of 6 weeks in advance of the NIRSpec observing window.


Positional Accuracies, Target Acq, and Pre-imaging

Pointing Accuracies

Most MOS science will require accurate astrometry delivered by MSATA (using reference stars).
Note that the delivered TA pointing accuracy depends on the input Catalog relative astrometric accuracy.

TA Type	Delivered Pointing Accuracy	Catalog Relative Accuracy	Science Goal
Optimal (MSATA)	20 - 25 mas (20 mas is 1/10th shutter)	5 - 15 mas (HST: ~ 10 mas is possible. NIRCam: 5 mas is the goal)	Best possible photometric accuracy
Relaxed (MSATA)	< 50 mas	< 40 mas	Extended sources, or reduced flux accuracy w/ MSA
VERIFY_ONLY	~ 100 mas (TBD)	No ref stars required	Special cases – extended source

If accurate astrometry is required for the science, and if HST imaging does not exist – request NIRCam pre-imaging in your Proposal submission. Pre-imaging needs to be fully executable.

Target Acquisition Considerations

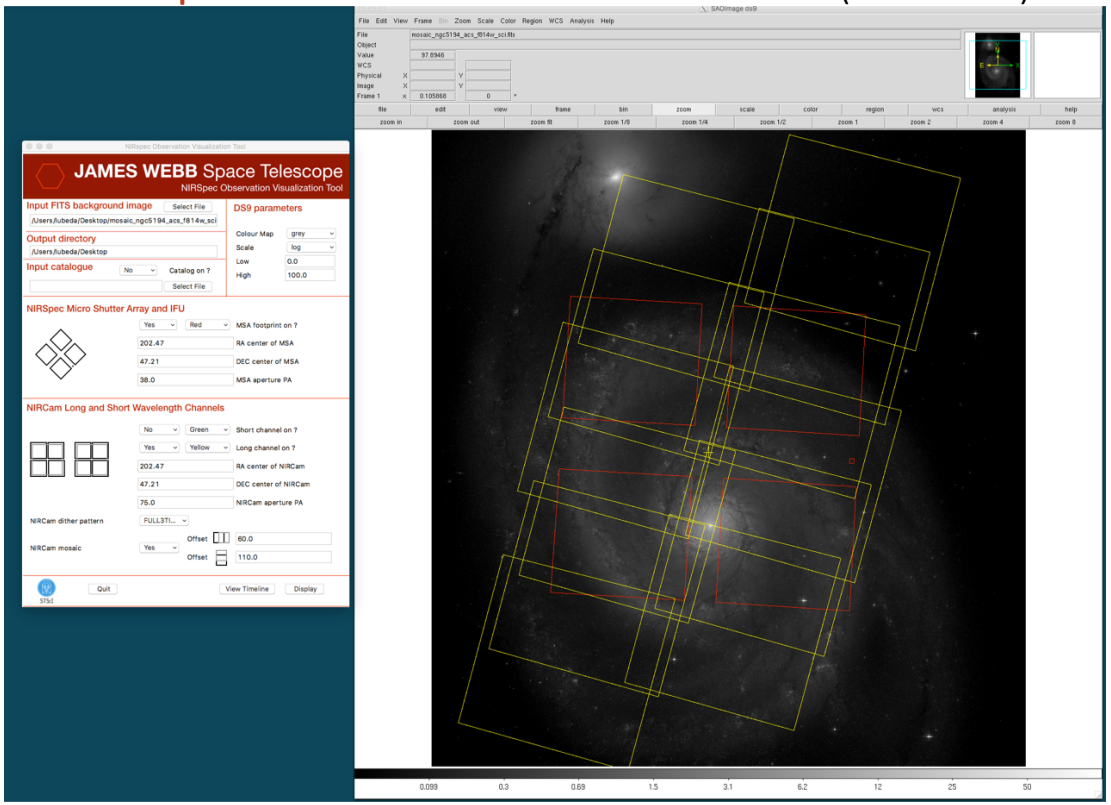
- Moving targets cannot use MSATA – must use WATA instead. WATA does not require pre-imaging, only a good ephemeris.
- For Program Update submissions - MPT will be used to select reference stars at the assigned APA that will not be behind MSA bars or in failed shutters. This vetting is done at the Visit level at the first pointing in the Visit.
- MSATA requires defining 5-8 reference stars. Programs using MSATA will be charged a **fixed overhead** equivalent to an average charge for 8 reference stars.
- 8 reference stars have been determined to be optimal
  - tradeoffs between increased accuracy and overheads.
  - Will be adjusted if needed.
  - Can be increased with permission, for slightly better results.

Pre-imaging with NIRCam

- Is imaging available that is
  - **deep enough** to identify sources,
  - **wide enough** to plan ref stars, and
  - **accurate enough** to plan MOS obs?

- If not –> request NIRCam pre-imaging in your Proposal.
  - Area should be large enough to allow for any APA for the NIRSpec obs: Ideally 5 x 5 arcmin: typically 2x1 mosaic + dithers to cover the gaps.
  - NIRCam observations must be flight ready at proposal submission.

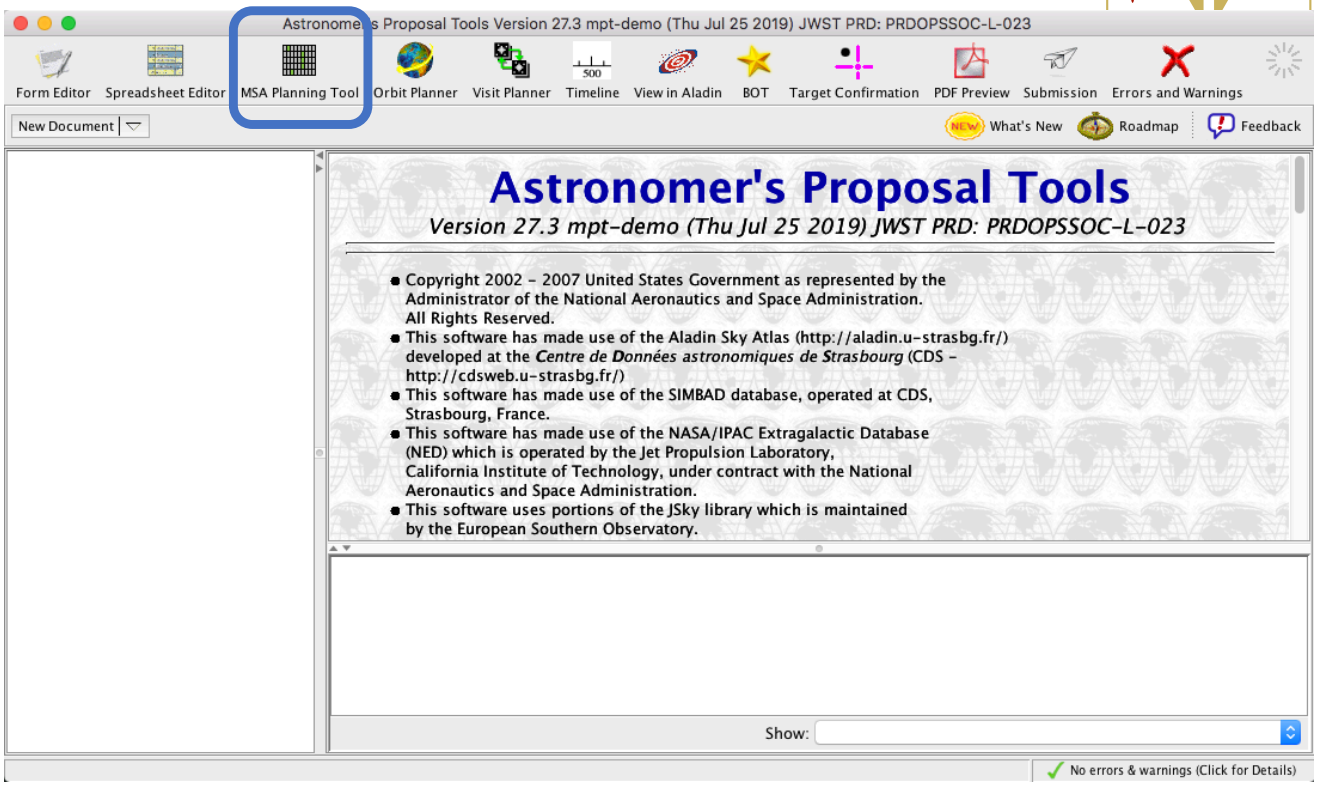
NIRSpec Observation Visualization Tool (L. Ubeda)




The MSA Planning Tool in APT

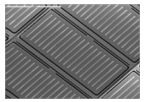
MSA Planning Tool (MPT) in APT

- NIRSpec MOS observing mode is able to obtain spectra of tens to hundreds objects within a 3.6’ x 3.4’ FoV at the same time.
- The MPT was designed to align science sources with the very small MSA shutters (0.2” x 0.46”)

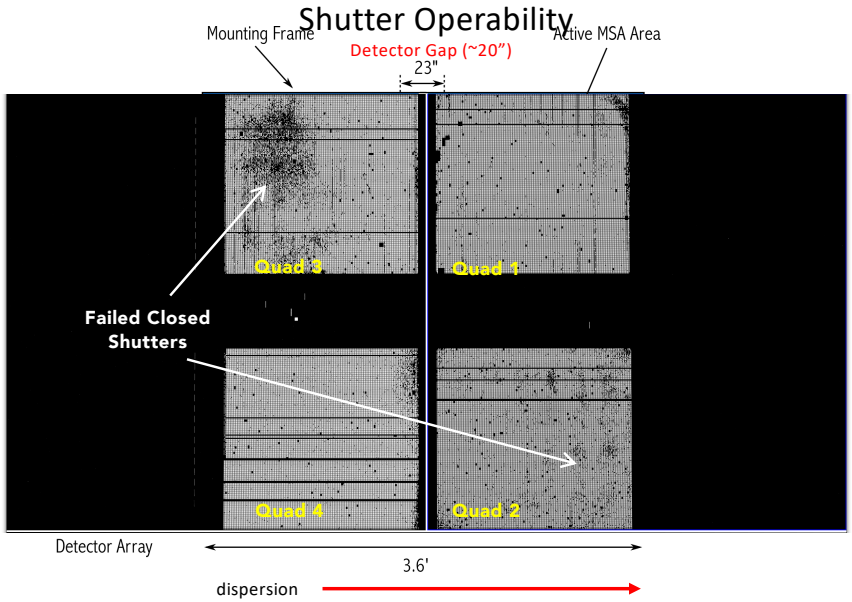


Why use MPT?

- The MSA is a **fixed grid** (with bars that vignette light from sources behind them)

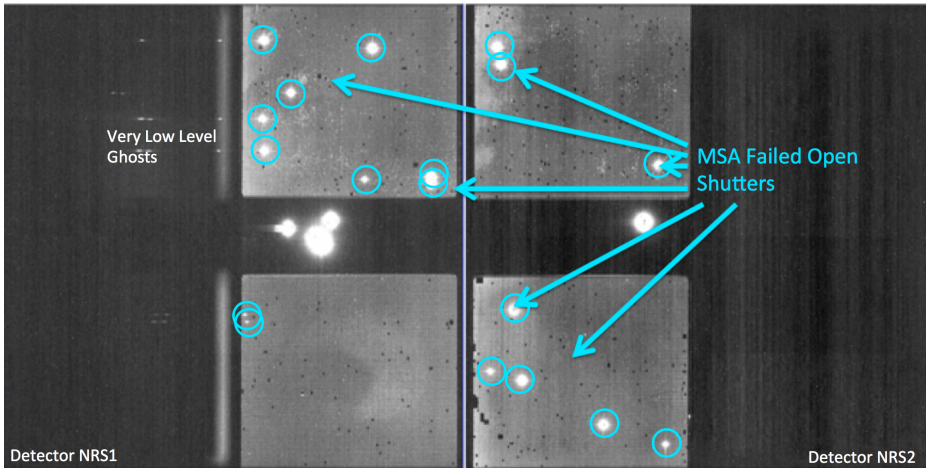


- There is a **gap** between the 2 detectors → missing wavelengths.



- The MSA has **Failed shutters, shorted rows/columns**. Shutter status evolves! MPT plans using the most up-to-date operability.
- Source positions in MSA require knowledge of **optical distortions** and **velocity aberrations** at a planned Aperture Position Angle.

MSA failed open shutters

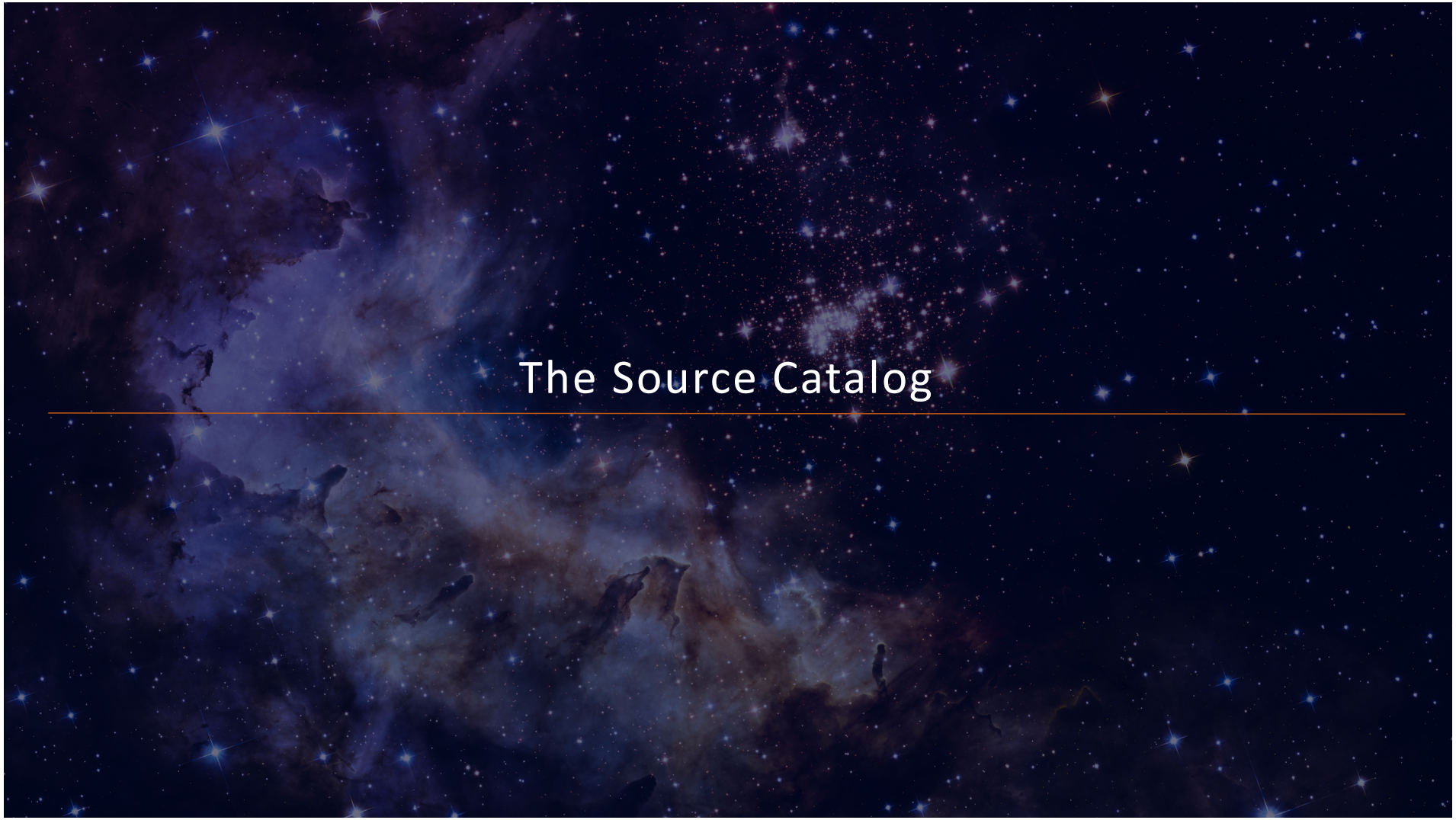


What's needed to run the MSA Planning Tool?

- An internet connection:
  - ➢ to access the most up-to-date MSA shutter operability
  - ➢ To check for Guide Stars during planning

- A complete and accurate astrometric Catalog
  - ➢ With accurate source positions (< 15 mas relative accuracy) – may require pre-Imaging with NIRCam

- MPT produces: "Plans" with Pointings, MSA configurations, Target Sets
- One or multiple plans can be selected and made into an Observation


The Source Catalog

Source Catalog Requirements

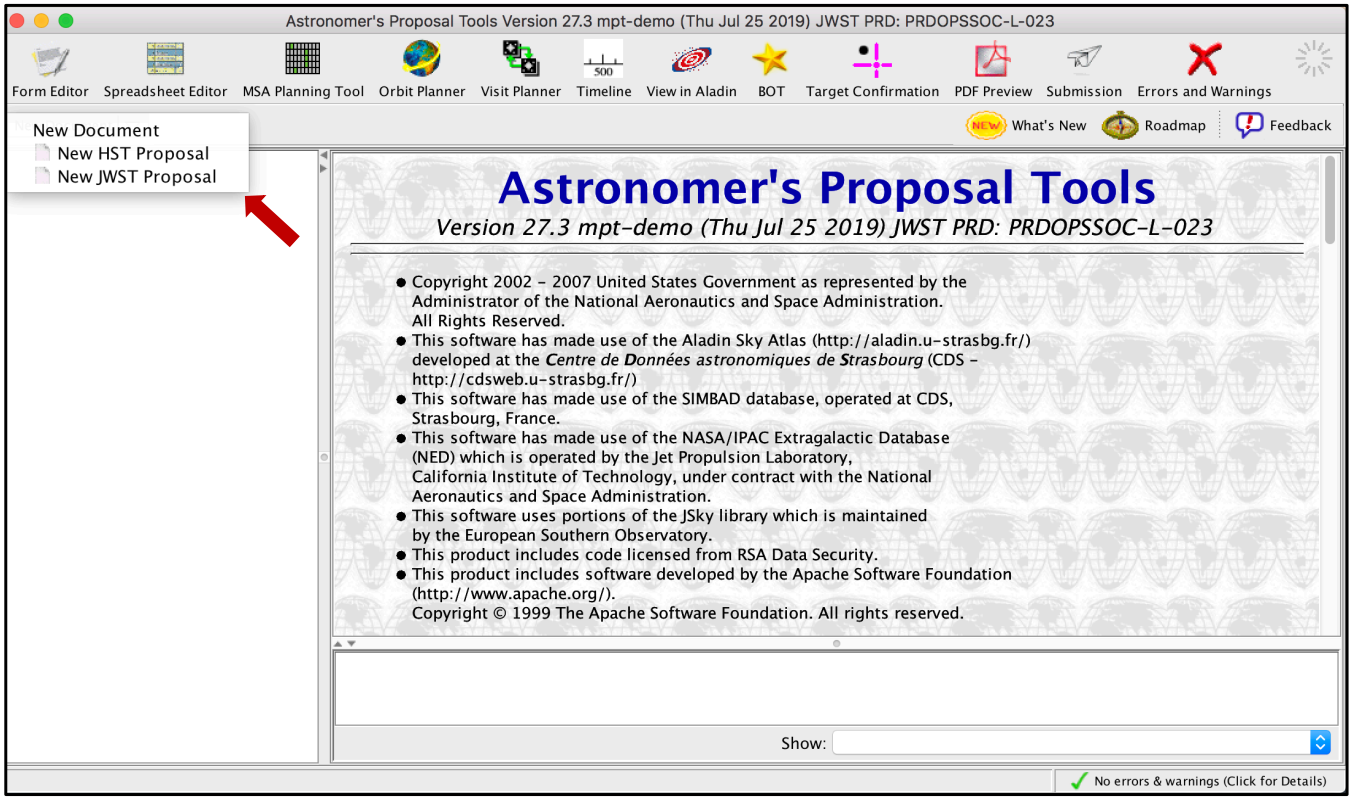
The first step to creating a NIRSpec MOS observation is to create a complete catalog of sources. The catalog should include all known sources in the field.

- The source catalog is an ASCII file
- It must contain J2000 RA and Dec expressed in degrees or hexadecimal units.
- It cannot have duplicate IDs nor NULL entries.
- A header is optional. The header is marked with "#".

Because of the small size of the shutters (just 200 mas in width) the relative positional accuracy of the planning catalog must be between 5 and 50 mas.

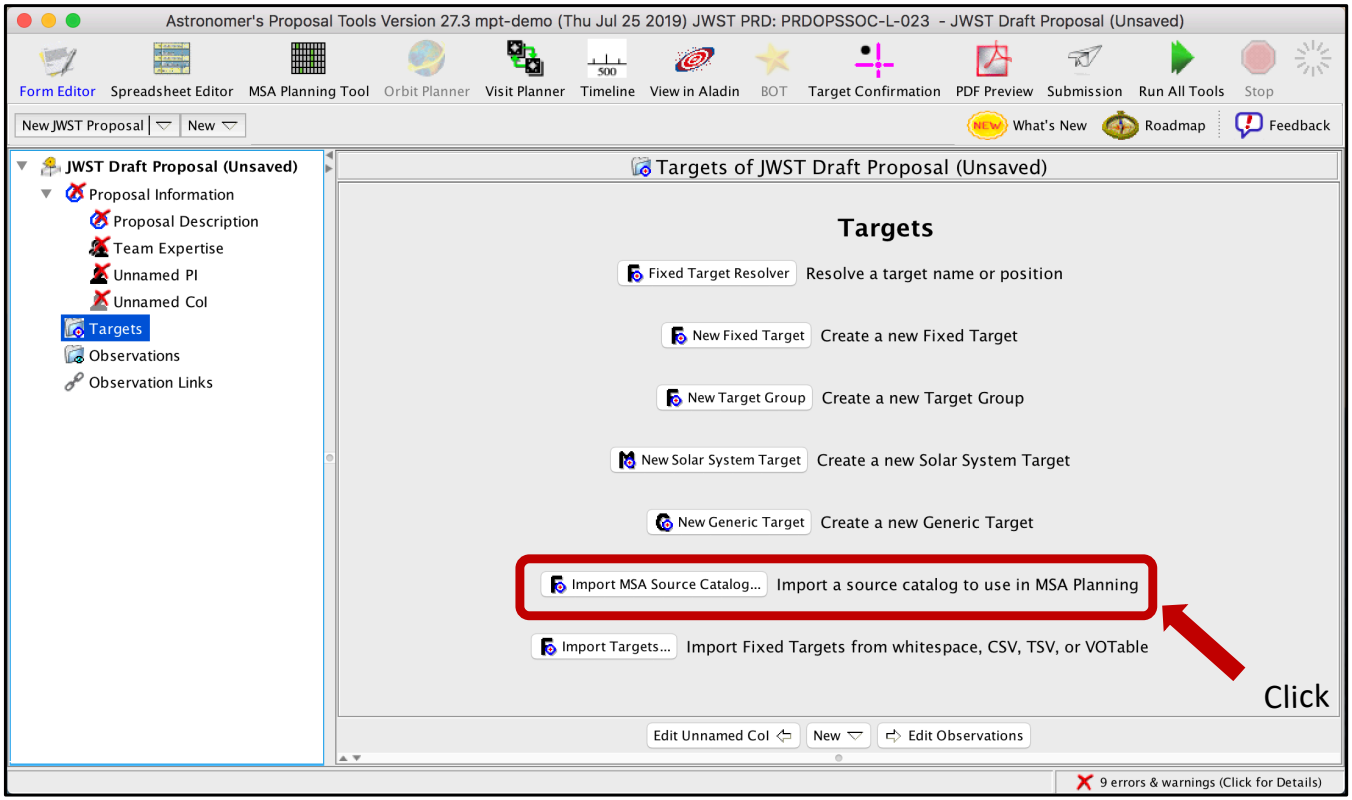
ID	RA	DEC	Size	Redshift	Reference	Stellarity	MAG_F160W	NRS_F110W	NRS_F140X	NRS_CLEAR	W
23796	03 32 39.0842	-27 46 1.79	0	1.415	Yes	0.92	20.122	20.674	20.366	20.122	
54454	03 32 35.5075	-27 46 26.13	0	1.268	Yes	0.03	20.384	20.845	20.474	20.384	
22410	03 32 39.8827	-27 47 15.06	0	1.107	Yes	0.03	20.711	21.199	20.786	20.711	
24439	03 32 37.1930	-27 46 8.08	0	1.101	Yes	0.03	19.494	20.254	19.672	19.494	
23546	03 32 38.4836	-27 47 2.42	0	0.919	Yes	0.03	20.088	20.785	20.261	20.088	
21268	03 32 42.4216	-27 47 58.80	0	0.779	Yes	0.94	17.811	18.026	-99	17.811	
22990	03 32 38.7749	-27 47 32.14	0	0.767	Yes	0.03	20.286	20.695	20.415	20.286	
21840	03 32 37.3079	-27 47 29.36	0	0.708	Yes	0.03	18.793	19.473	18.966	18.793	
22951	03 32 40.6729	-27 47 30.99	0	0.692	Yes	0.03	20.163	20.839	20.34	20.163	
24350	03 32 38.4386	-27 46 31.90	0	0.69	Yes	0.03	20.68	21.324	20.855	20.68	
24353	03 32 38.5957	-27 46 31.36	0	0.663	Yes	0.03	20.768	21.177	20.893	20.768	
21298	03 32 39.2188	-27 47 58.36	0	0.662	Yes	0.03	19.618	20.265	19.785	19.618	
21281	03 32 35.7539	-27 47 58.82	0	0.66	Yes	0.03	19.35	19.991	19.507	19.35	
23847	03 32 38.7915	-27 46 48.90	0	0.657	Yes	0.03	20.287	20.927	20.451	20.287	
22428	03 32 41.4054	-27 47 17.17	0	0.612	Yes	0.03	19.596	20.241	19.767	19.596	
24587	03 32 40.7814	-27 46 15.69	0	0.571	Yes	0.03	19.482	19.901	19.615	19.482	
24348	03 32 38.9675	-27 46 30.23	0	0.447	Yes	0.03	20.152	20.541	20.258	20.152	
24685	03 32 41.7599	-27 46 19.40	0	0.383	Yes	0.04	20.047	20.635	20.189	20.047	
21671	03 32 38.0057	-27 47 41.71	0	0.253	Yes	1	18.276	18.562	18.369	18.276	

Starting from scratch in APT



Load the Catalog as an MSA Catalog Target

Notice that we are in the Form Editor

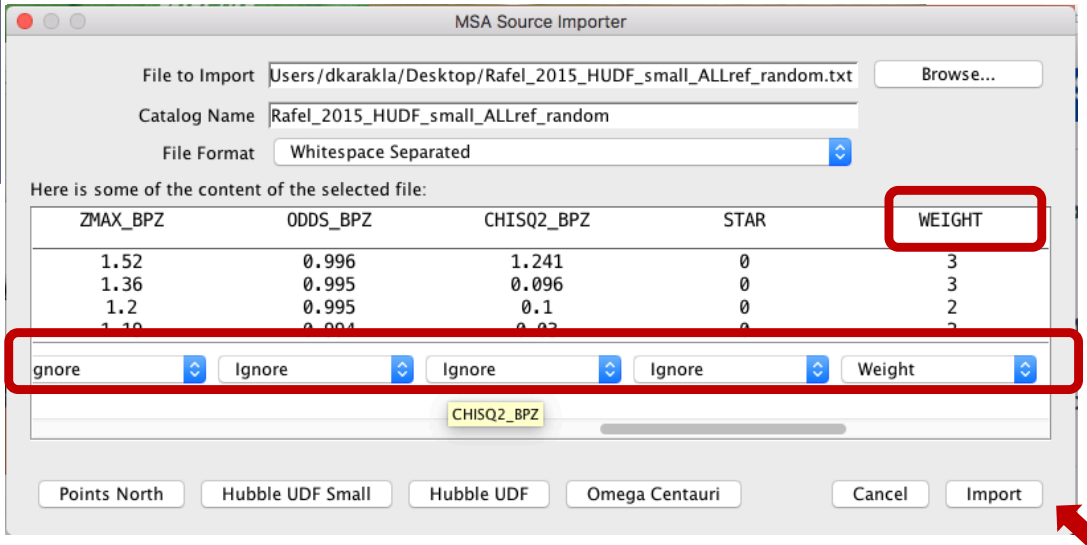


Load the Catalog as an MSA Catalog Target

A window will pop up…

- Browse and select the Catalog file.
- Choose a name and file format

MPT tries to identify the type of data in each column



Weights can be used to prioritize the targets. Higher weights are for more interesting targets.

Click

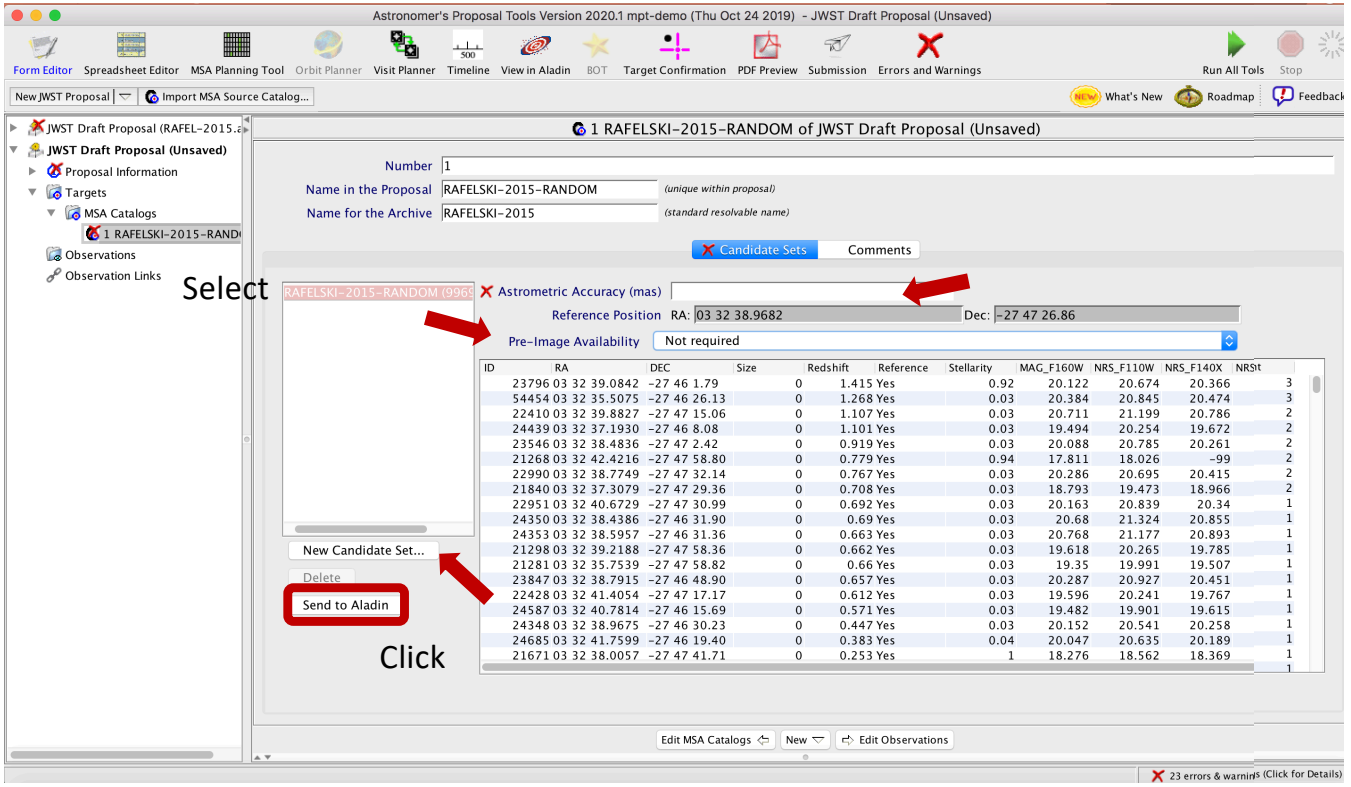
Catalog declarations and making Candidate Sets

MPT complains because:

1) The target is not used in the proposal (yet! – It's just a warning)
2) We must specify the astrometric accuracy

3) We must tell MPT if we need pre-imaging or not:

- If NIRCam pre-imaging will be done **in this program**, it is linked here for archival purposes.



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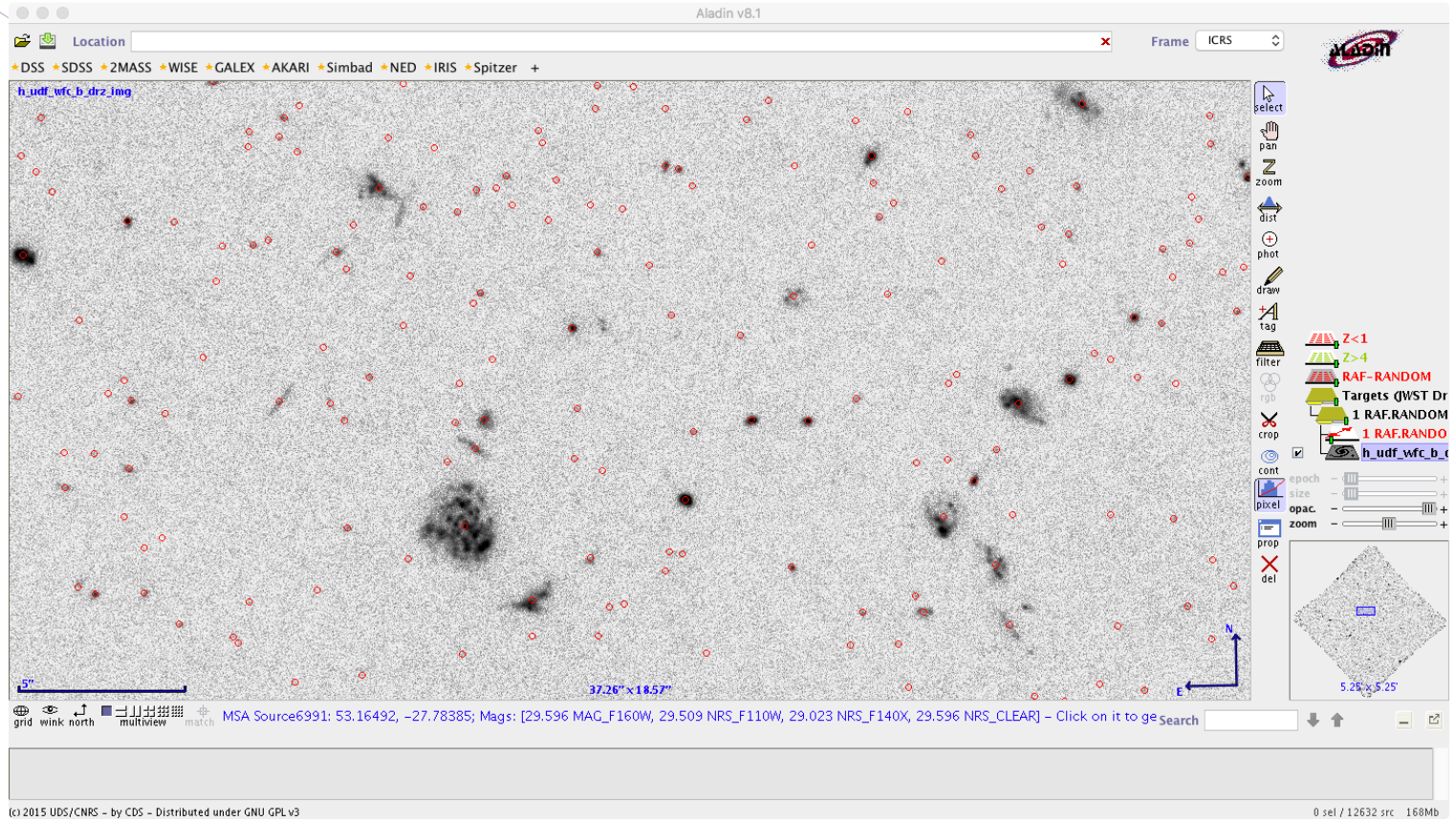
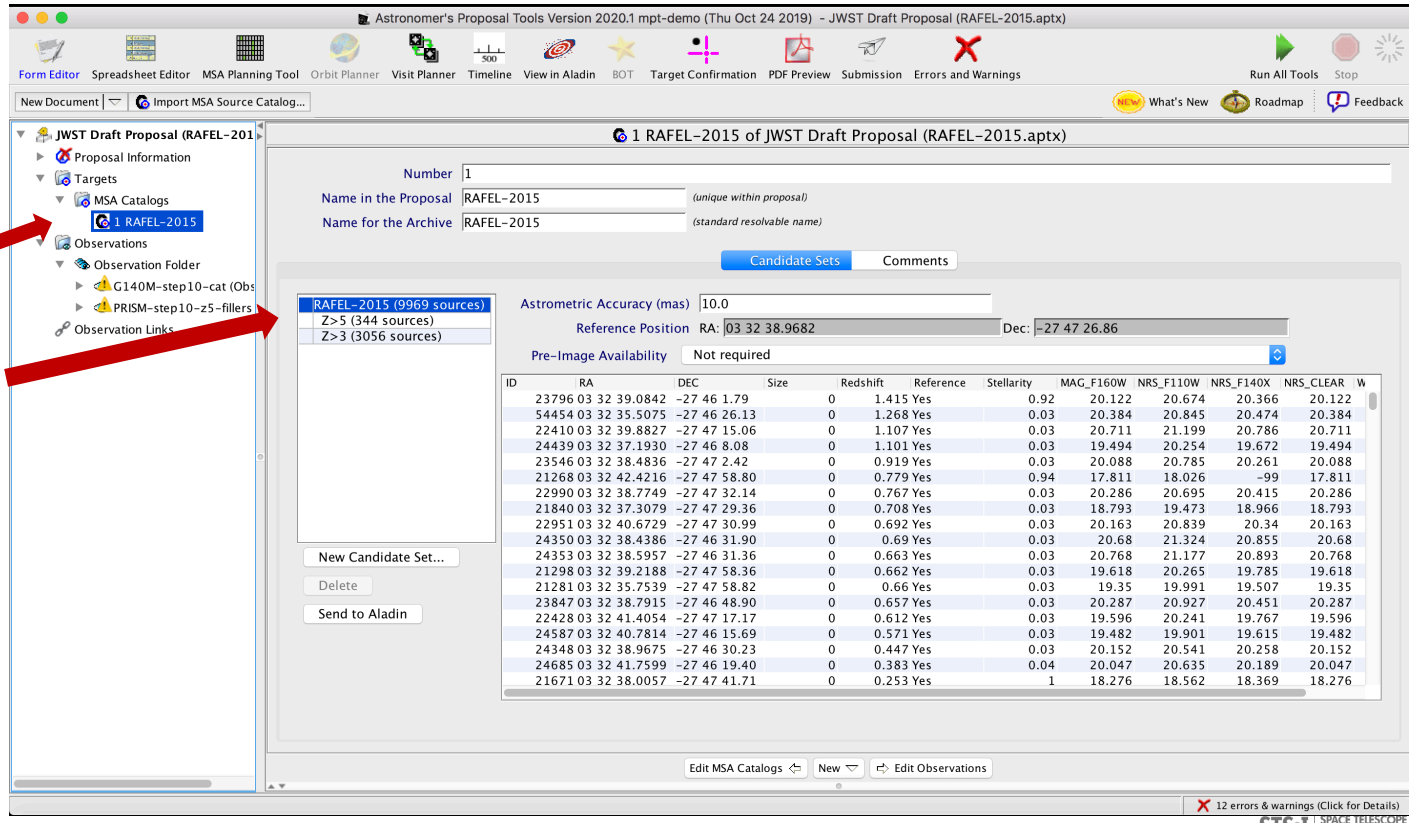
Catalog sources displayed in Aladin



MSA Catalog Target

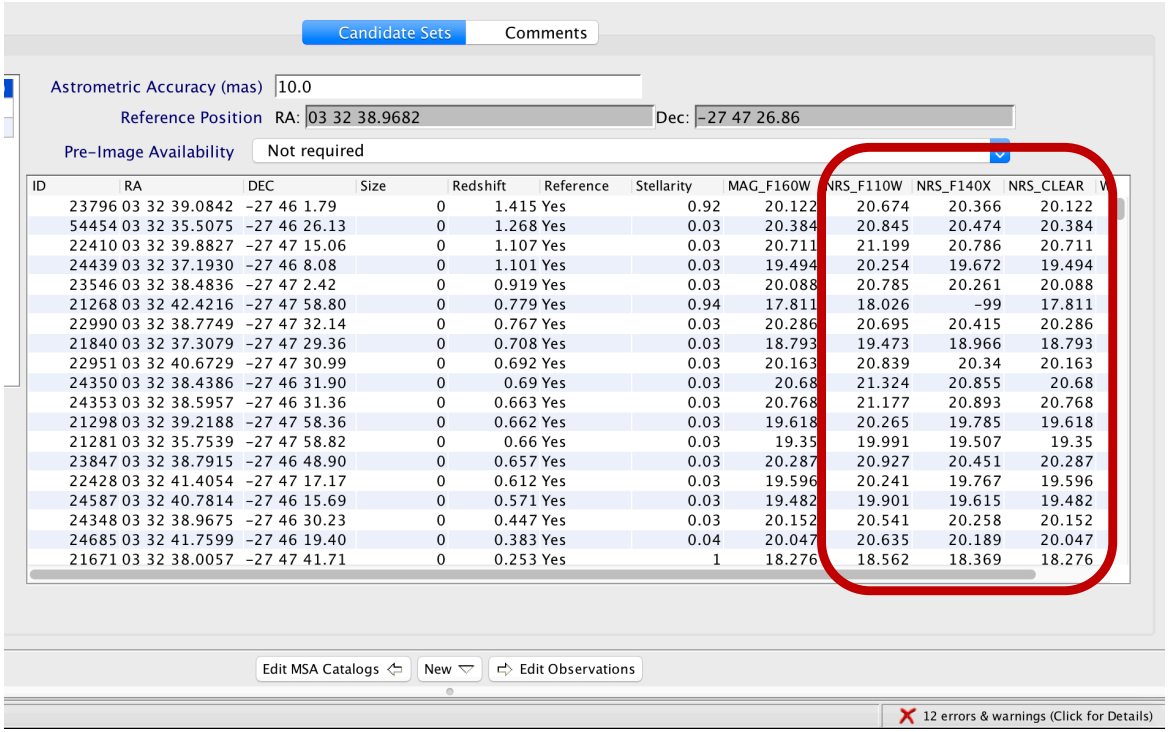
The MSA Catalog Target is now in the Targets Folder

Highlight/select the Catalog to see its data



Source Catalog at Program Update

- For (later) program update submission
  MPT needs magnitudes in TA filters to properly define the reference stars.
- There will be a tool for creating this data by converting HST magnitudes (it will be made available in time for updates).



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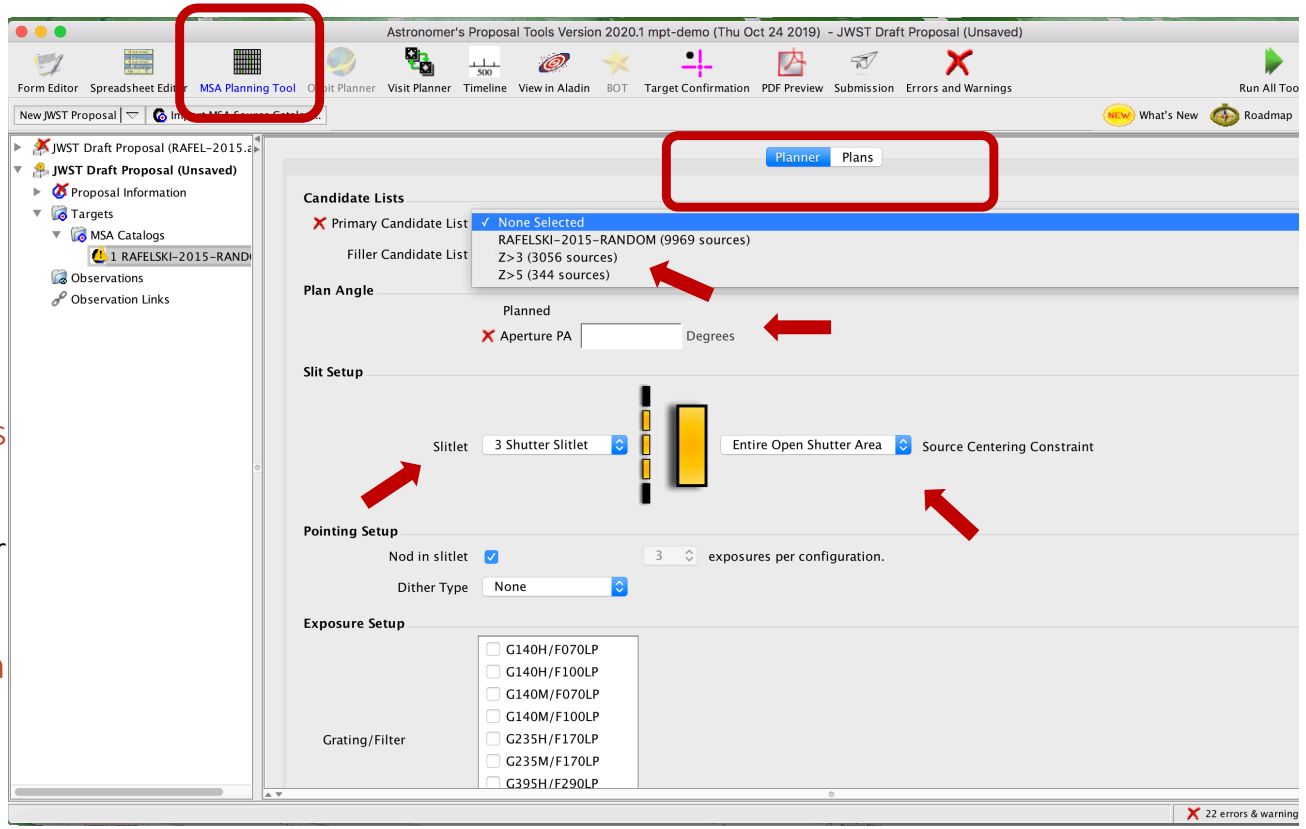
The MSA Planning Tool

The MPT Planner

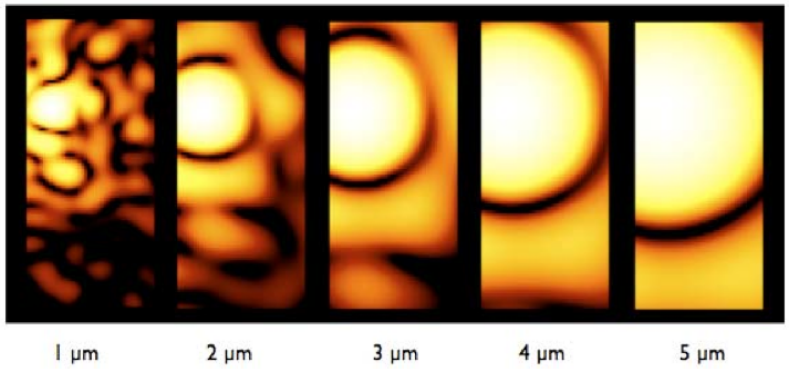
Select the MSA Planning Tool in the APT toolbar –

Select the Planner tab.
The Planner is where you design plans for your MOS observation.

- Choose the Primary Candidates (and Filler Candidates)
- Choose an APA (place holder or assigned from STScI)
- Choose the slitlet configuration
- Choose the source centering constraints



Source Centering and Slit Losses



Slit throughput or slit loss is a function of wavelength and the relative placement of the science source in the MSA shutter

Source Centering Constraint

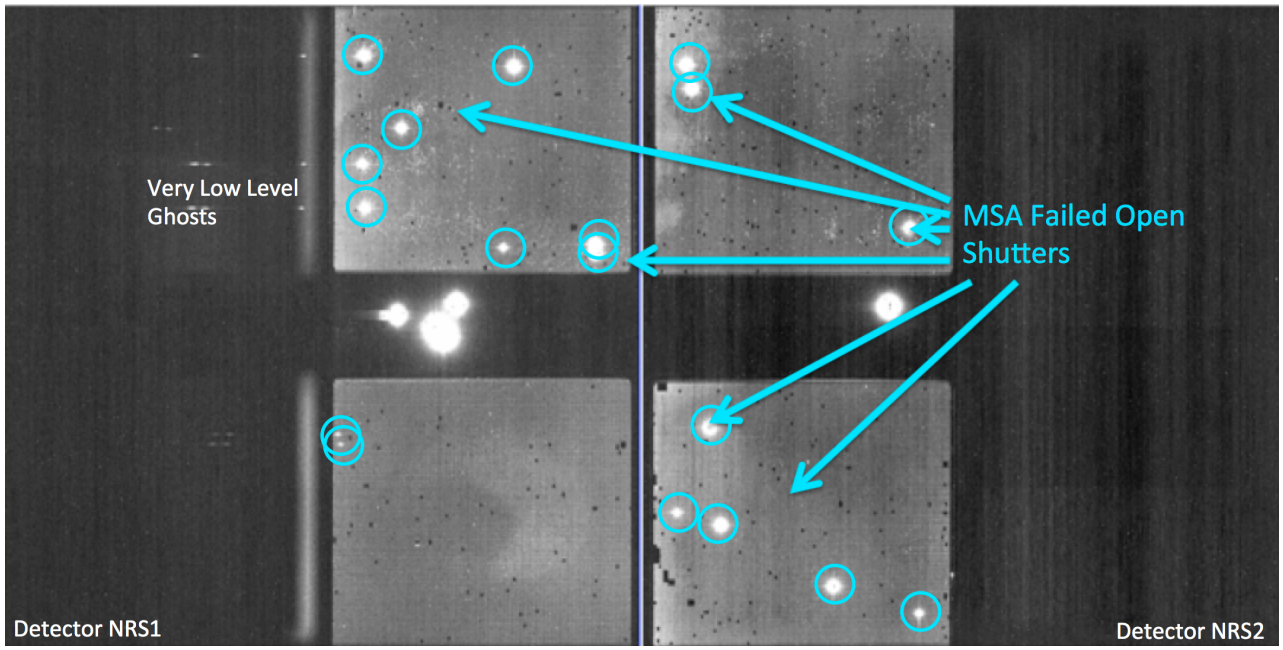
A tighter constraint yields more accurate photometry and higher flux, but may reduce the number of observable targets. Important for point sources.

Source Centering Constraint	Figure†	Minimum Relative Flux Transmission at 2.95 μm††	Margin (milli-arcsec)
Unconstrained (sources can be behind the MSA bars)		12%	0
Entire Open Shutter Area (default)		30%	38
Midpoint		62%	59
Constrained		75%	72
Tightly Constrained		85%	91

Benefits of dithering

In addition to improving the sampling of the PSF and correcting for hot/bad pixels, dithering helps with:

- Improved background subtraction (Nodding)
- Recovers important wavelengths that could fall in the detector gap (Fixed dither)
- Mitigates effects of light leakage through the MSA
- Dithers also help to observe additional sources behind bars or mounting plate.
- MPT takes dithers into account and will attemt to observe as many sources as possible at all dithers.



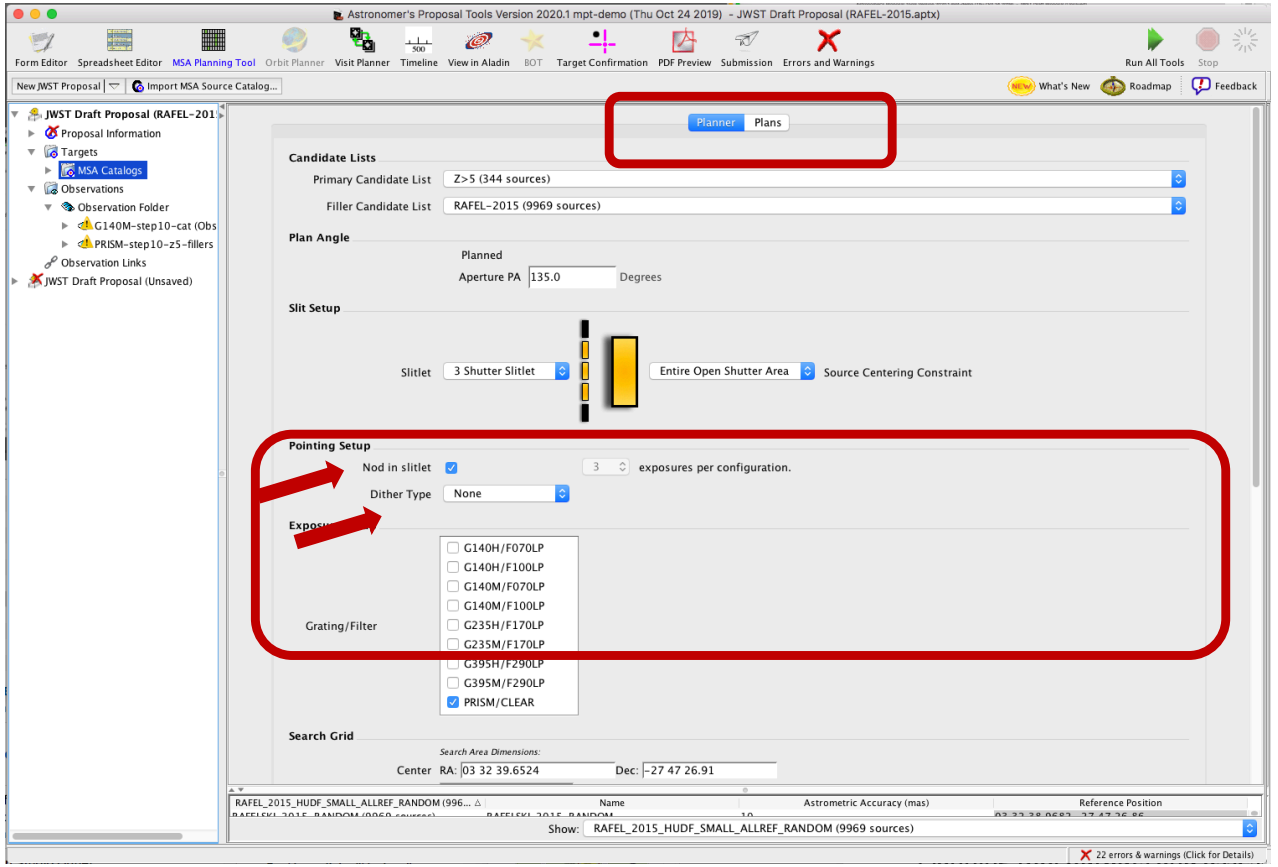
Specifying Dithers and Nods in the MPT Planner

The **Planner** is where you decide how to dither:

<u>Nodding</u> moves the sources within the slitlet – no shutter reconfiguration

<u>Fixed Dither</u> moves the sources by a finite number of shutters specified by the user along the dispersion and/or the cross-dispersion direction.

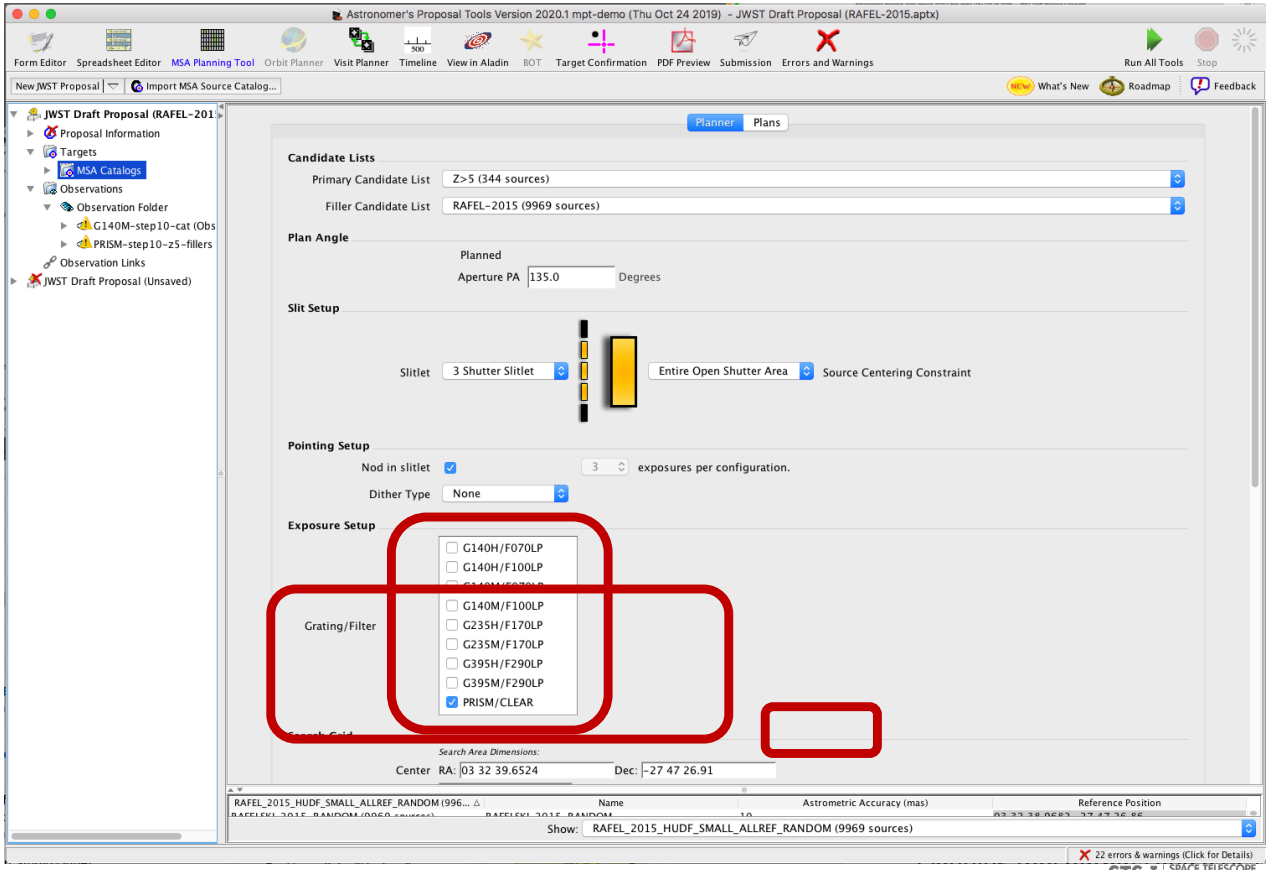
Nodding and dithering can be used together or independently.



A few more options, and then Create a Plan in MPT

Grating and Filter combination must be selected in the Planner (each has different masking to prevent spectral overlaps).

Can select "Use Weights" and "Enable Monte Carlo" to test randomly shuffled ordering of sources.



MSA Operability: Failed shutters and shorts

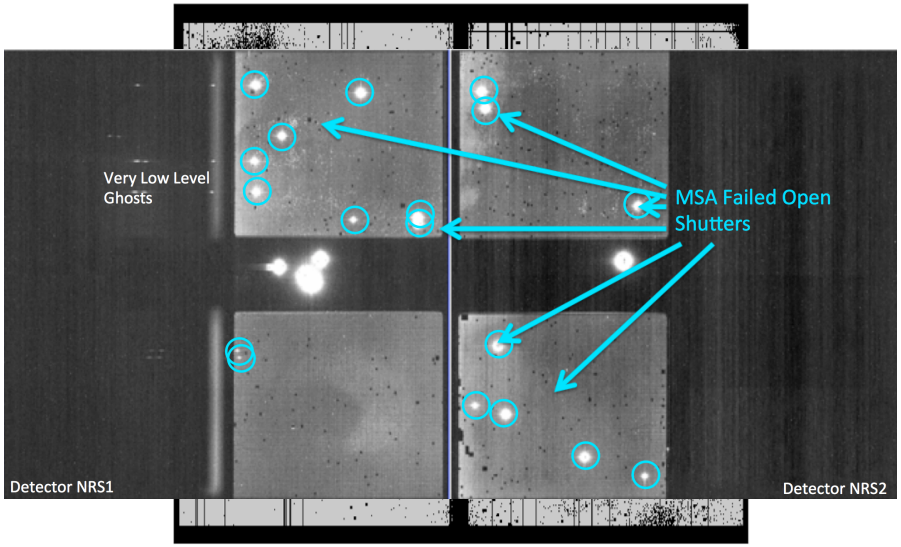
Some of the MSA shutters are not operable…

Failed Closed shutters affect sources that may happen to fall into them.

Shorts between columns and rows can occur, but are expected to be fairly stable.

Failed Open shutters have the most severe impact on the observations, and can prohibit observing sources over a sizeable area. Unintended spoilers can contaminate spectra of planned sources.

At each test pointing, MPT plans around failed shutters and shorts and searches for the optimal configuration. The latest operability information is used.

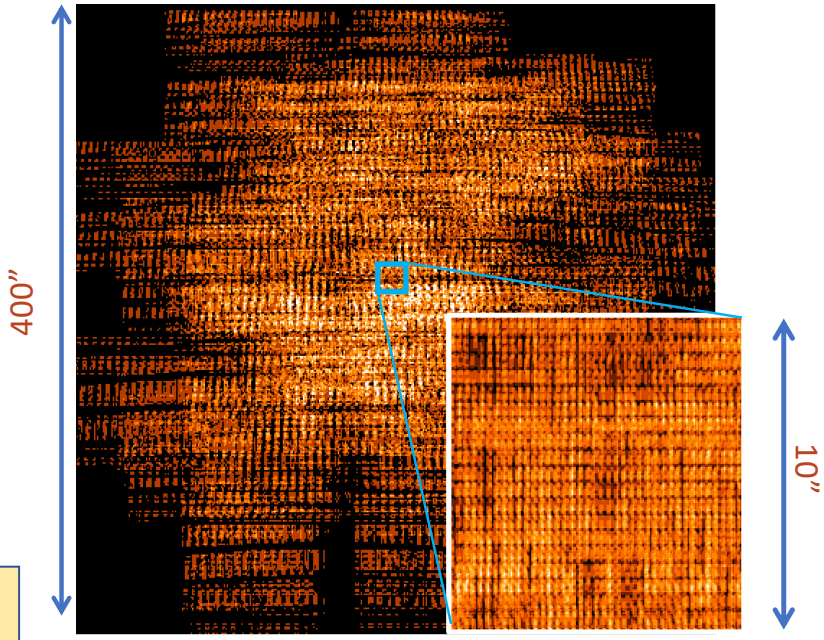


How MPT works

- The Catalog sources are mapped to the MSA plane.
- MPT creates a grid of test pointings over the area of the Primary candidate list using the user-specified search grid parameters.
- At each test pointing, MPT checks each source in the Primary list (in the order given) to find those that are in operable shutters and within constraints set in the Planner, and that present no conflict to other selected sources. These checks are done at all of the points in the user-specified dither pattern before accepting a source.

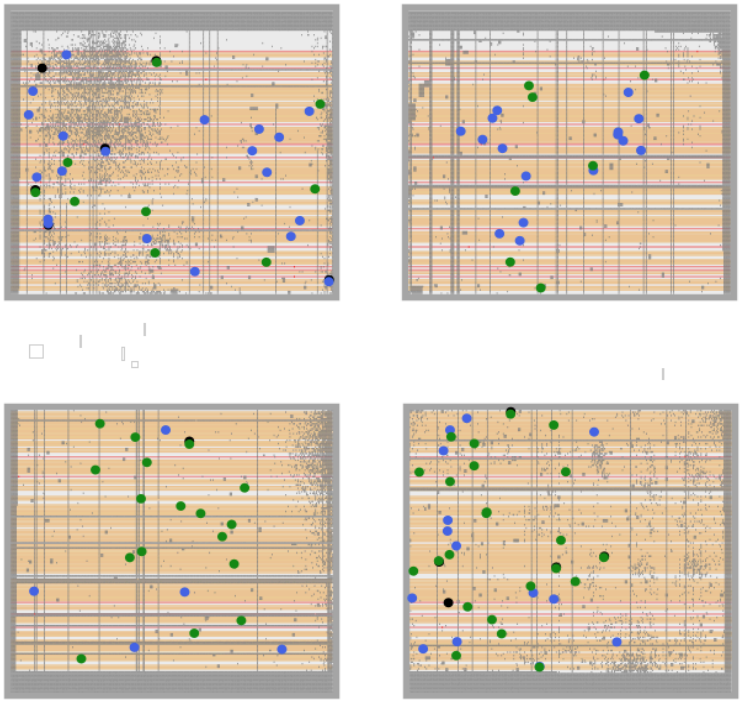
- At each test pointing, the weights of all observable primary sources in an MSA configuration are summed. These steps are repeated at each test pointing. The result is a Heatmap.

Heatmap:
Every point is the sum of source weights



How MPT works

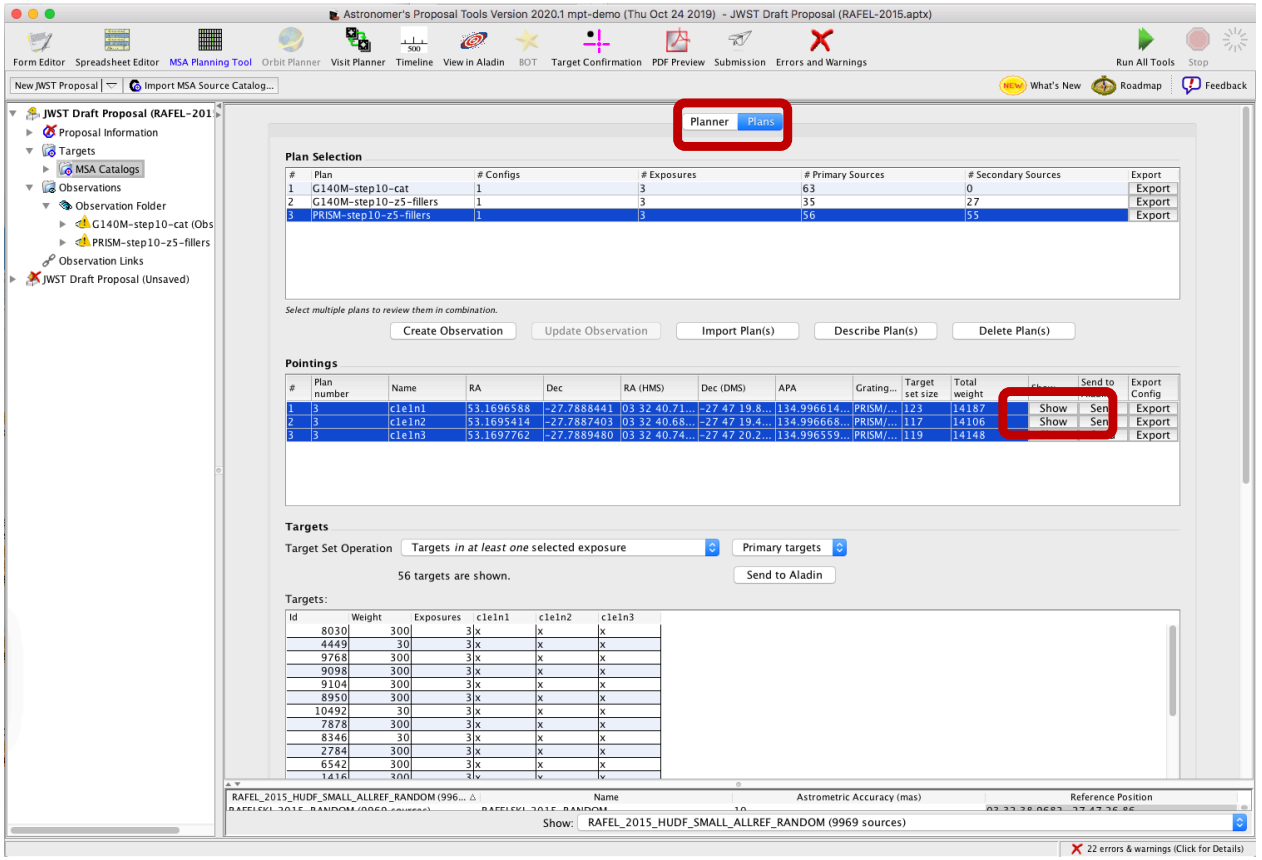
- The “best” pointing is selected. (Or, a **set of pointings,** if dithers were specified.)
- A Plan is created in MPT.
  - Plans have Pointings, a set of sources that will be observed, and associated MSA configurations.
- One or more Plans are selected by the user and made into an Observation.



Examine and Visualize Plan Results

Examine plan results in the Plans pane of MPT

- MSA shutter view
- Collapsed shutter view

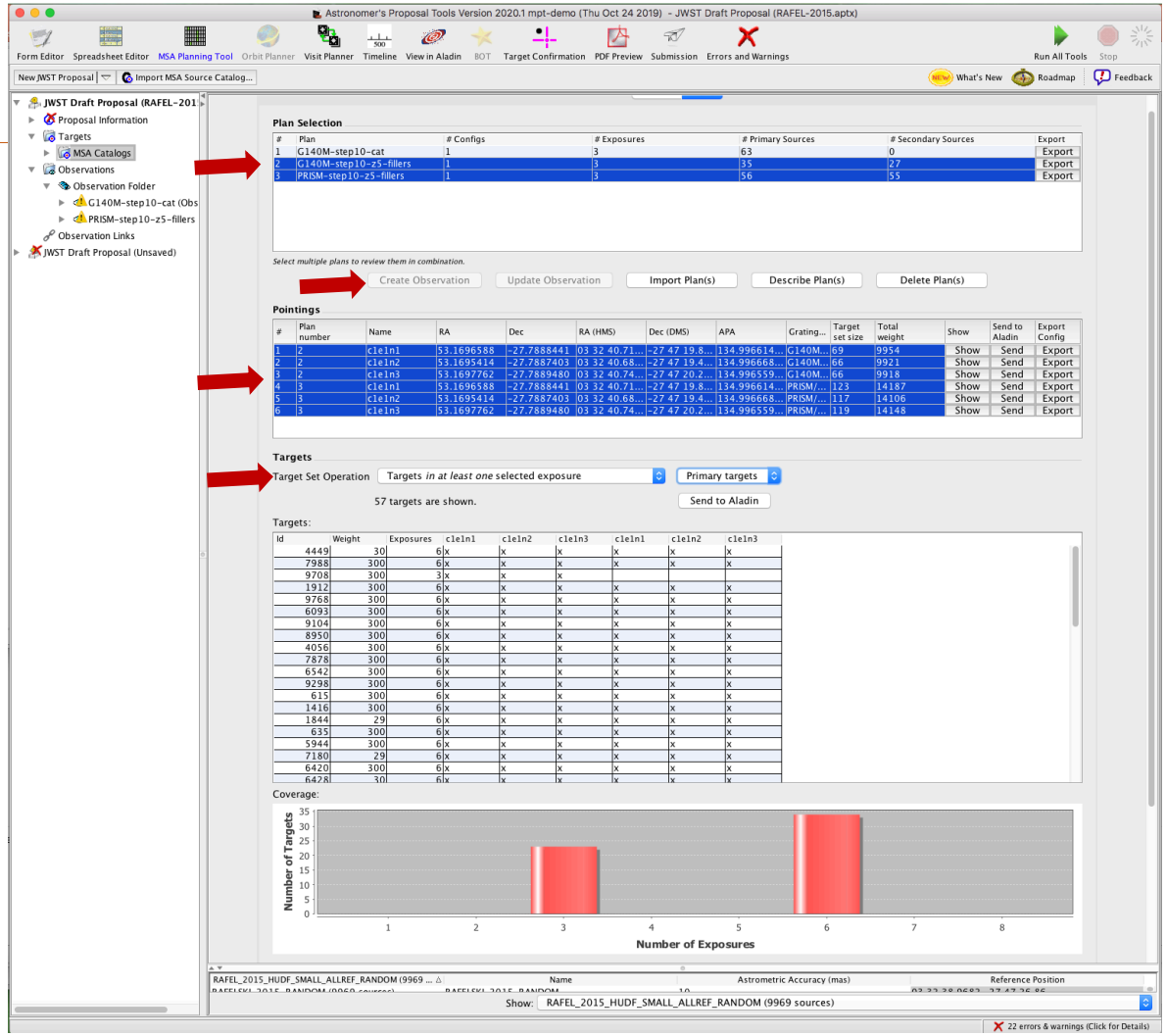


Create an Observation

Examine plan results in the Plans pane of MPT

- Highlight a Plan or Plans, and Exposures
- Filter results

...and Create an Observation!



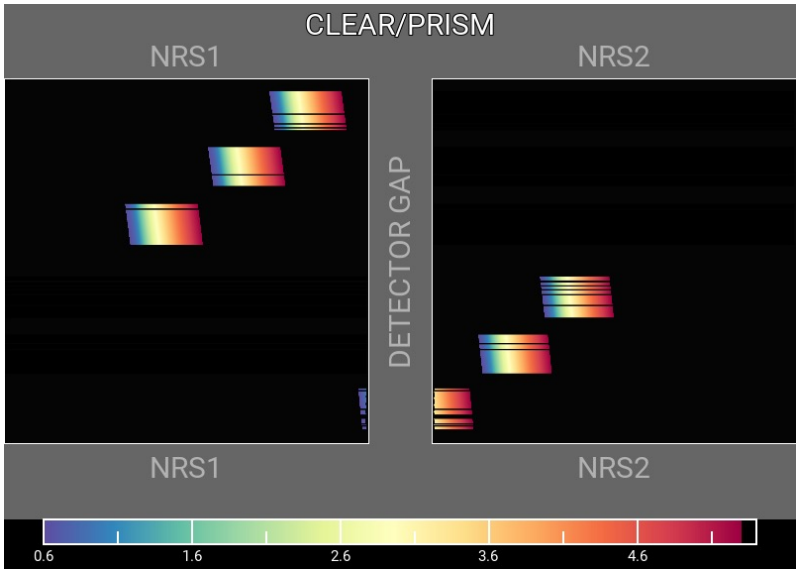
MSA Spectral Visualization Tool

MSAVis is a standalone tool that can be downloaded from GitHub.

It takes the export file “MPT Target Info” output from MPT and projects the spectra of the observed targets on the 2 NIRSpec detectors for both visual inspection and a report indicating wavelength cutoffs.

Instructions to download, install and run MSAVis can be found in the NIRSpec JDox:

https://jwst-docs.stsci.edu/near-infrared-spectrograph/



Take Away

- New version of MPT will be available for the Cycle 1 call for proposal – easier to use, more intuitive and discoverable, lighter
- Need high precision relative astrometry – 5-20 mas for point sources – up to 50 mas for extended objects
- MOS is one of the very few observing modes of JWST that will follow a multi-step planning process.
- MOS requires an aperture position angle – it is assigned by STScI (although it may be requested at the time of call for proposals, but have to be strongly justified)
- NIRSpec overheads for MSA are considerable – USE MPT to have a good estimate
- You can use MSAVis to verify that wavelengths are properly sampled
- You can use NOVT to visualize NIRCam pre-imaging relative to MSA observations
- Dither! Dither!! Dither!!! It improves background subtraction, wavelength coverage, etc.


END

Helpful Hints

- Order the input Catalog by target weights prior to ingest into MPT. When building an MSA configuration, MPT tries adding sources in the order they appear in the Catalog.
- Include Primary candidates in the Filler list to obtain extra observations of them.
- Only the weights of the Primaries matter (not the Fillers), so to help ensure observations of certain sources, include them in the Primary candidate list.
- Add Fillers to maximize efficiency/multiplexing.
- If feasibility windows are large, test several APAs to see if it makes a statistical difference. If so, set conservative limits on requested exposure time. Add an Orient SR only if needed, with a min range of 30 deg.
- If using the high-res gratings (G140H, G235H, G395H), attempt to get most sources onto the leftmost quadrants to avoid detector cutoffs.
- Use Aladin FoV to show the position of NIRCam parallells wrt NIRSpec MSA.
- Your catalog should be **complete** to be able to check for contaminants getting into Failed Open shutters, or into planned target shutters/slitlets.
- The MSA Config Editor can be used to make changes to your MSA configurations designed automatically with MPT. It's found at the observation level in APT.


EXPANDING THE FRONTIERS OF SPACE ASTRONOMY