STScI | SPACE TELESCOPE SCIENCE INSTITUTE

EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

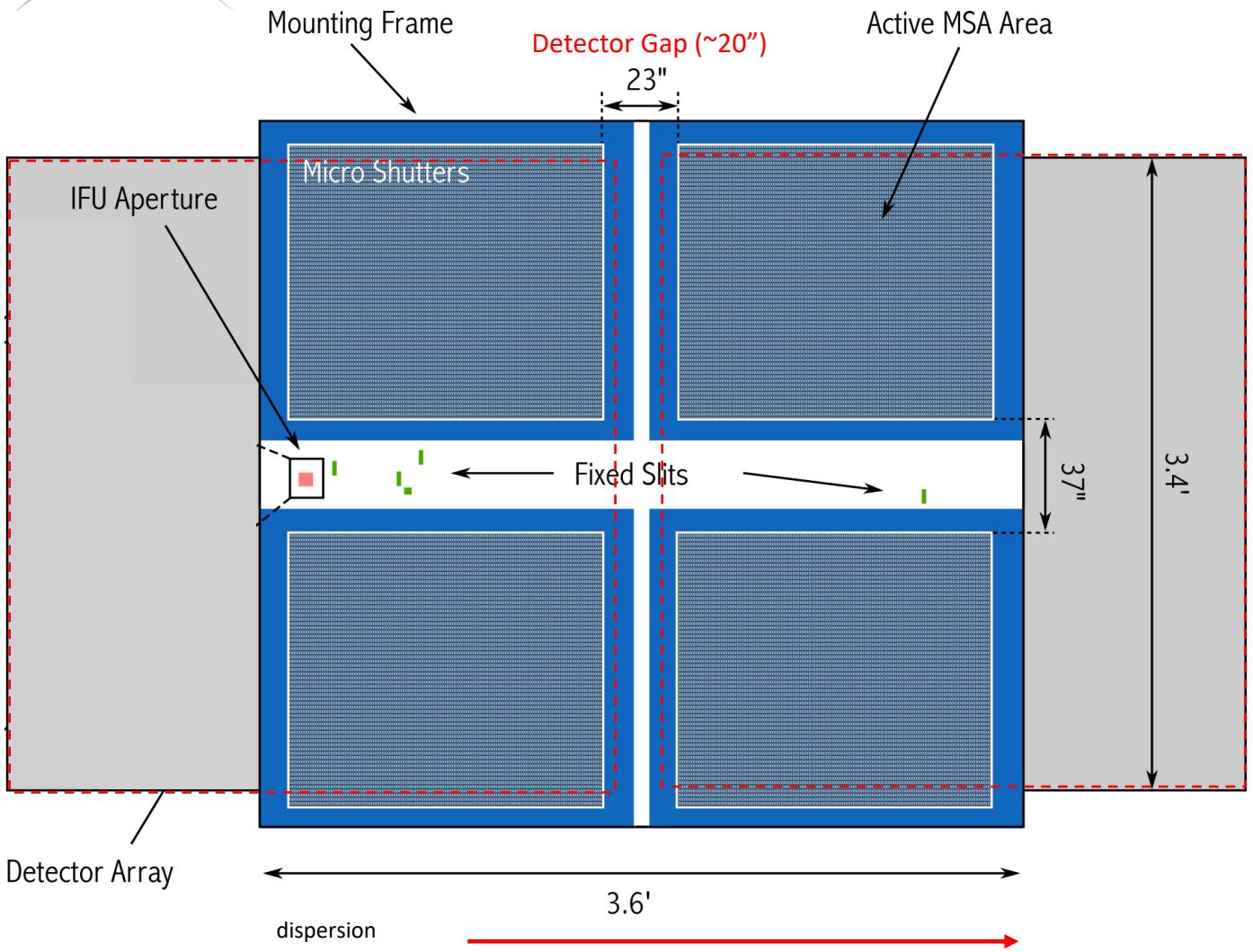
# Planning MOS Observations

JWST Master Class November 18-22, 2019

Diane Karakla, NIRSpec Instrument Team

# The NIRSpec Micro-shutter Assembly

# NIRSpec MSA for multi-object spectroscopy (MOS)




- The Micro-Shutter Assembly (MSA) is a 4 quadrant array of tiny configurable shutters. The entire array has nearly 250,000 shutters.
  - Each shutter is just 200 x 450 mas
- The MSA Field of View is ~3.6' x 3.4'
- 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 MOS Observing Process

# Multi-step process

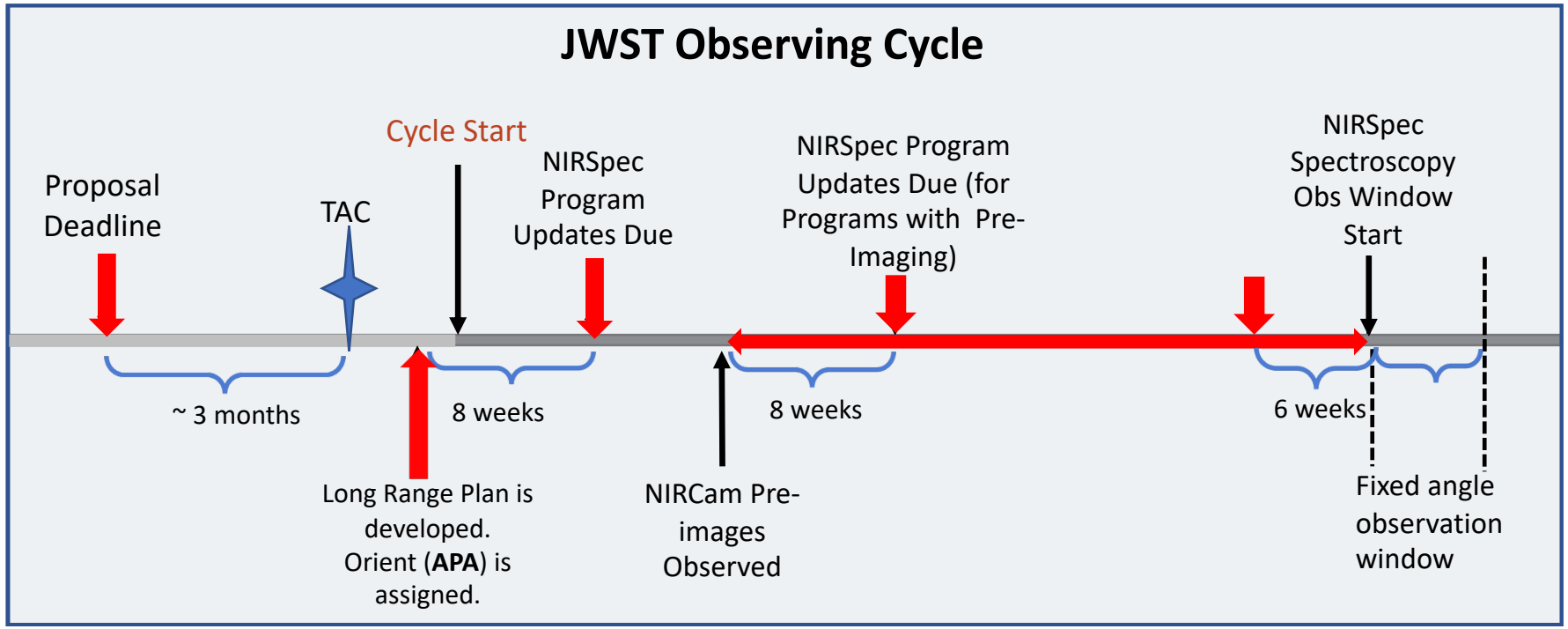
To accurately align science sources within the small MSA shutters, NIRSpec MOS mode observations must be planned and executed at a fixed instrument Aperture Position Angle (APA), assigned by STScI. Hence, a multi-step planning process.

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)

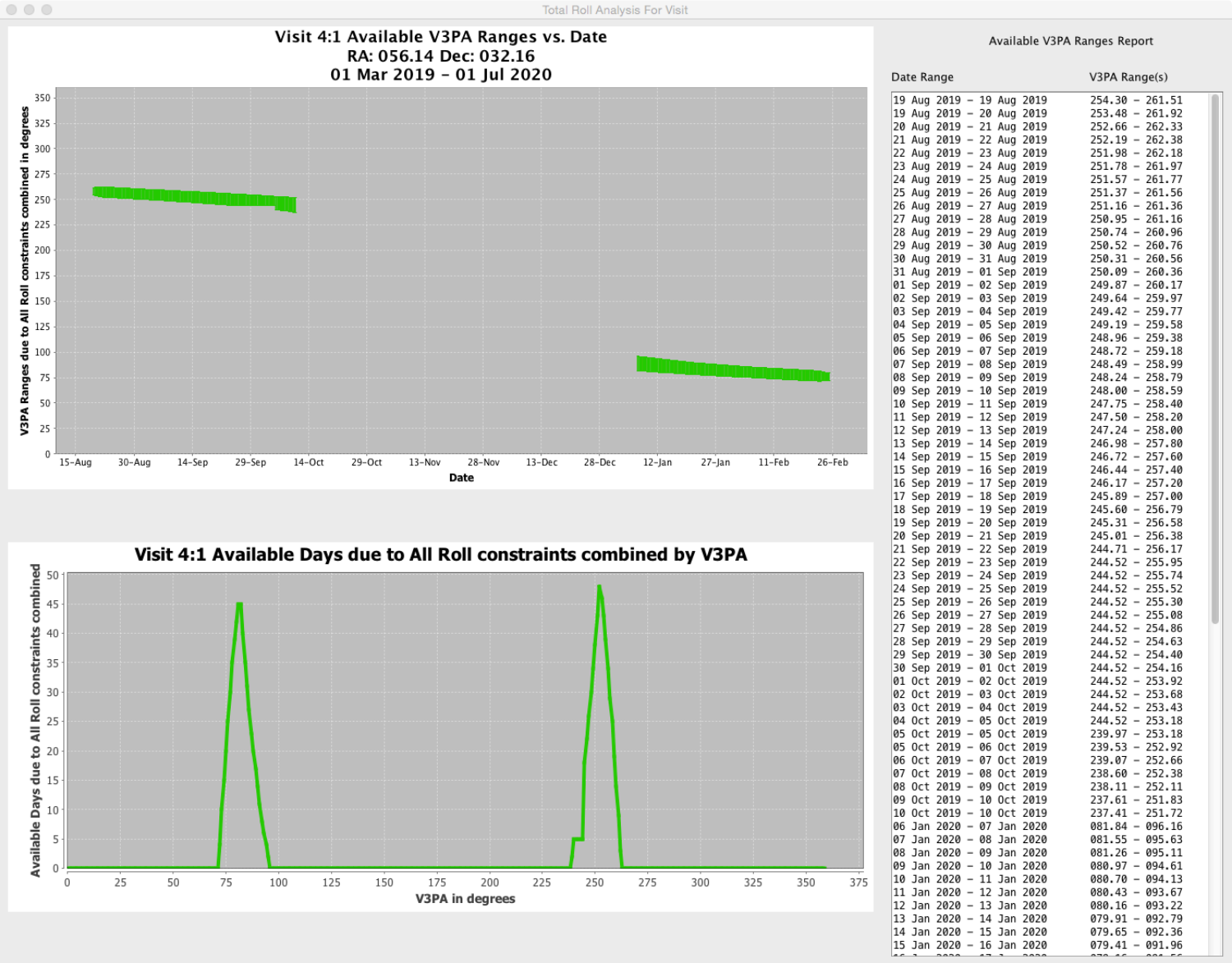
Or, 8 weeks after the NIRCam pre-imaging is observed.




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.

# Target visibility




For most targets, there will be two visibility windows, separated by about 180 degrees

Can assess the target visibility using the TVT or in APT using the Visit Planner

# Positional Accuracies, Target Acq, and Pre-imaging

# Pointing accuracies

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

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

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

# Target acquisition considerations

- Moving targets must use Wide Aperture TA. WATA does not require pre-imaging or reference stars, only a good ephemeris.
- For their Program Update submissions – observers will use MPT 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 for Cycle 1 requires 5-8 reference stars.
  - MPT will impose a limit of 8 maximum.
  - 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.
  - This means that **more than 8 suitable candidates** should be defined in the Catalog.
  - There are tradeoffs between increased accuracy and overheads.
  - The number will be adjusted if needed.

# Pre-imaging with NIRCam

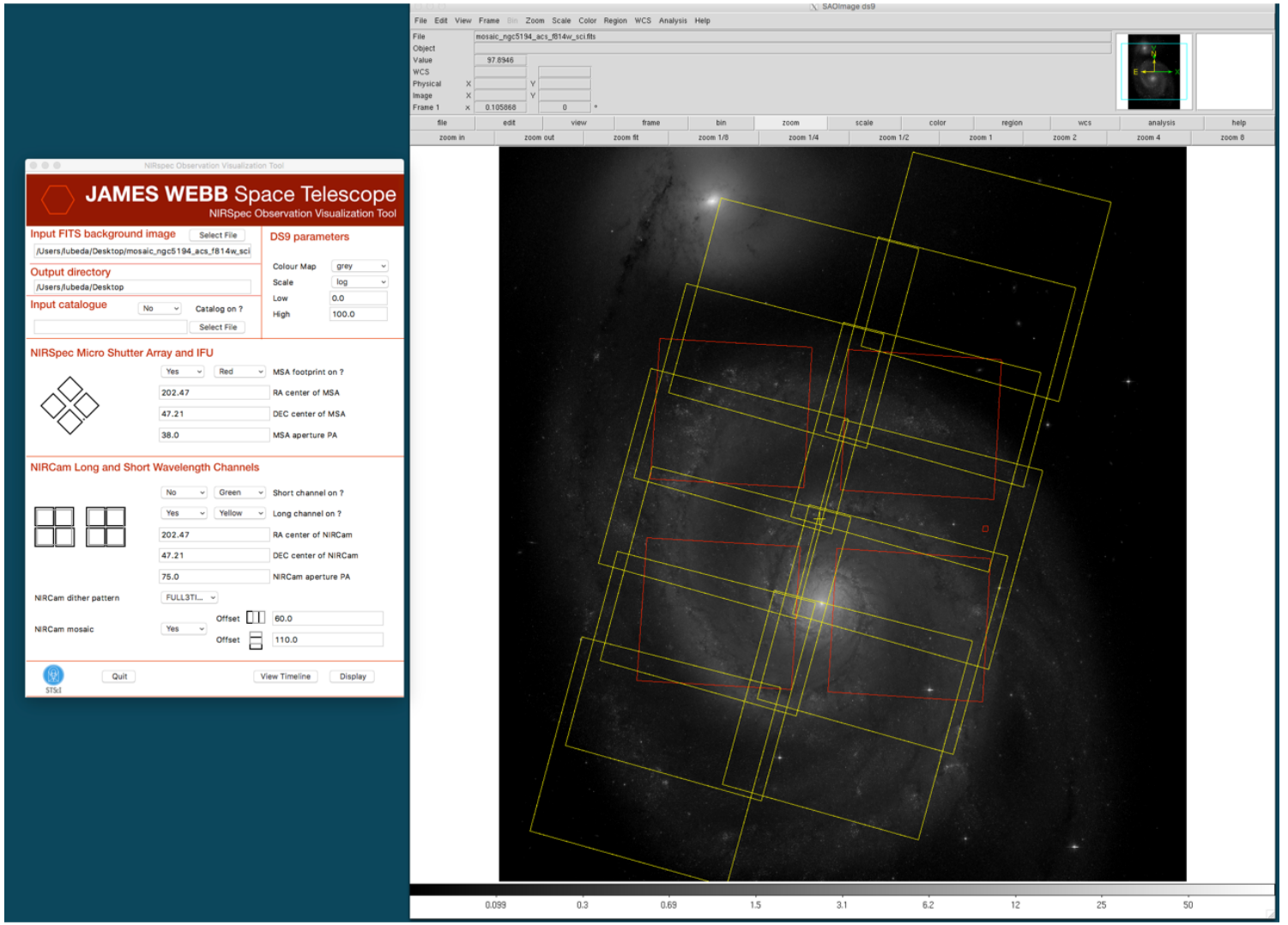
## Is imaging available that is :

- **Deep enough and wide enough** to identify sources and reference stars.
  - The brightest reference stars must be no brighter than 18-19$^{th}$ mag.
- **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 a 2x1 mosaic + dithers to cover the gaps.
- NIRCam observations must be fully executable at proposal submission.

## NIRSpec Observation Visualization Tool, NOVT (L. Ubeda)



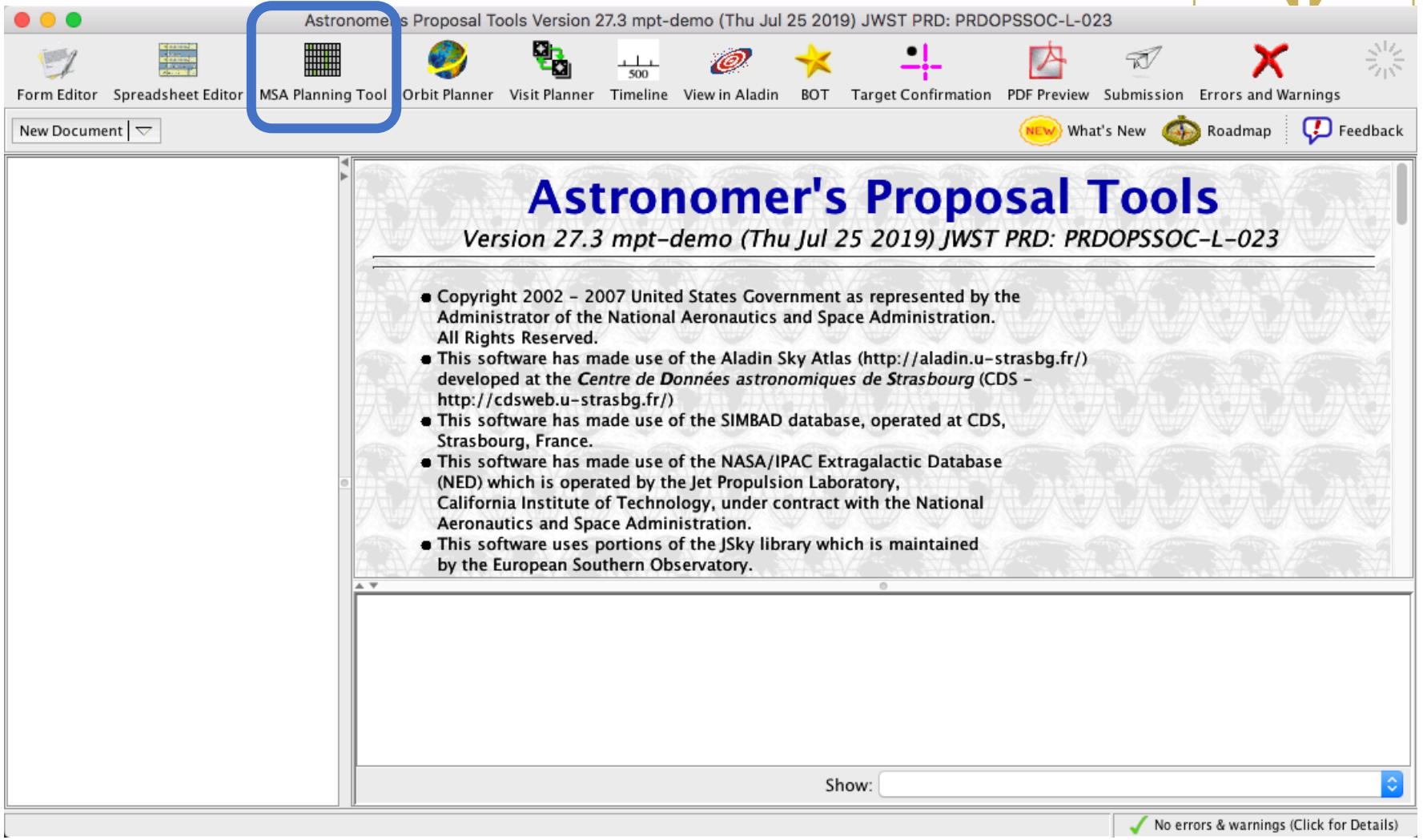
# The MSA Planning Tool in APT

# The MPT Cast

| | | | | |
|---|---|---|---|---|
| Tracy Beck | Gary Curtis | Tom Donaldson | Karrie Gilbert | Josh Goldberg |
| Rob Hawkins | Alaina Henry | Diane Karakla | Susan Kassin | Ernie Morse |
| Andrew Myers | Daniel Nemergut | Karla Peterson | Klaus Pontoppidan | Christine Ritchie |
| Sasha Shyrokov | David Soderblom | Andrew Spina | Jeff Valenti | Emily Wislowski |

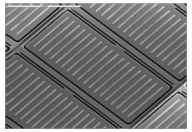
# MSA Planning Tool (MPT) in APT

- NIRSpec MOS observing mode is able to obtain spectra of tens to hundreds objects within the 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” )

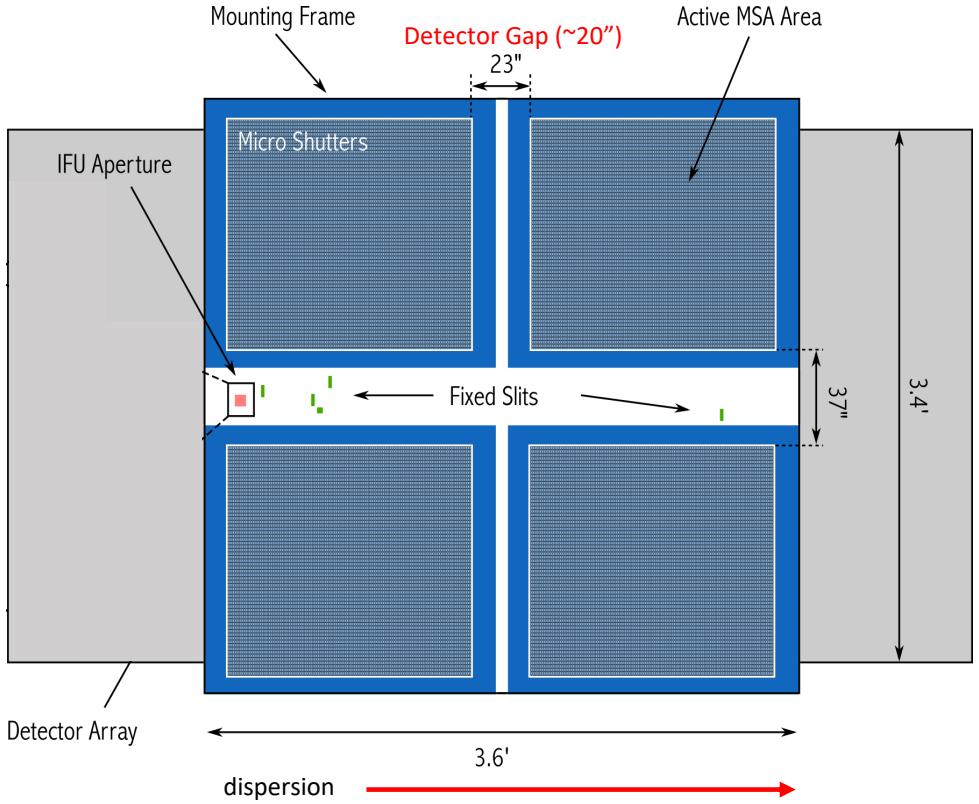


# Why use MPT?

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

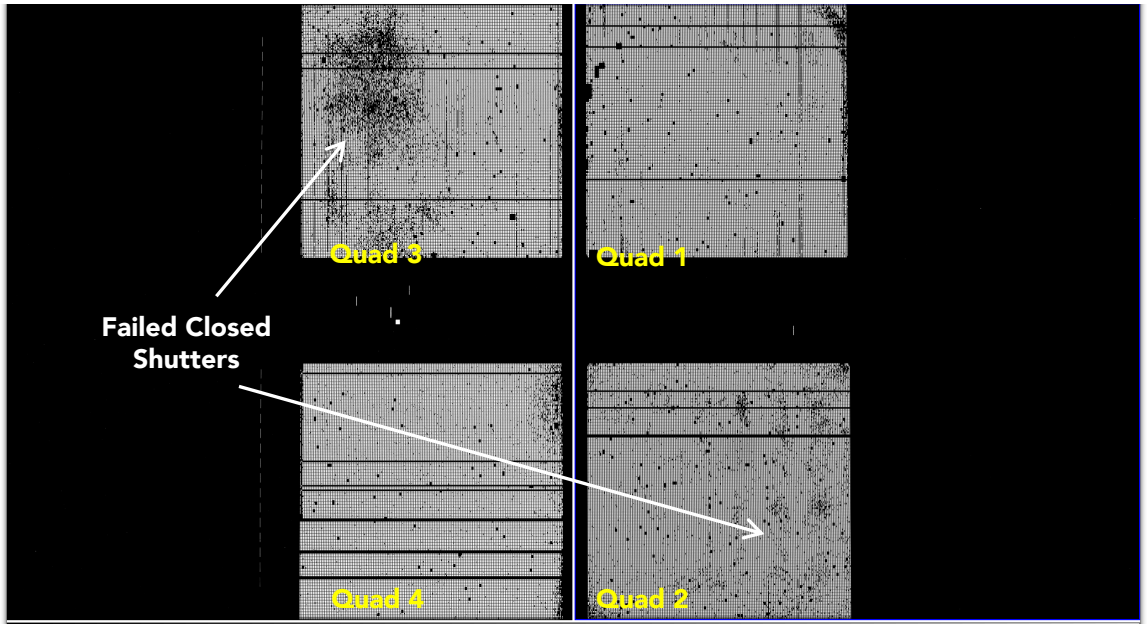


- There is a gap between the 2 detectors → missing wavelengths.




- 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.

Shutter Operability



# 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 astrometric Catalog**
  - ➢ With accurate source positions (< 15 mas relative accuracy for optimal TA) – may require NIRCam pre-imaging.
  - ➢ "Complete" to indicate when planned sources are impacted by nearby sources.

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 - create a complete catalog of sources. The catalog should include all known sources in the field.

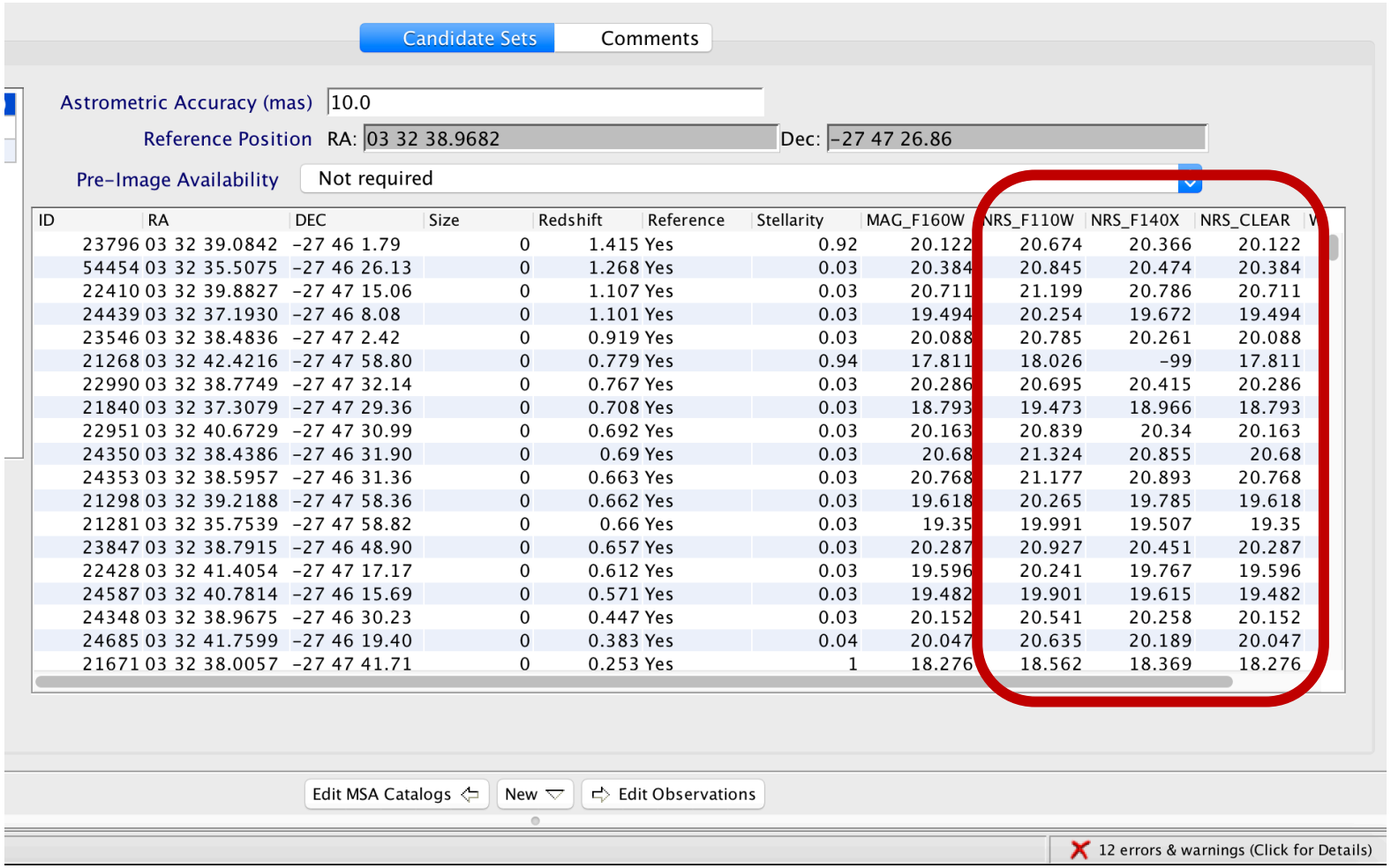
- The source catalog is an ASCII file
- It must contain J2000 RA and Dec expressed in degrees or hexadecimal units.
- It cannot have duplicate IDs nor NULL entries.
- A header is optional. The header is marked with "#".

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 40 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 | |

# 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. (The tool will be made available in time for updates.)




| ID | RA | DEC | Size | Redshift | Reference | Stellarity | MAG_F160W | NRS_F110W | NRS_F140X | NRS_CLEAR |
|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

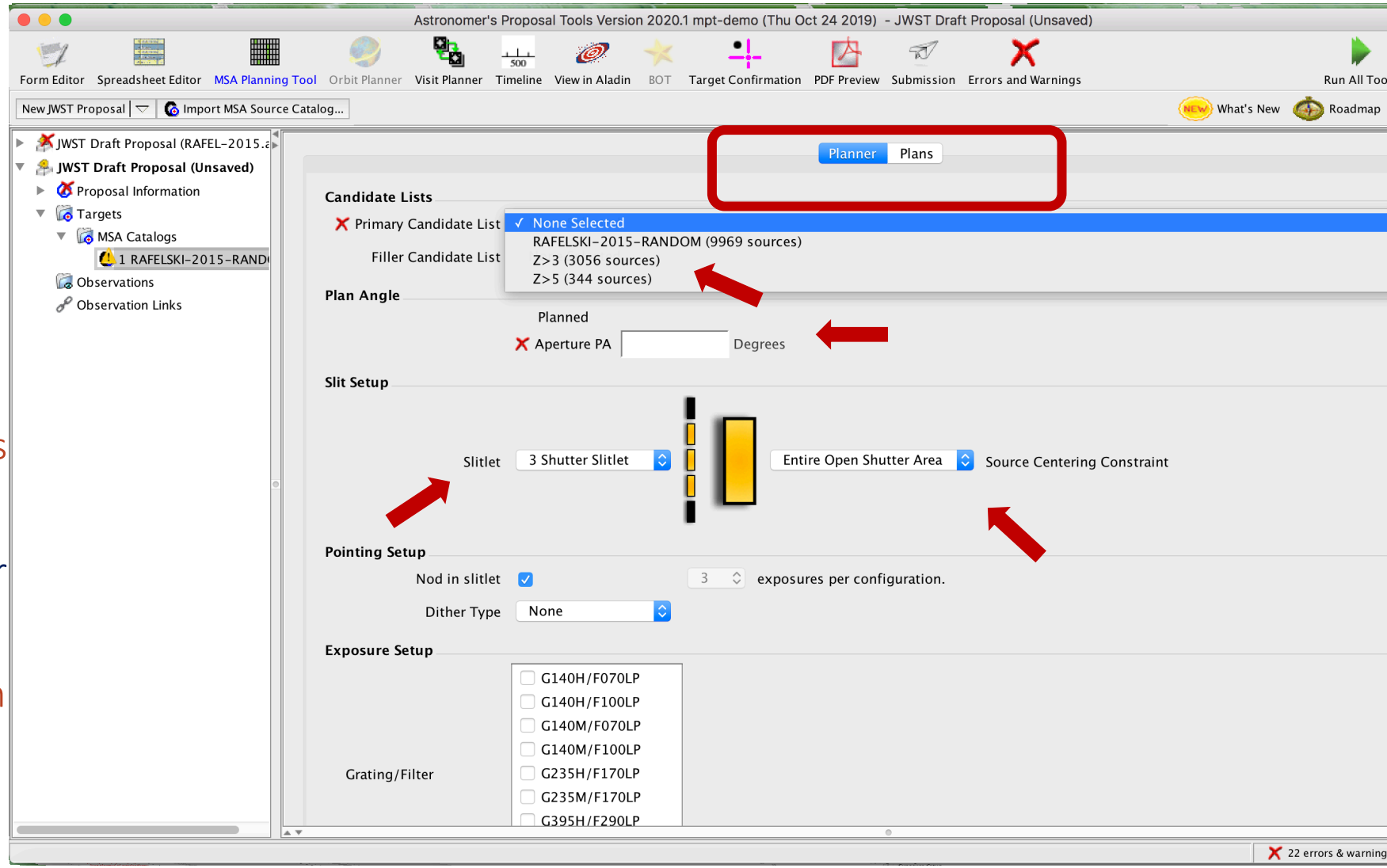
# The MPT Planner
# Making a plan for an observation

# The MPT Planner

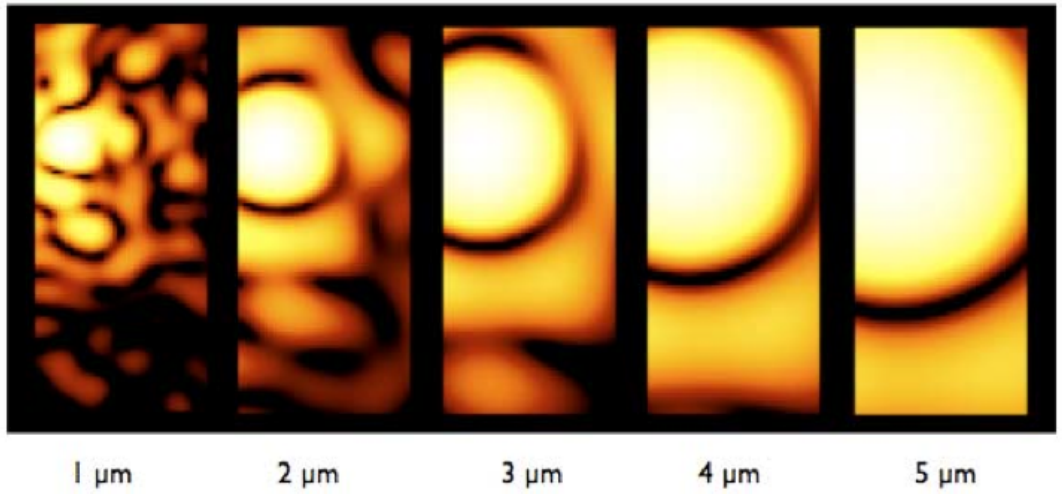
In the MSA Planning Tool -

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 on the source shutter yields more accurate photometry and higher flux, but may reduce the number of observable targets. Important for point sources.

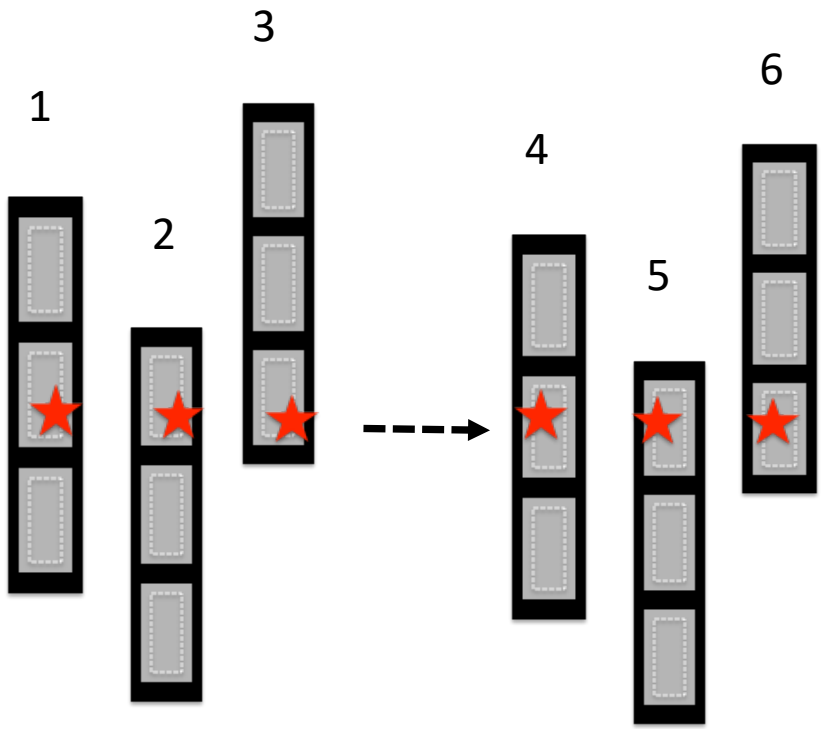
| Source Centering Constraint | Figure† | Minimum Relative Flux Transmission at 2.95 μm†† | Margin (milli-arcsec) |
|---|---|---|---|
| ***Unconstrained*** (sources can be behind the MSA bars) |  | 12% | 0 |
| ***Entire Open Shutter Area*** (default) |  | 30% | 38 |
| ***Midpoint*** |  | 62% | 59 |
|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

# The benefits of dithering

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

- Improve background subtraction (Nodding)
- Recover important wavelengths that could fall in the detector gap (Fixed dither)
- Mitigate the effects of light leakage through the MSA
- Observe additional sources behind bars or mounting plate.

Nod in 3-shutter slitlet: 3 exposures




**Fixed dithers**: MSA is reconfigured at the new dither point.

MPT takes dithers into account and will attempt to observe as many sources as possible through a set of dithers.

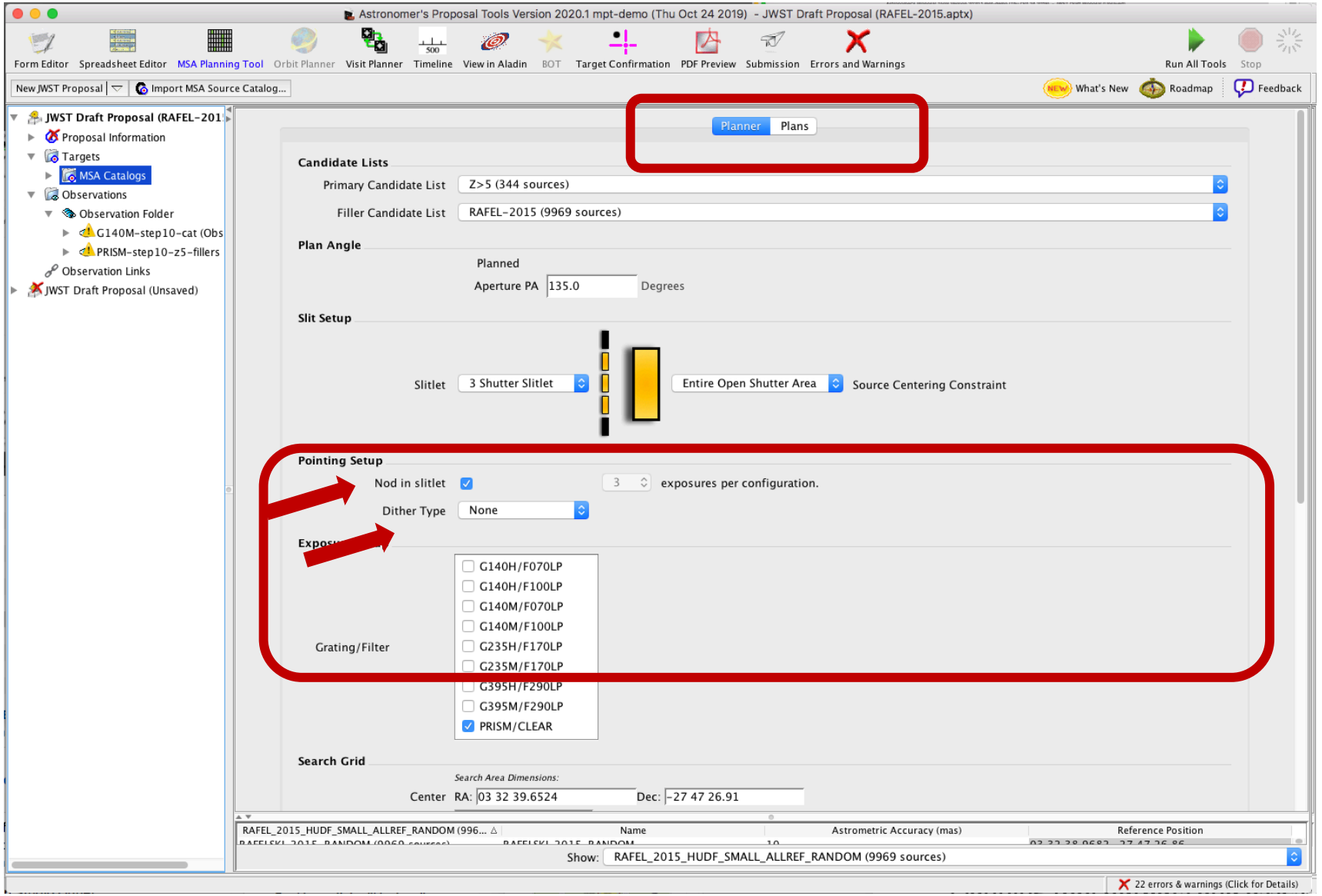
# Specifying dithers and nods in the MPT Planner

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

**Nodding** moves the sources within the slitlet – no MSA reconfiguration.

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

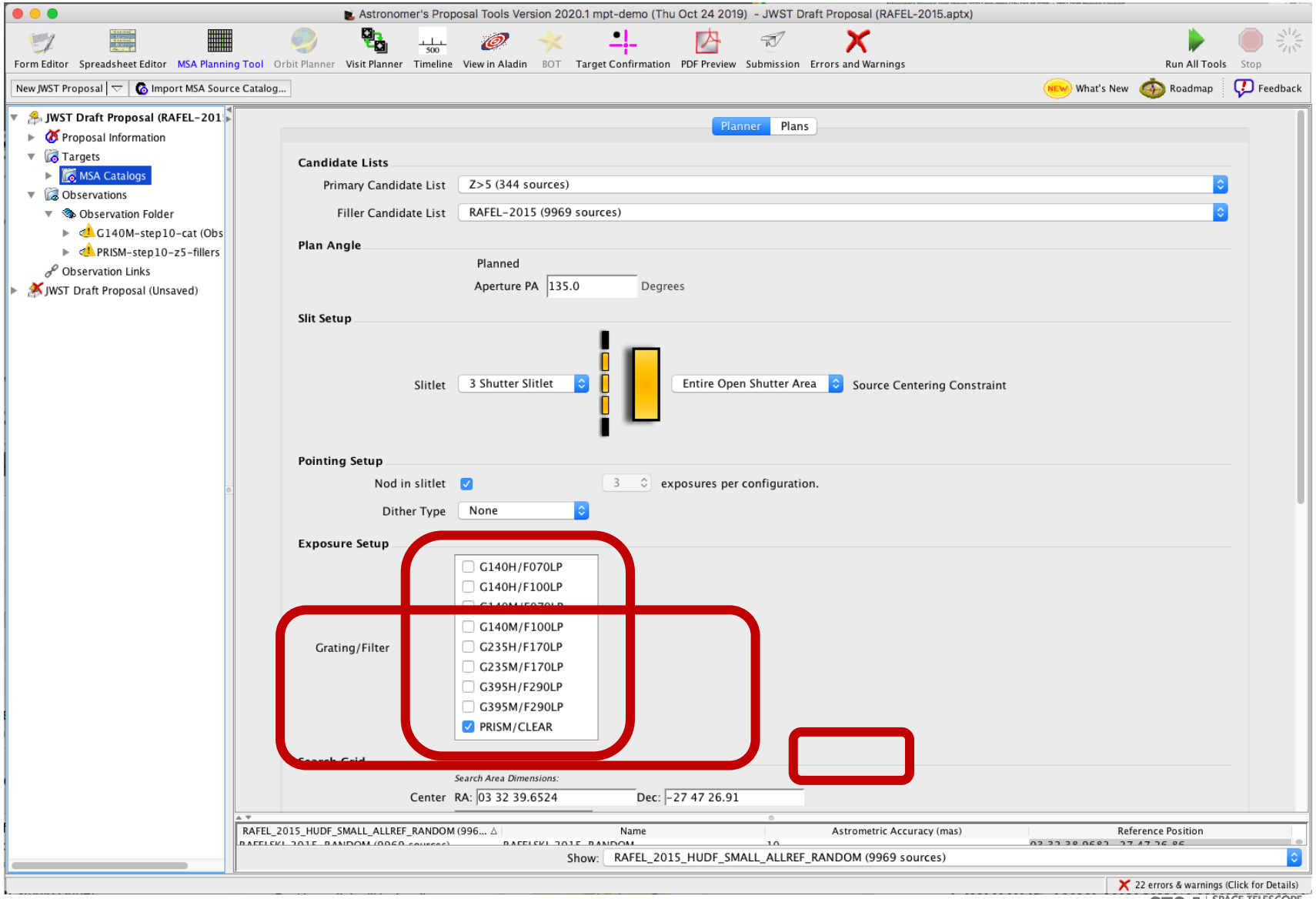
Nodding and dithering can be used together or independently.



# 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

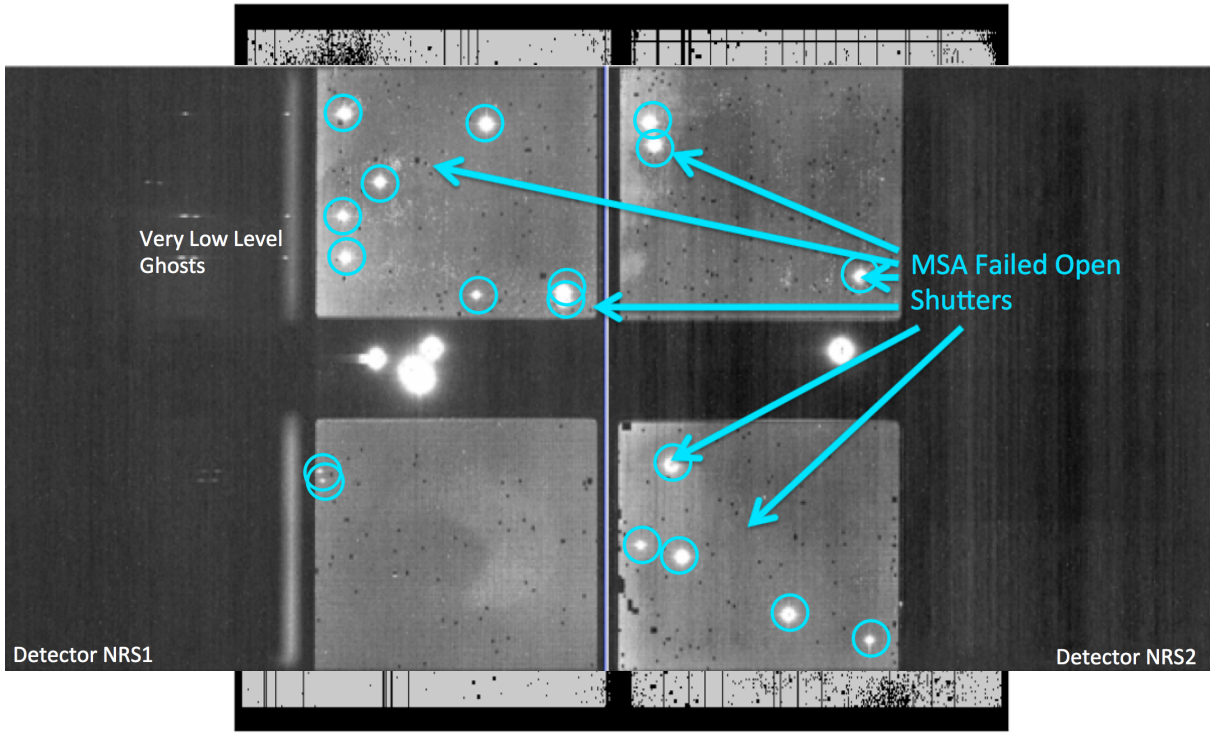
Some of the MSA shutters are not operable…

**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.

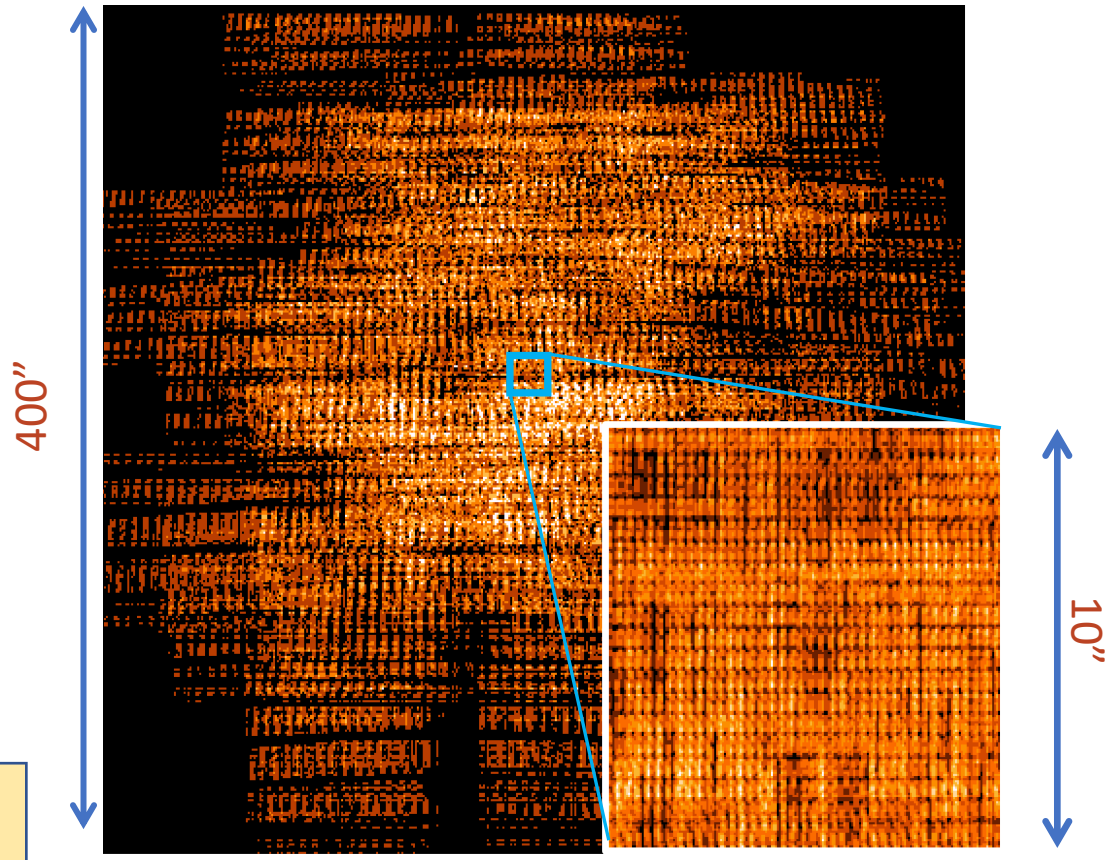
At each test pointing, MPT plans around failed shutters and shorts and searches for an optimal MSA configuration. The latest operability information is used.



# How MPT works

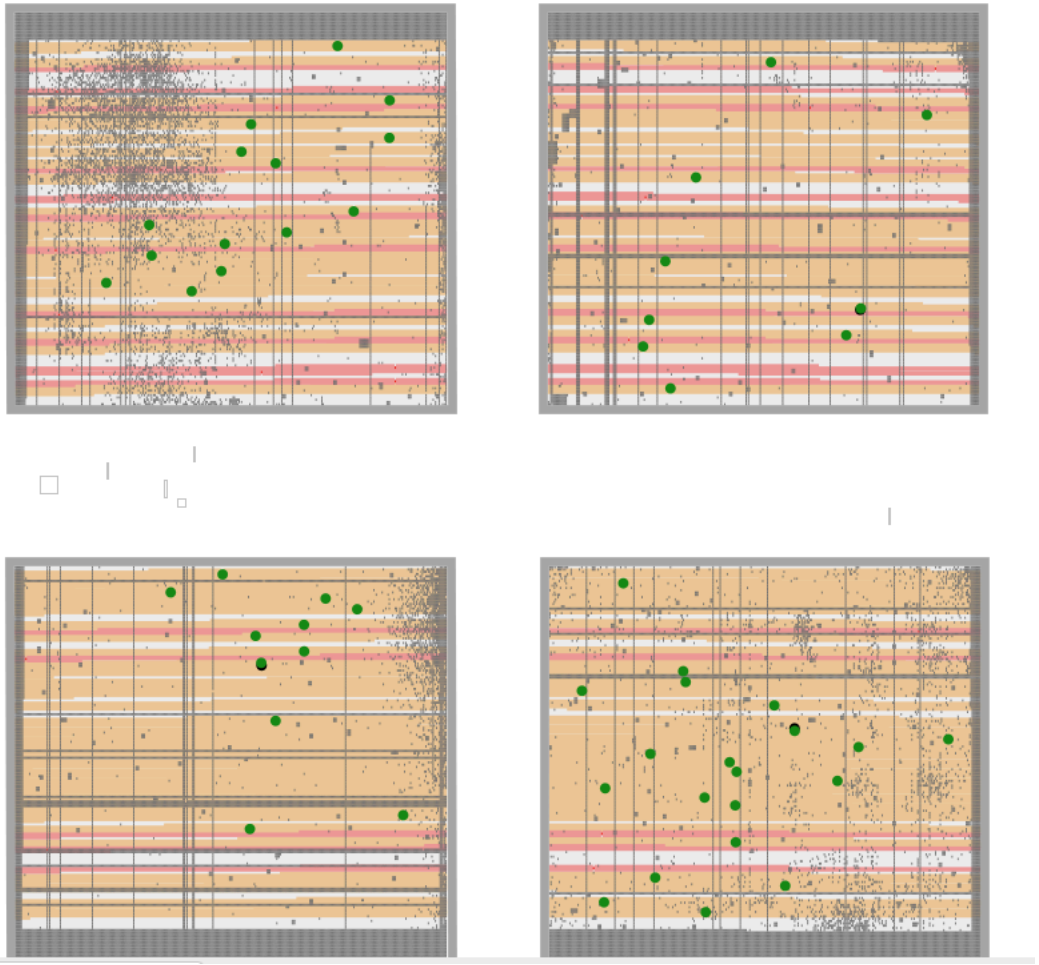
- The Catalog sources are mapped to the MSA plane.
- MPT creates a grid of test pointings over the area of the Primary candidate list using the user-specified search grid parameters.
- At each test pointing, MPT checks each source in the Primary list (in the order given) to find those that are in operable 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.) These are solely based on the Primary candidates.
- The MSA configs for the selected pointings are built, and Filler sources are added.
- 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.

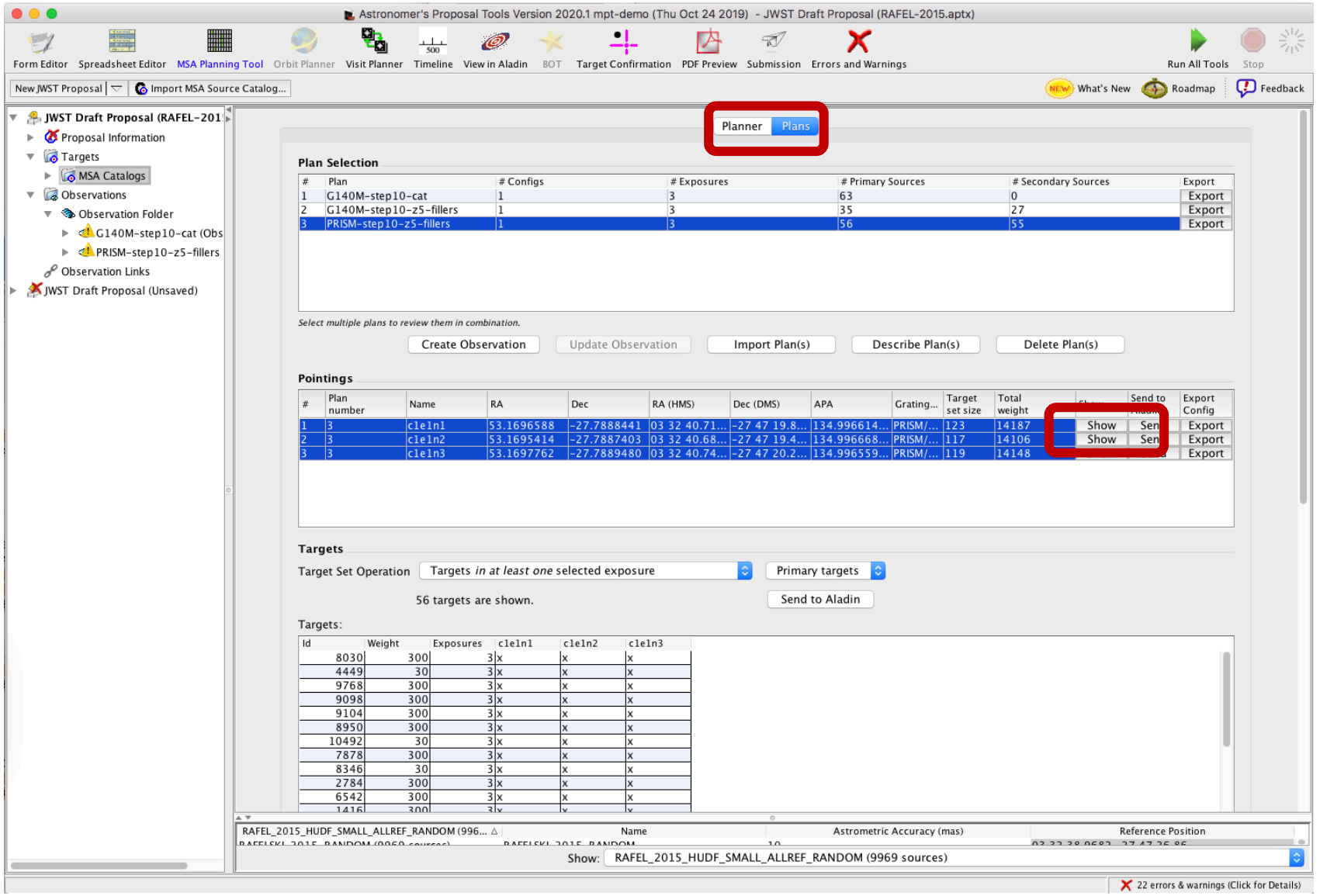



The MPT Plans
Evaluating and selecting plans for an observation

# Examine and visualize Plan results

Examine plan results in the Plans pane of MPT

- MSA shutter view
- Collapsed shutter view



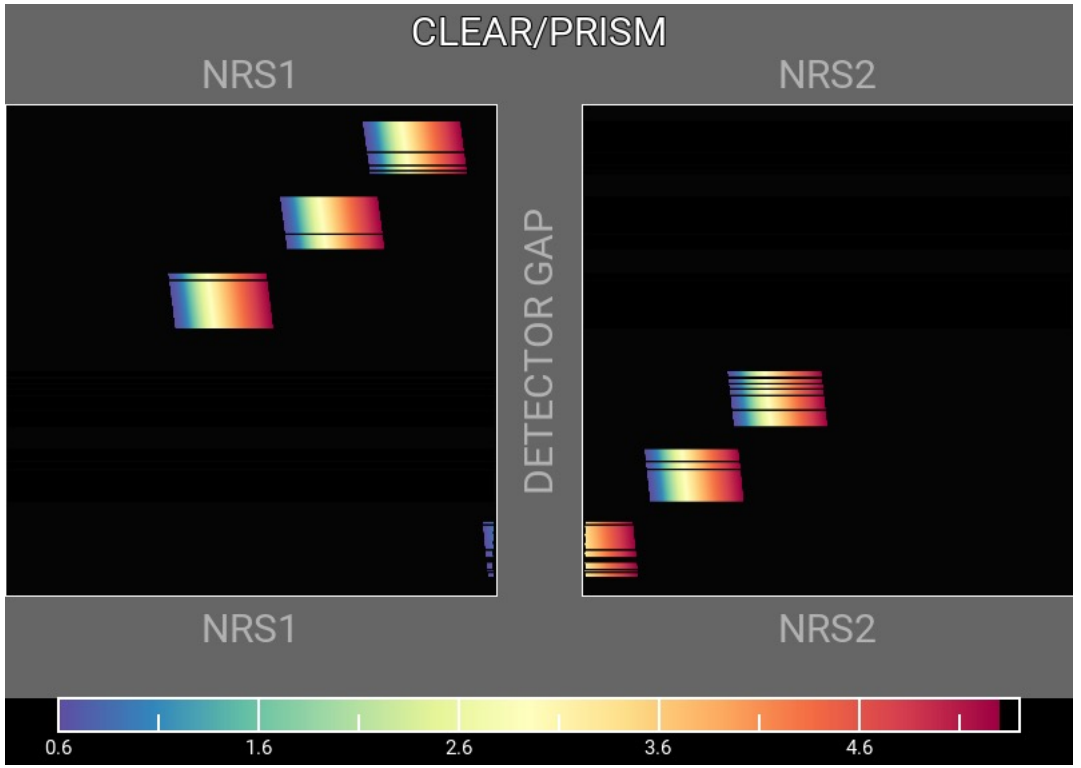
# MSA Spectral Visualization Tool

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

It takes the export file “MSA 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/




G. Kanarek

# Take Away

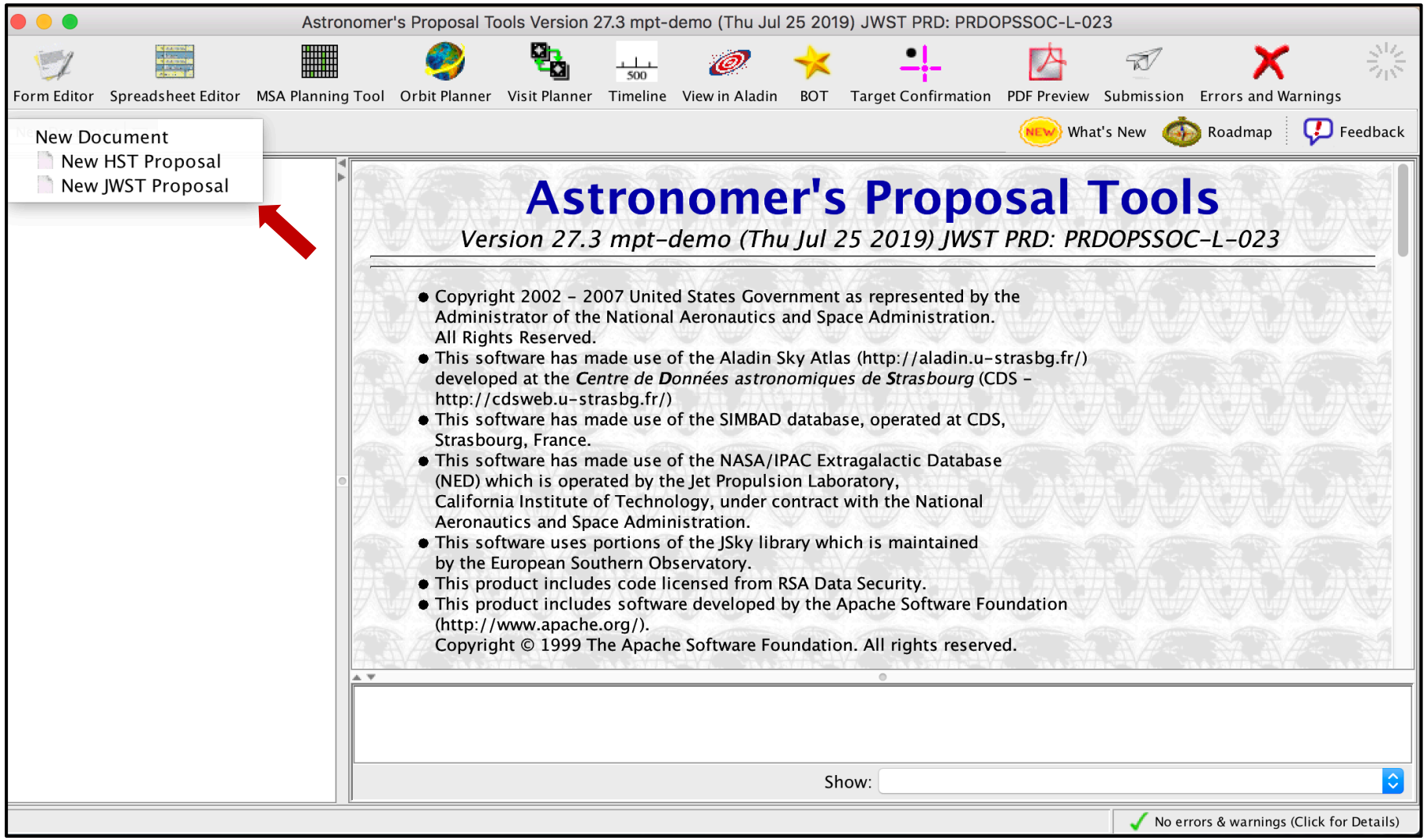
- New version of MPT will be available for the Cycle 1 call for proposal – easier to use, more intuitive and discoverable, lighter.
- Need high precision relative astrometry – 5-15 mas for point sources – up to 40 mas for extended objects.
- MOS is one of the very few observing modes of JWST that will 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 Nirspec Obs Visualization Tool (NOVT) to visualize NIRCam pre-imaging relative to MSA observations.
- Dither! Dither!! Dither!!! It improves background subtraction, wavelength coverage, etc.

# 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 if you want to obtain observe more 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, **with appropriate weighting**.
- 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 20 - 30 deg.
- If using the high-res gratings (G140H, G235H, G395H), try to get your sources onto the leftmost quadrants to avoid red-end detector cutoffs.
- Use Aladin FoV to show the position of NIRCam parallells with respect to the 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.

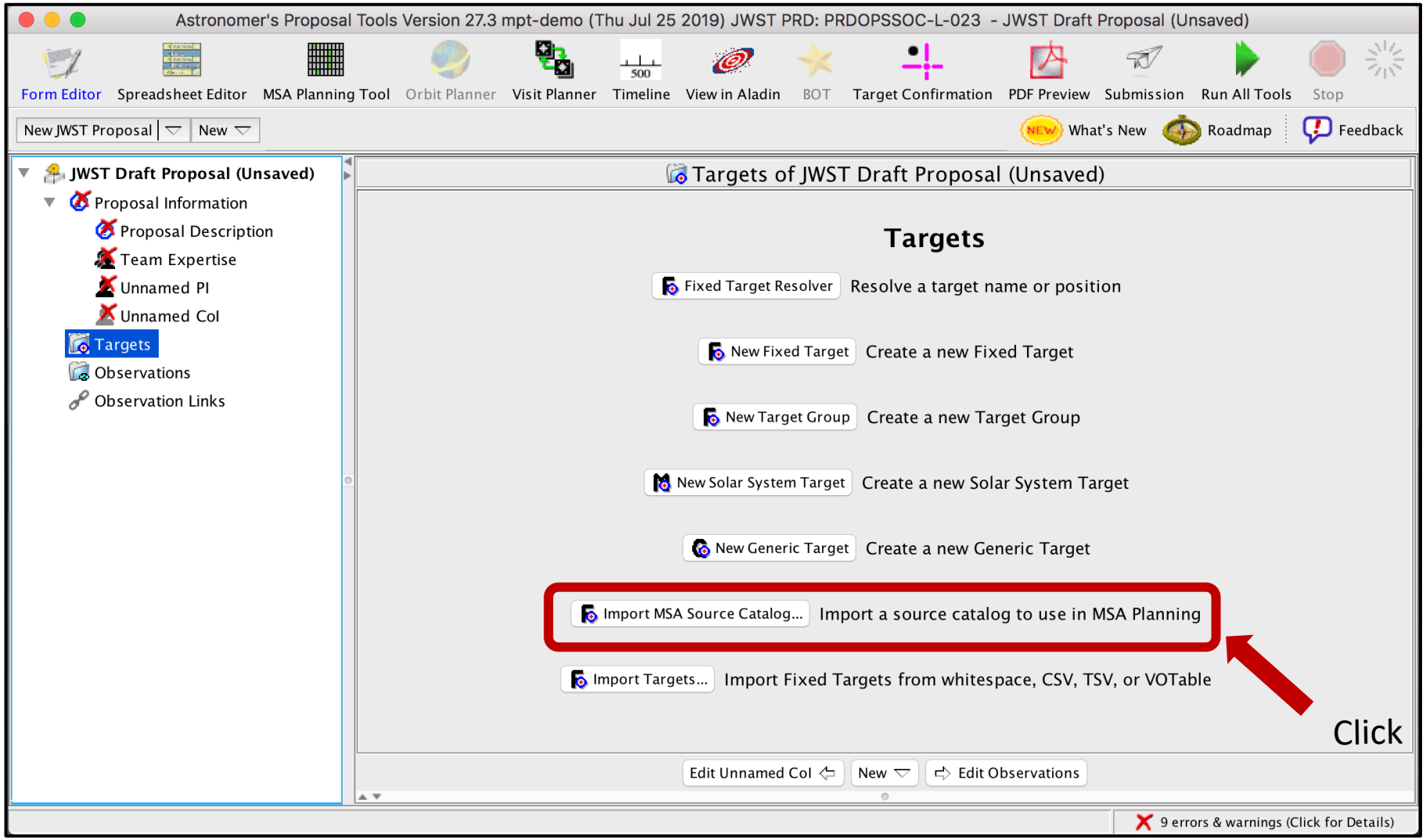

END

# Starting from scratch in APT



# Load the Catalog as an MSA Catalog Target

Notice that we are in the Form Editor

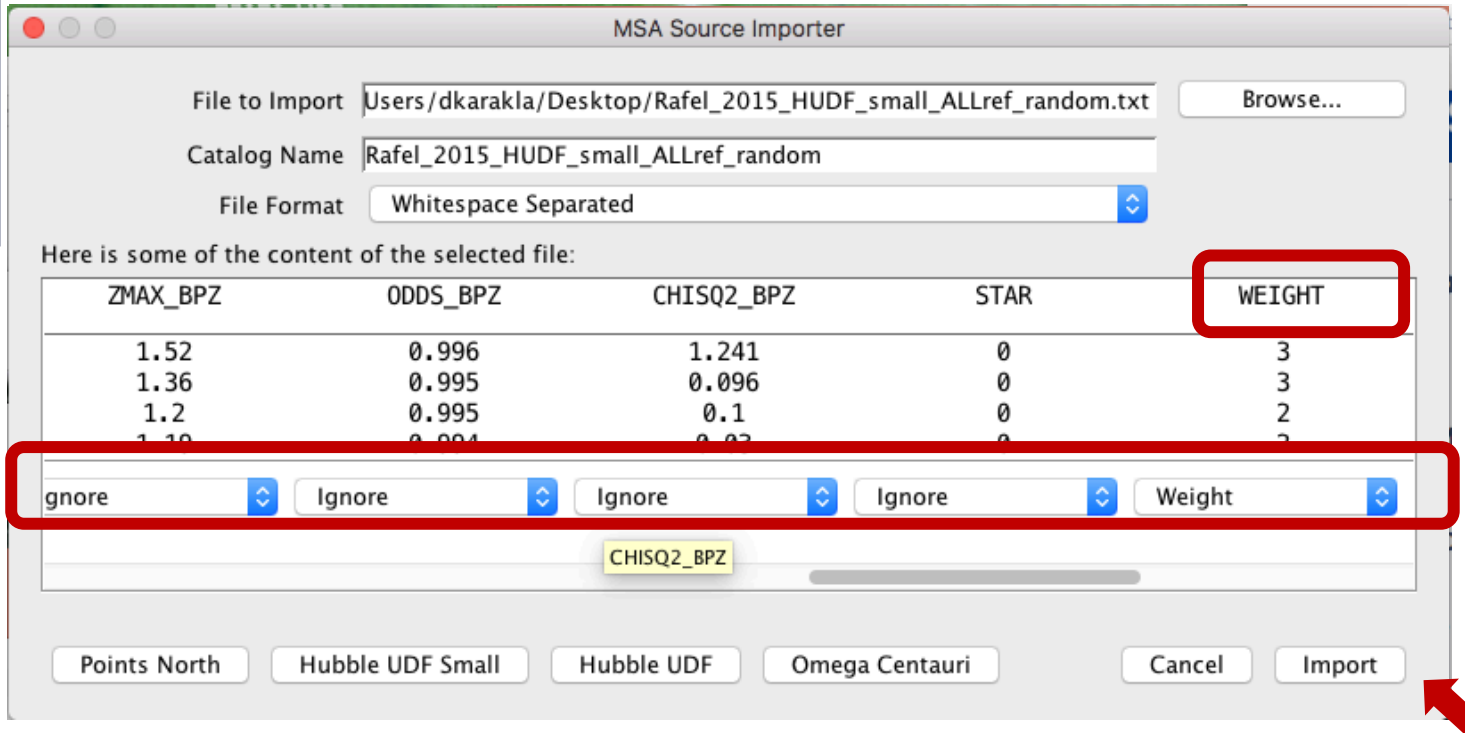


# Load the Catalog as an MSA Catalog Target

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

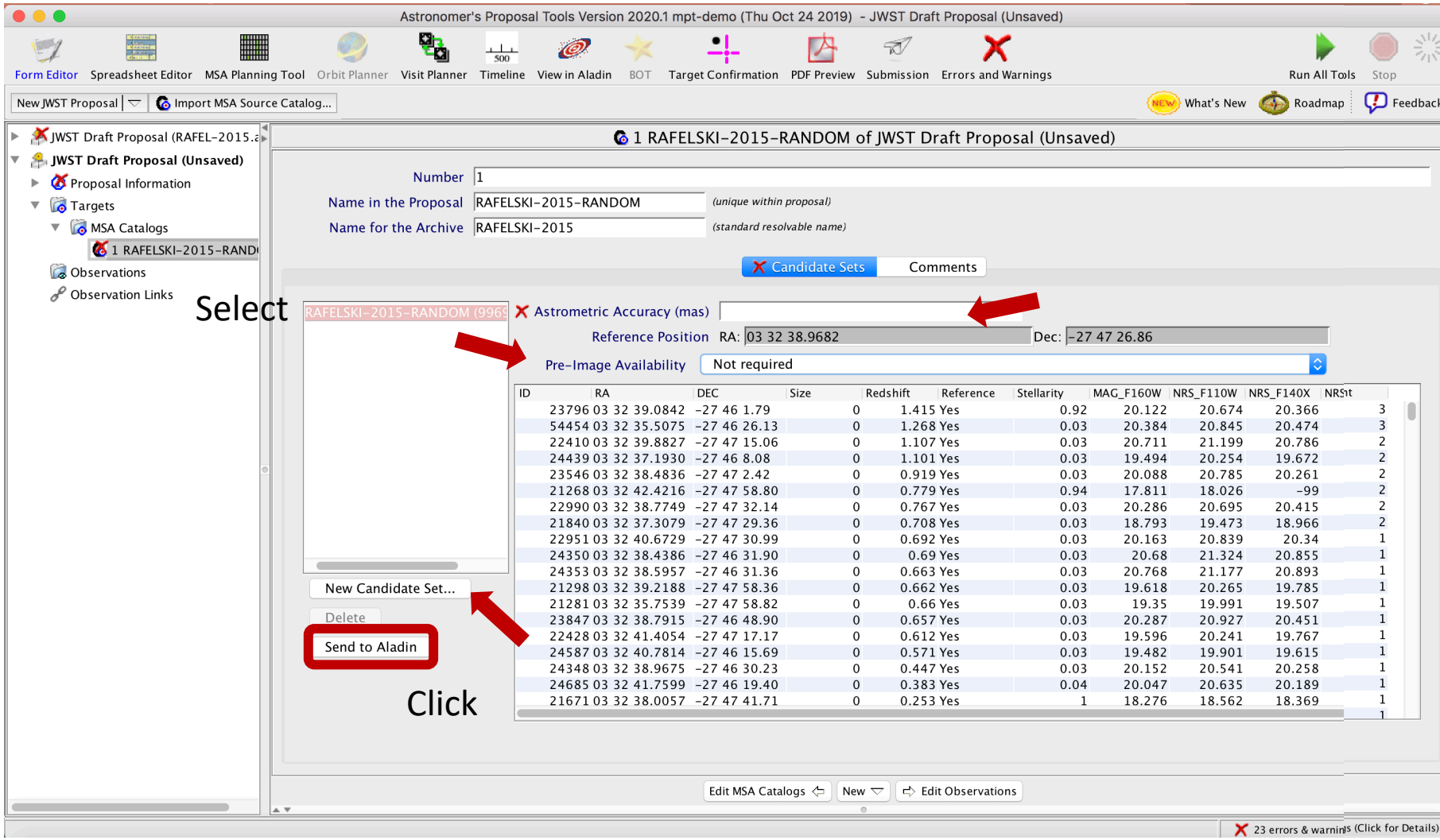
# Catalog declarations and making candidate sets

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

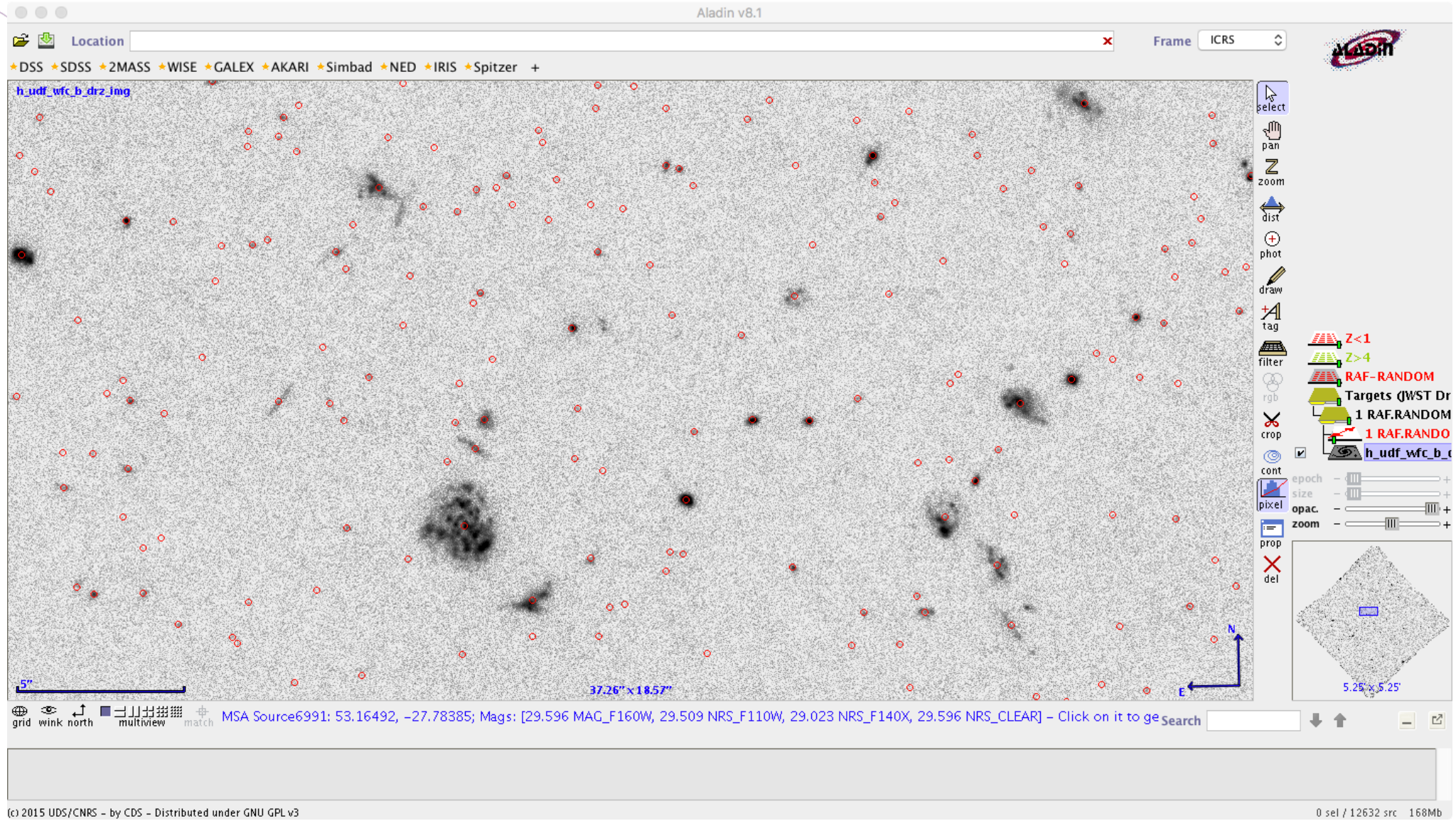
3) We must tell MPT if we need pre-imaging or not:

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




Notice that we are in the Form Editor

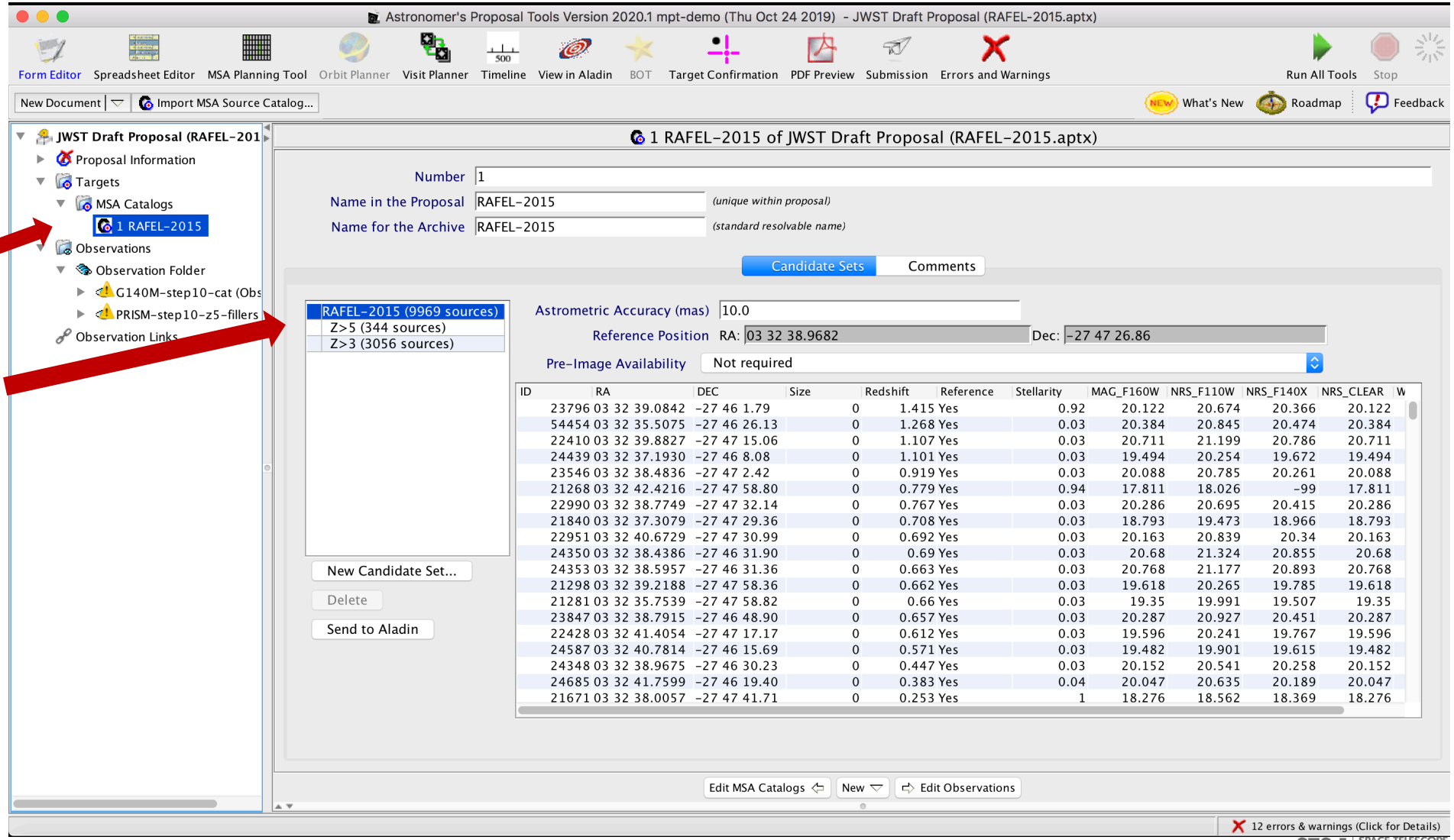
# Catalog sources can be displayed in Aladin



# MSA Catalog Target

The MSA Catalog Target is now in the Targets Folder

Highlight/select the Catalog to see its data

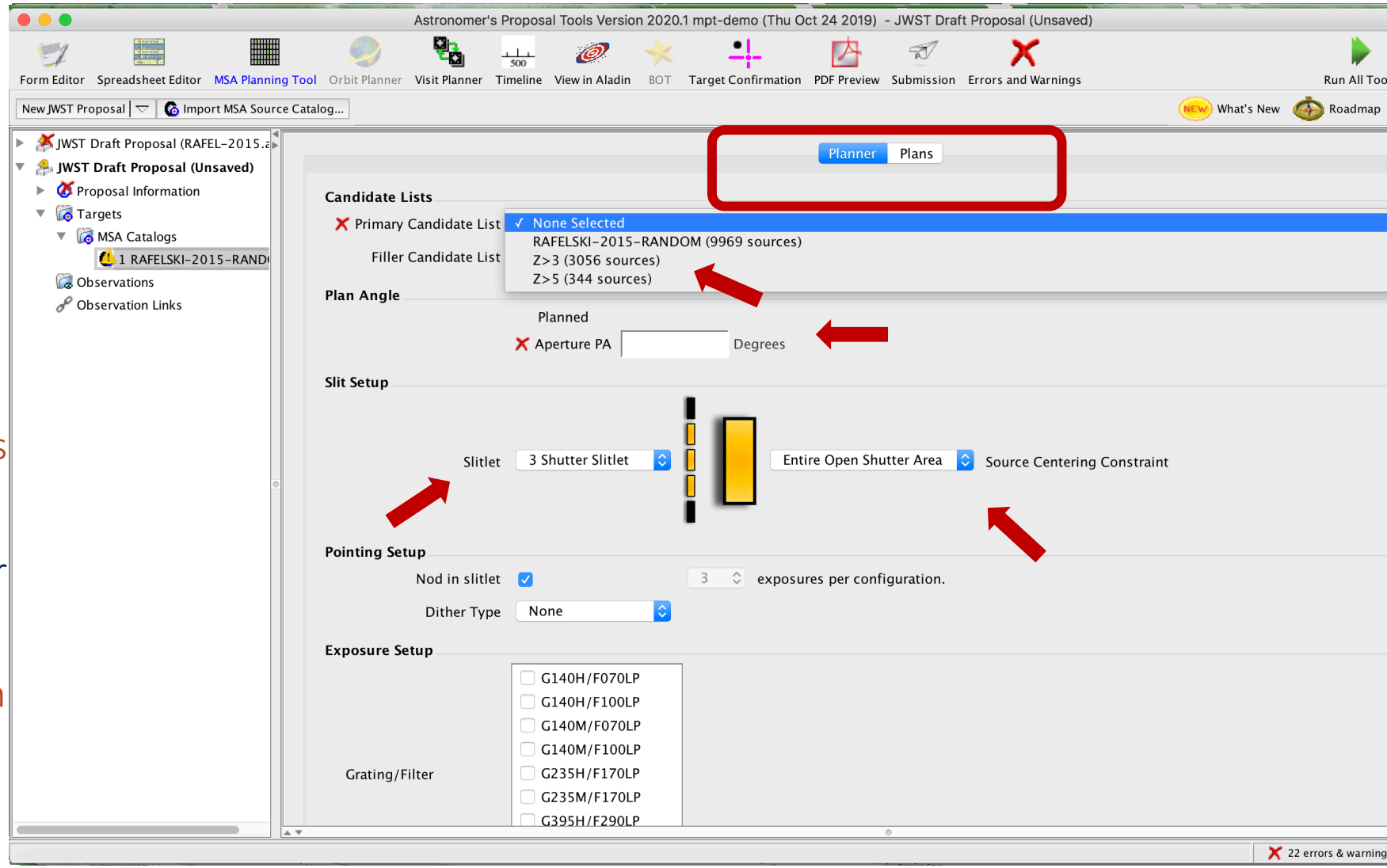


# The MPT Planner

In the MSA Planning Tool -

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



# 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!


EXPANDING THE FRONTIERS OF SPACE ASTRONOMY