STScI | SPACE TELESCOPE SCIENCE INSTITUTE

EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

Integral Field Spectroscopy with JWST Level 2

MIRI MRS and NIRSpec IFU Observation Planning

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JWST Master Class

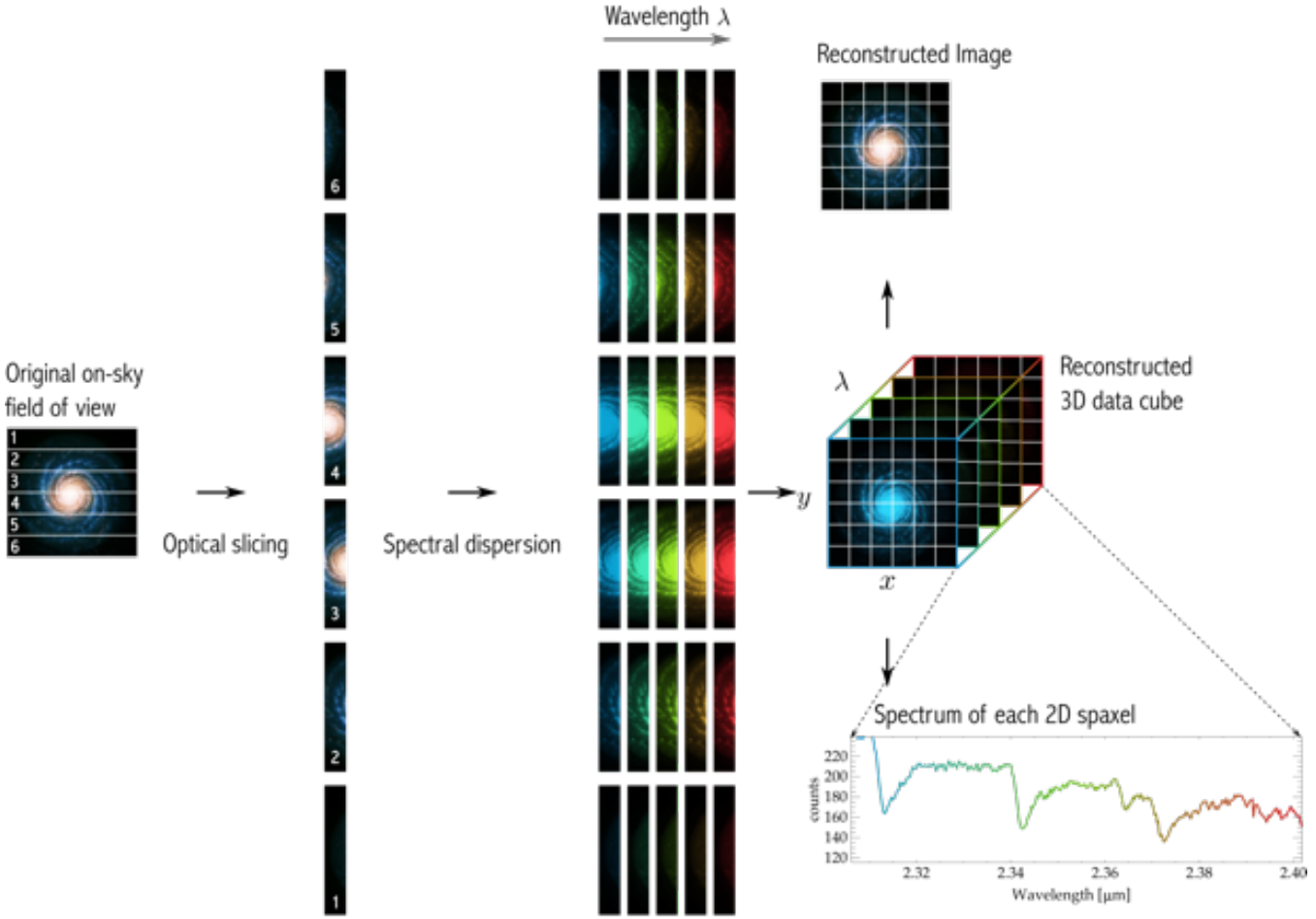
November 2019

Introduction

Integral Field Spectroscopy

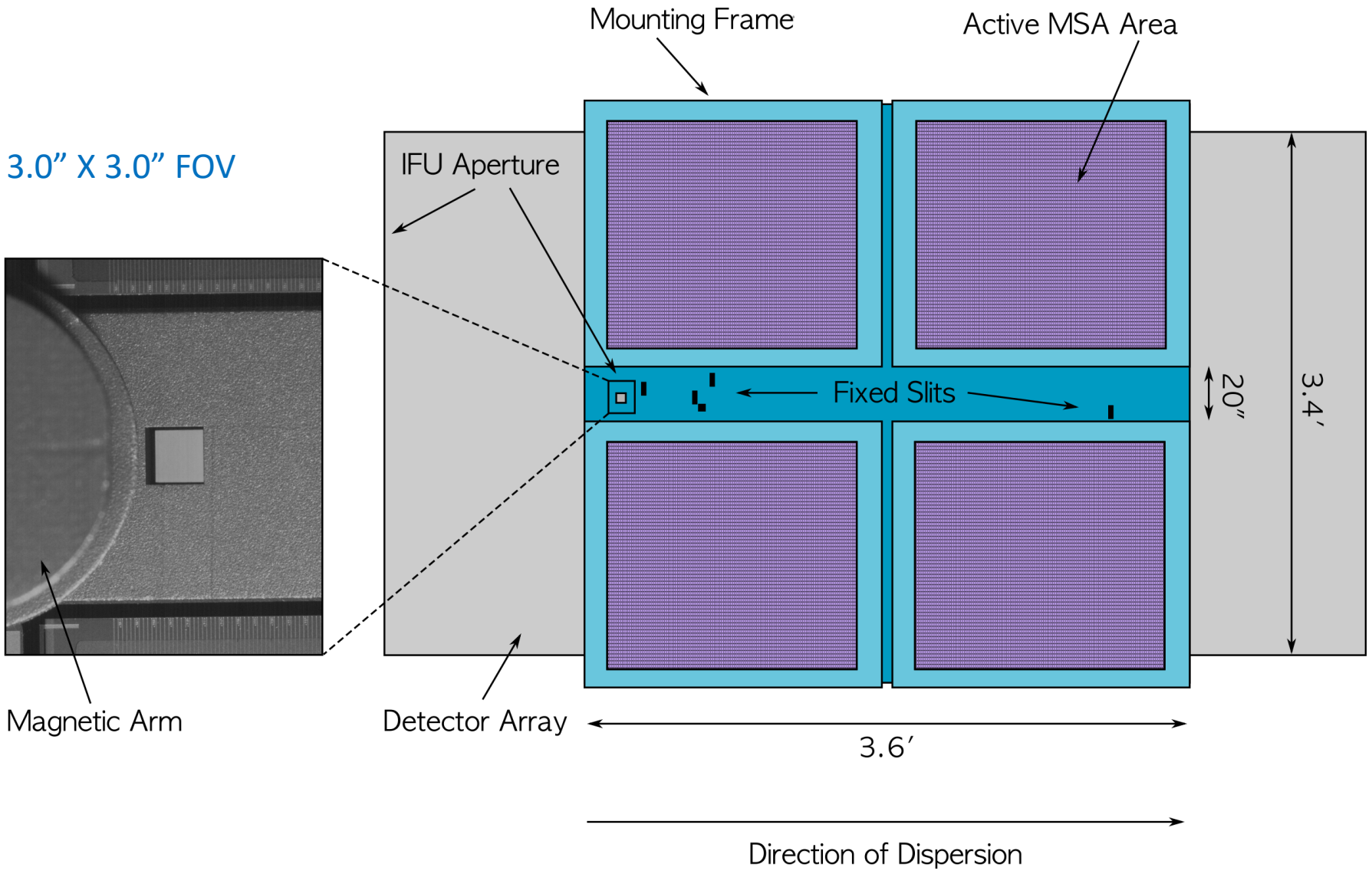
Image Slicing

- NIRSpec and MIRI use Slicers
- Slices are dispersed in wavelength
- Signal recorded on detector
- Pipeline constructs cube from slices



From N. Luetzgendorf

NIRSpec IFU Spectroscopy



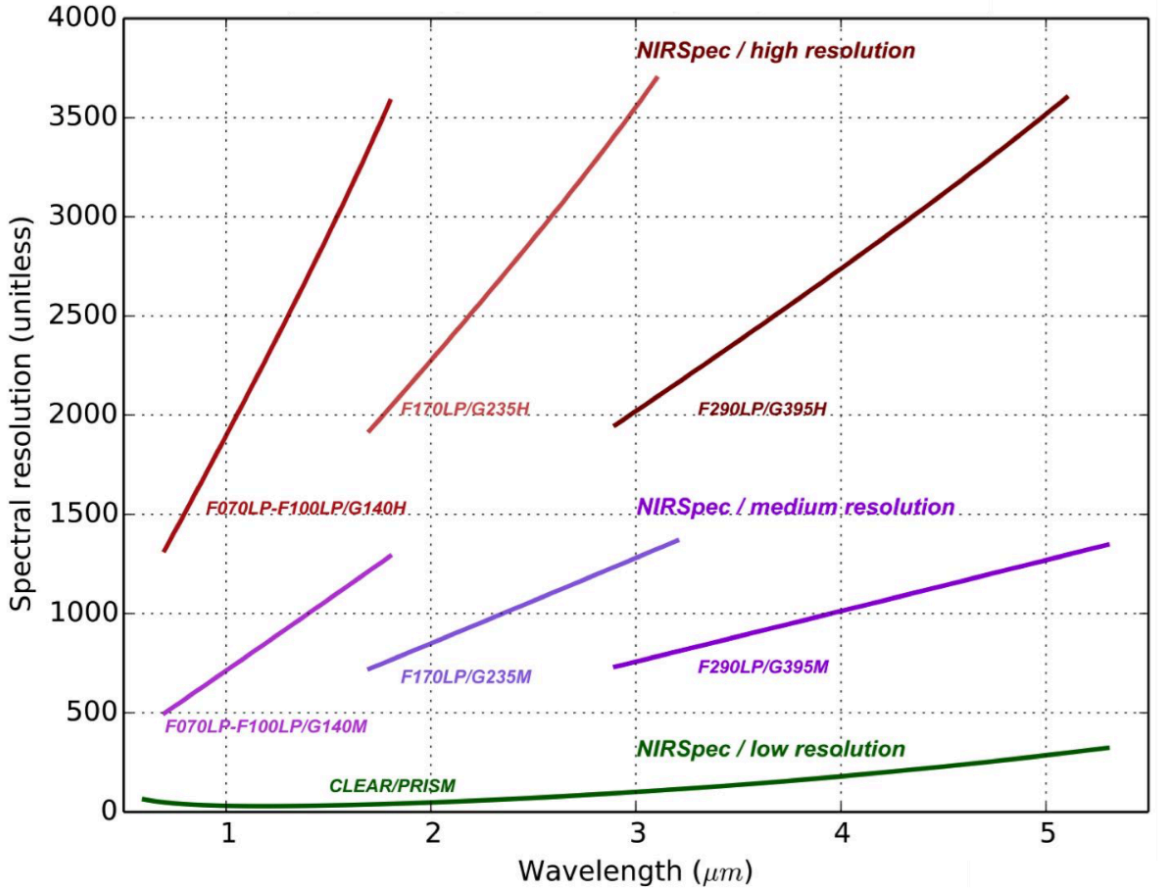
NIRSpec IFU Wavelength Coverage

Gratings

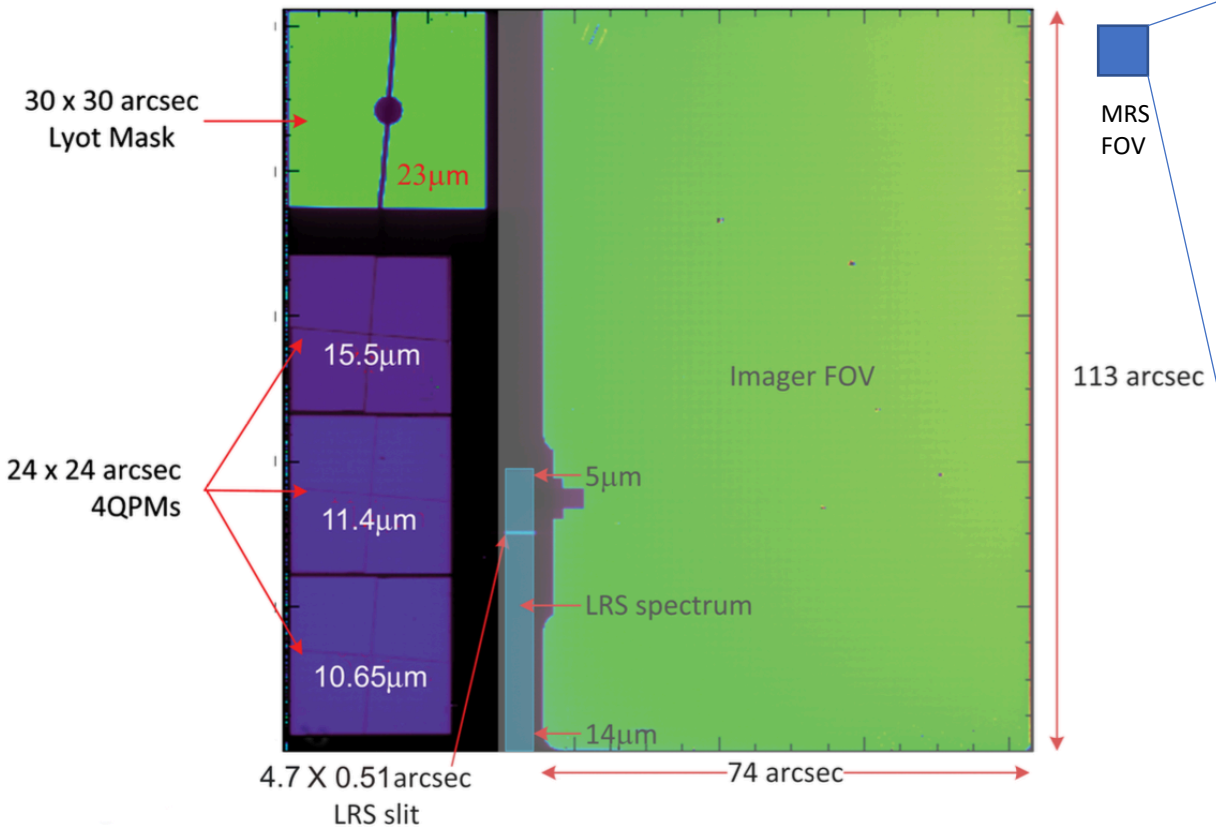
- High resolution:
  - G140H, G235H, G395H
- Medium resolution:
  - G140M, G235M, G395M
- Low resolution:
  - PRISM

Filters paired with dispersers

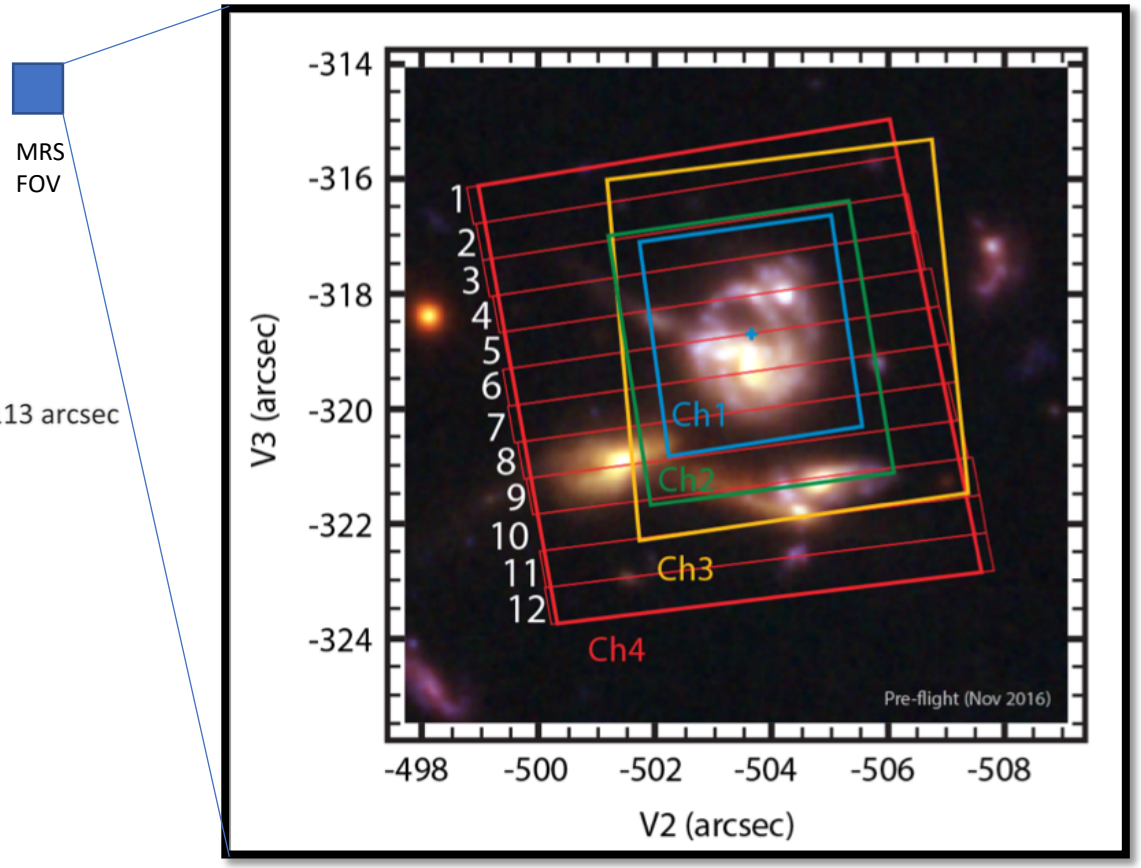
e.g. F170LP/G235H



MIRI Medium Resolution Spectroscopy (MRS)



MIRIM: MIRI Imager



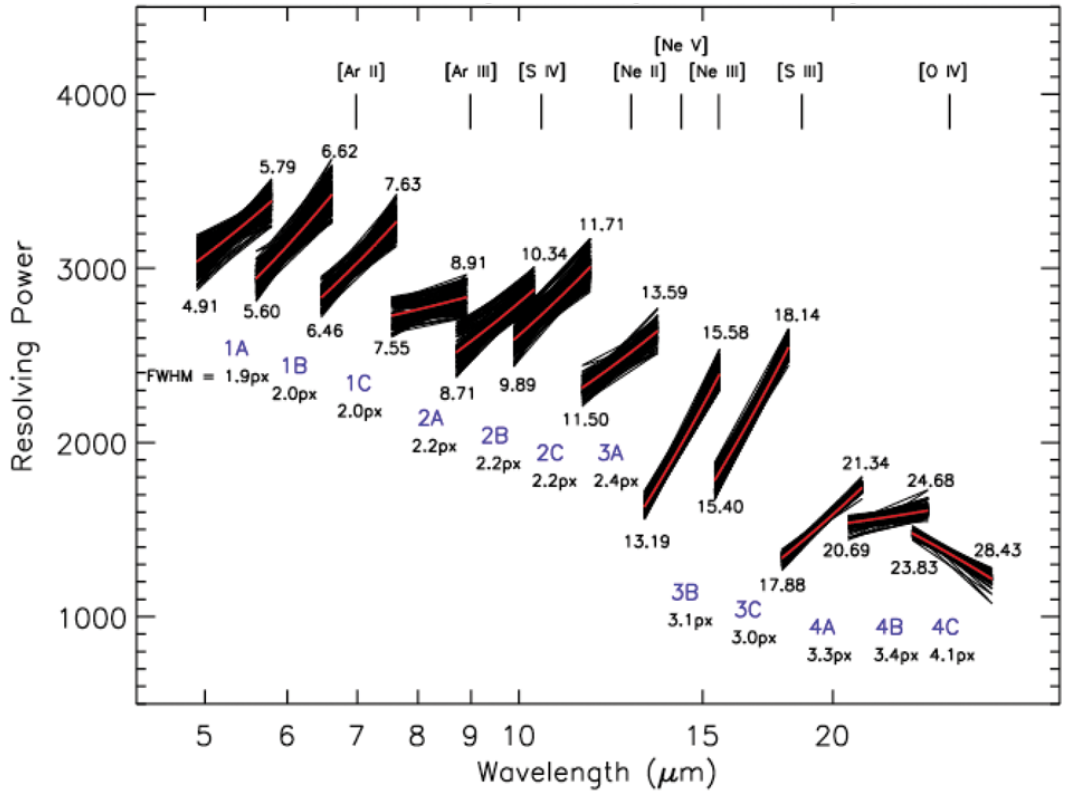
MRS: Medium Resolution Spectrometer

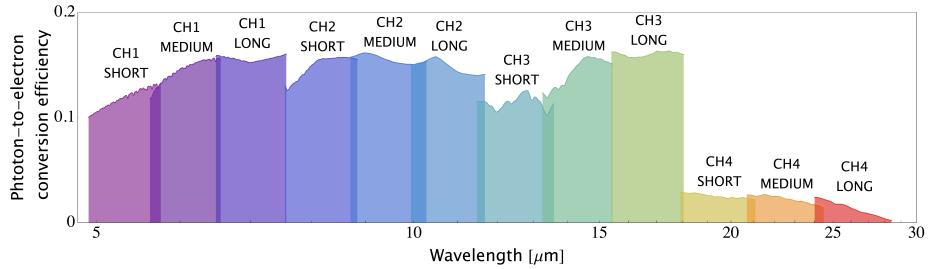
MIRI MRS Wavelength Coverage

Wavelength sub-bands

- Short: 1A, 2A, 3A, 4A
- Medium: 1B, 2B, 3B, 4B
- Long: 1C, 2C, 3C 4C

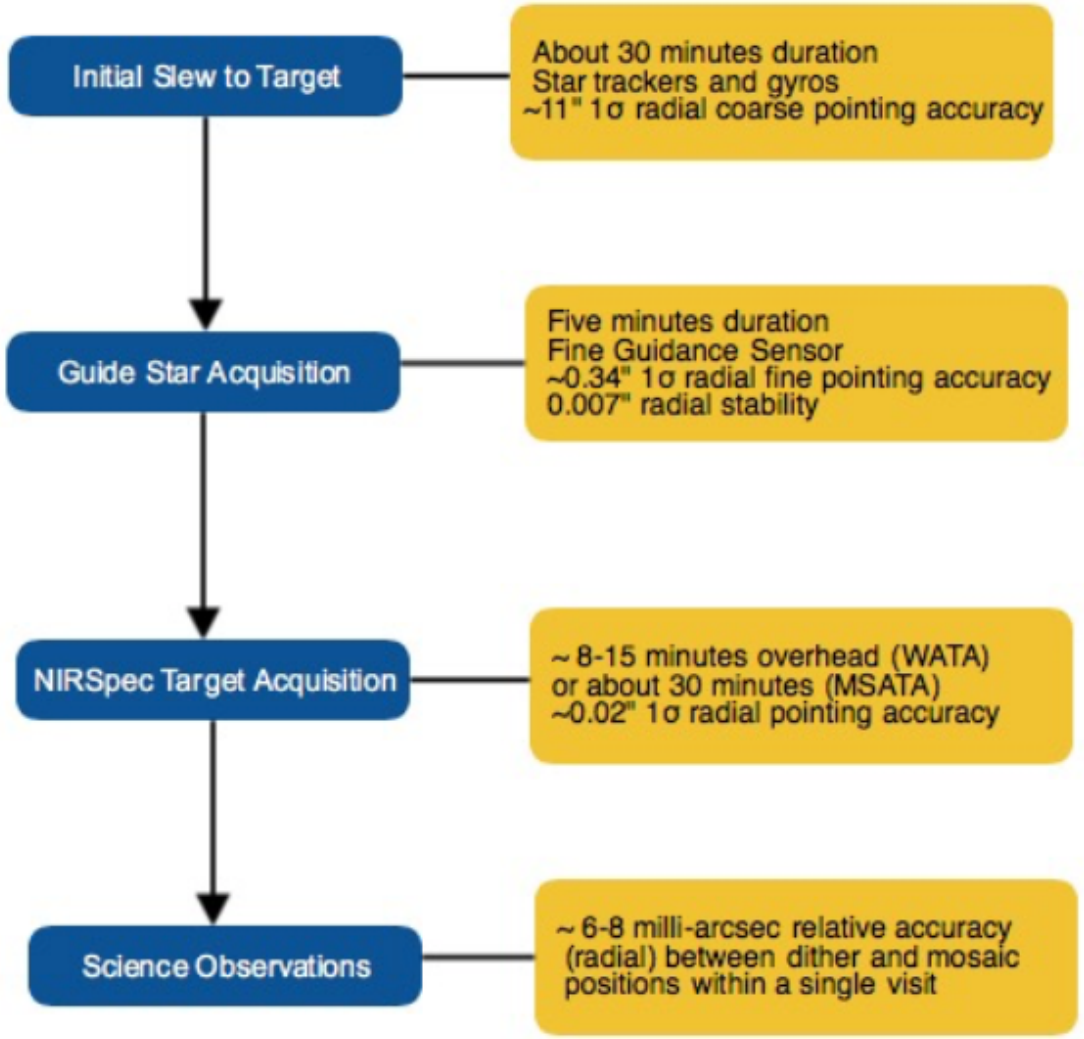
Need 3 exposures to cover all 3 sub-bands.





Observation Planning with APT

NIRSpec IFU Target Acquisition



NIRSpec IFU Target Acquisition

Methods

- NONE: JWST FGS pointing accuracy (radial σ = 0.34”)
- WATA (radial σ = 20 mas, 11-18 minute overhead)
  - Limited by bright (e.g. 2MASS) reference star availability
- MSATA (radial σ = 20 mas, 24-30 minute overhead)
  - Requires 8 fainter reference stars (or compact sources)
- VERIFY-ONLY (8-14 minute overhead)
  - IFU + MSA (custom, ALLOPEN, or ALLCLOSED) imaging

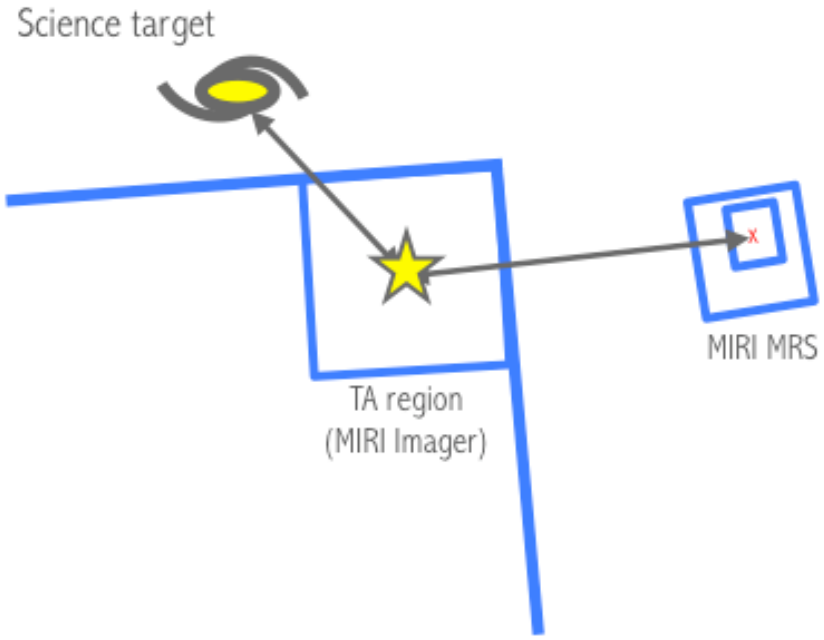
Reference Star Suitability

- Ref star must not have brighter point source within 2”
- WATA ref star coordinate absolute accuracy 150 mas
  - 38” visit-splitting limitation
  - J = 11.9-25.7 AB mag, depending on filter and readout
- MSATA: recommend accurate JWST or HST pre-imaging
  - K = 19.5-25.7 mag, depending on filter and readout

MIRI MRS Target Acquisition

Methods

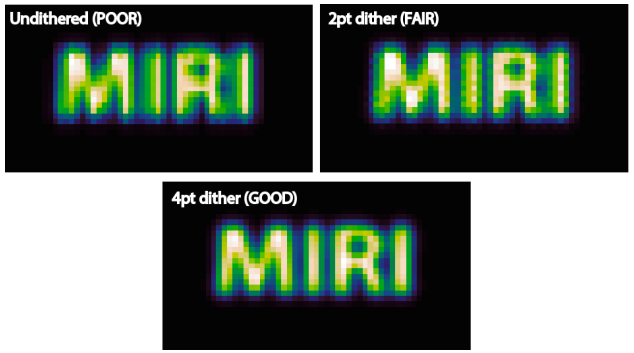
- NONE
  - JWST FGS pointing accuracy (radial σ = 0.34”)
- Self-TA (radial σ = 90 mas)
  - Suitability: unsaturated (<5 Jy) point sources
- Offset-TA (radial σ = 90 mas)
  - Reference star suitability: unsaturated (<5 Jy) point source
- Filters: FND, F560W, F1000W, F1500S

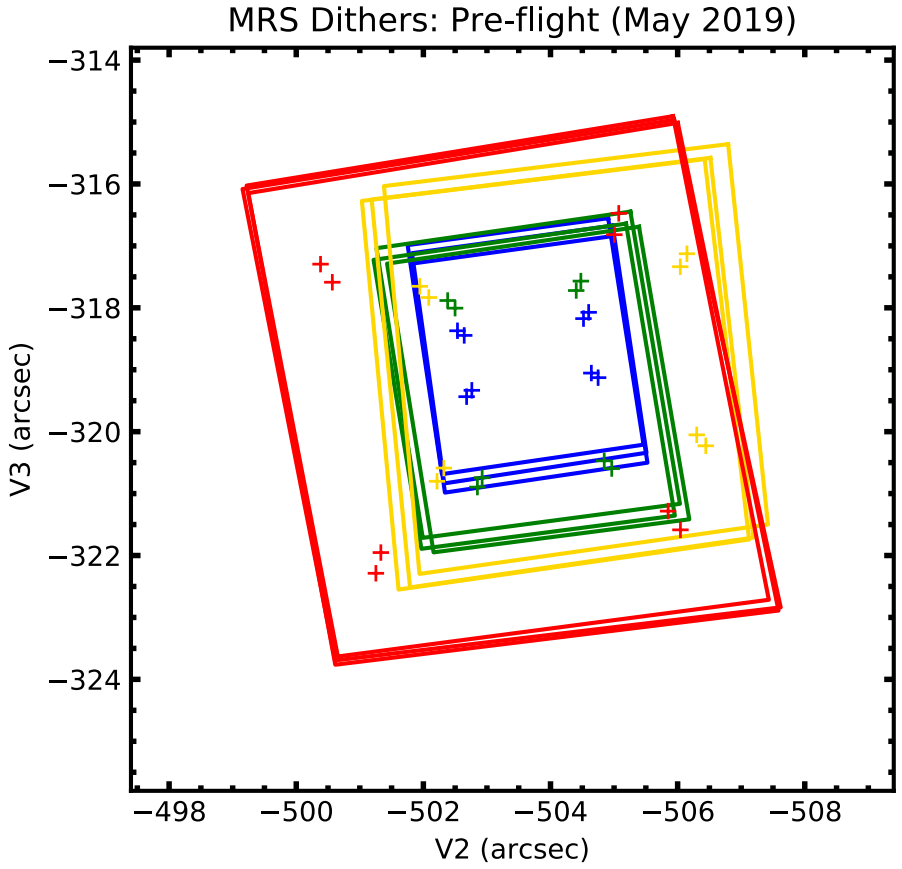


MIRI MRS Dithering

All MRS observations must be dithered

- *MIRI is a factor 2 spatially undersampled*
- Pattern determined by **Primary Channel** and **Point** or **Extended** source selection in APT:
  - Black=Extended, Blue=Ch1, Green=Ch2, Yellow=Ch3, Red=Ch4
  - Primary = Ch4 dither will move source out of Ch1 FOV!
  - **Direction** (Positive or Negative) rotates pattern 43º for **Point** source
- 2-pt dither pattern
- 4-pt dither pattern
- **4-pt ALL** preferred for point or extended sources.

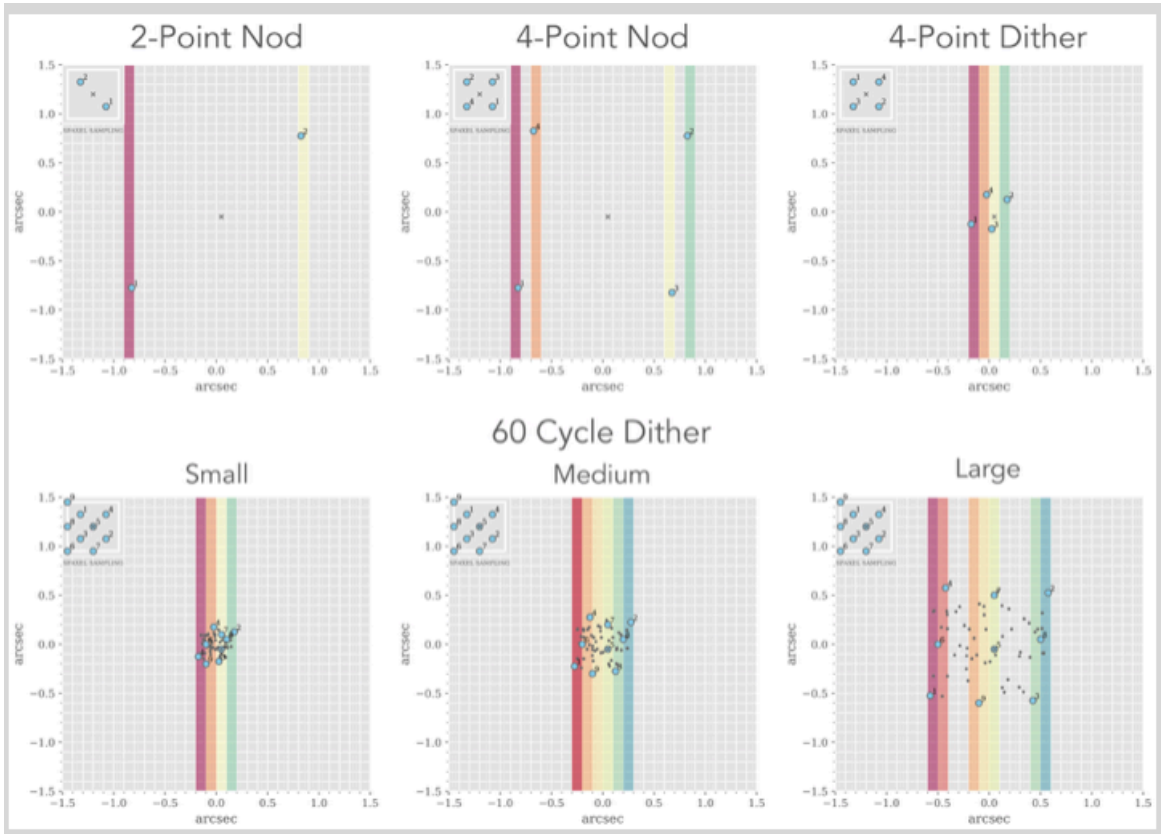




NIRSpec Dithering and Nodding

NIRSpec dithering options (or NONE)

- **Nod** = large offset for point/small source separation, used by pipeline to subtract background
  - 2-point nod
    - 1.6” in X and in Y, for point source separation
  - 4-point nod (*suggested for point source*)
    - 1.6” box
  - **TA recommended** so nod remains in-scene
- **Dither** = small offset for detector defect mitigation
  - 4-point dither (*suggested for extended source*)
    - 0.4” box
- **Cycling** = For PSF and detector sampling
  - Cycling (1-60-point pattern)
    - Small, Medium or Large spacings
  - Sparse cycling (1-60-point pattern)
    - Small, Medium, or Large spacings



Mosaics and Target Groups

Mosaics

- Small region
- Overlap or no overlap
- May be used for backgrounds

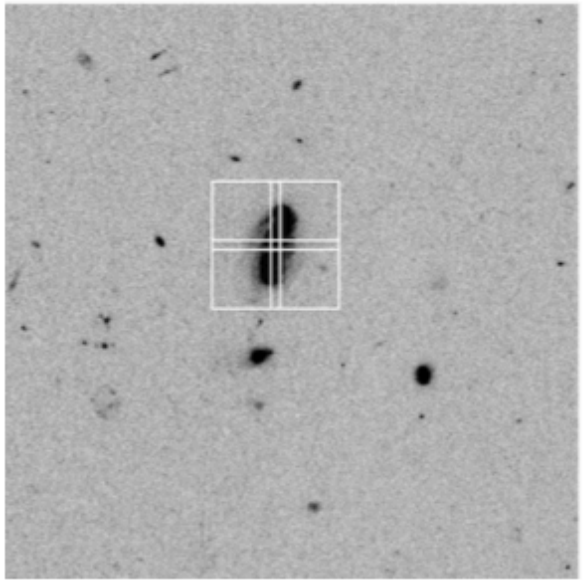
Target groups

- Multiple, linked pointings
- Stay within visit-splitting distance
- Useful for offset backgrounds

MOSAIC

(Extending Coverage, Regular)

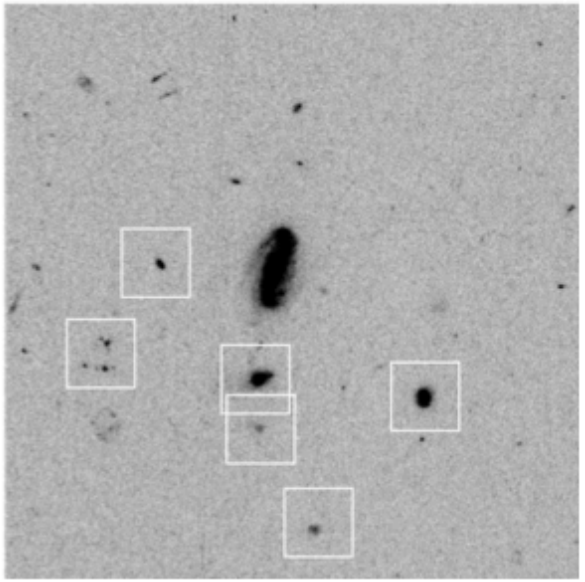
Available in the mosaic menu



TARGET GROUPS

(Proximity Targets, Irregular)

Available in targets menu



Offset Background Observations

NIRSpec IFU

- Not all observations require offset backgrounds. Check with ETC.
- Offset backgrounds suggested for:
  - Faint extended targets
- Use target groups or mosaics within visit-splitting distance to avoid variable background and non-repeatable grating settings.

MIRI MRS

- Most extended source observations require offset backgrounds. Check with ETC.
- Isolated point source observations may not require offset backgrounds

MIRI MRS Exposure Parameters

Readout

- FAST mode
  - New recommendation for most observations
  - Advantageous for expected high cosmic ray rates
- SLOW mode
  - Limits data rate when including MIRIM or parallels

Groups

- 5 or more recommended for calibration (or switch to FAST)

Integrations

- 1 Integration recommended to maximize groups and best slope fitting

Exposures

- Number must be the same for all detectors
- No explicit limit on exposure time

NIRSpec IFU Exposure Parameters

Readout

- IRS^2
  - NRSIRS2 (5 frames per group) *reduce data volume*
  - NRSIRS2RAPID (1 frame per group) *recommended*
- Traditional
  - NRS (4 frames per group)
  - NRSRAPID (1 frame per group) *for bright sources*

Groups/Int

- 2 or more recommended for accurate calibration

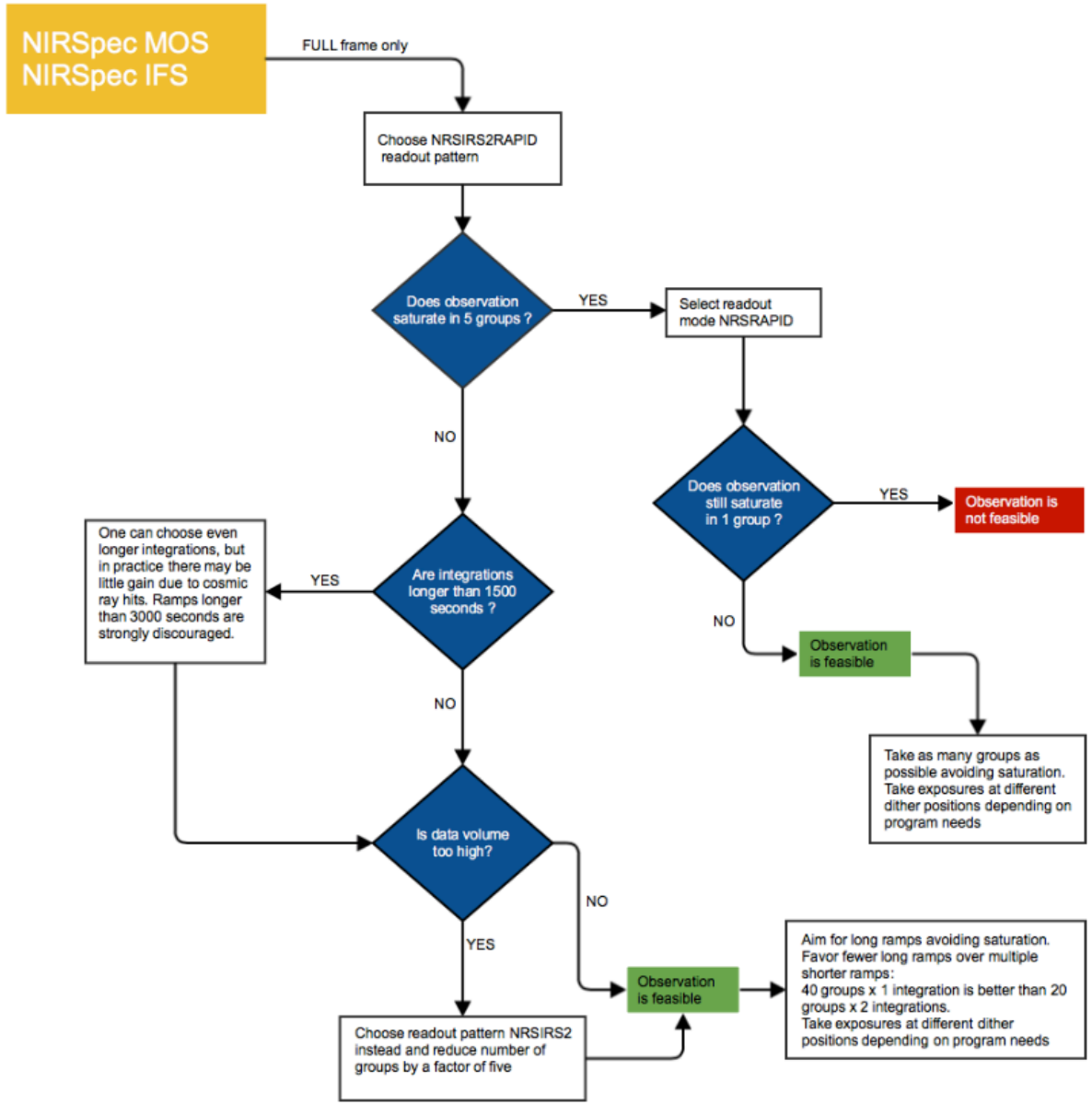
Integrations

- <1500 sec recommended to mitigate cosmic rays

Exposures

- Number must be the same for all detectors
- No explicit limit on exposure time

NIRSpec IFU Exposure Parameters



NIRSpec IFU: MSA Light Leaks

IFU observations may be affected by MSA light leaks

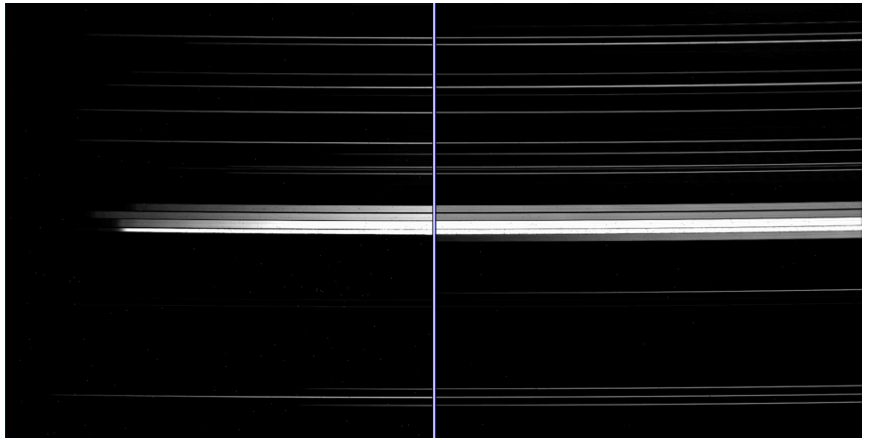
- Stars in open MSA shutters or bright star print-through
- Print-through from diffuse backgrounds (<3-10%)

Guidance on when Leakcal observations are necessary

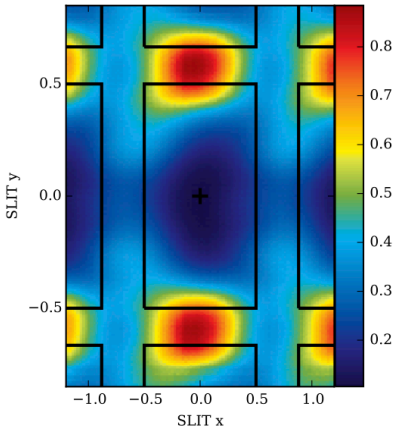
- Depends on source vs. spoiler signal
  - Print-through important for stars > 500x brighter than target
- Crowded stellar field
- Bright structured background (e.g. nebulae)

Mitigation Strategies

- Orient constraints
- Dithering (at 4 or more points) to reject stellar leaks
- Single Leakcal at one position to remove diffuse leakage
- Full set of Leakcals at every pointing is expensive
  - Full or shorter exposure



Light leaks through open shutters

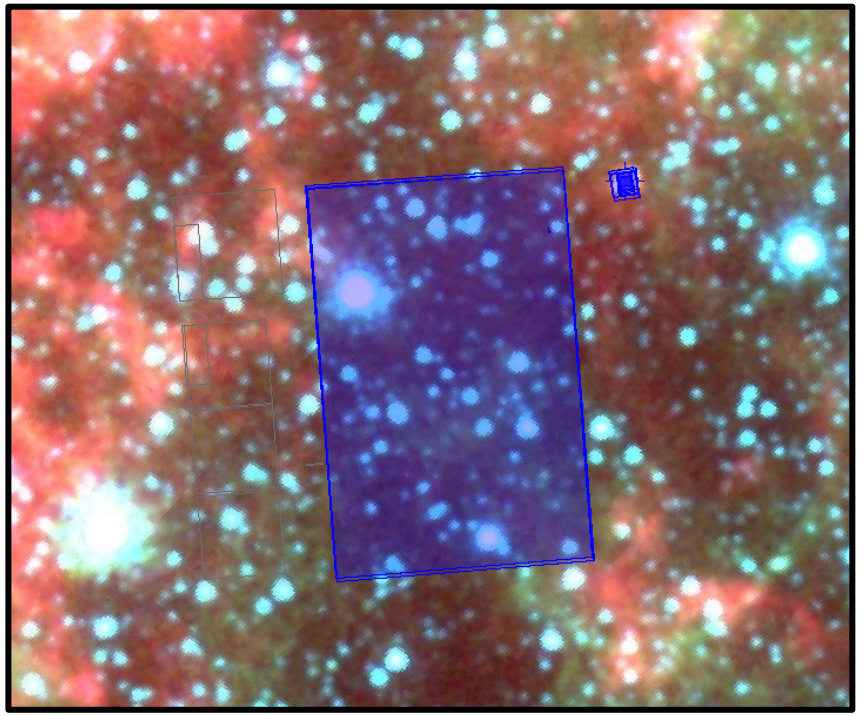


MSA print-through
<4x10^{-5} x 730 shutters

<3-10%, disperser-dependent

MIRI MRS Simultaneous Imaging

Default operational mode for the MRS, **not** a parallel imaging mode!



Why is it useful?

- Improves the astrometric accuracy of MRS observations
- Used to obtain additional science observations in an adjacent field of view

Should only be turned off if there are very bright targets in the imager field of view

Simultaneous imaging will not be available for MRS time series observations.

NIRSpec IFU Checklist (abridged)

Target Acquisition

- Are filter, readout, and exposure time right (S/N>5 and unsaturated)?
- For MSATA or Verify-Only, is there an ON-HOLD for orient special req.?
- Do reference star positions have sufficient accuracy and proper motions (2MASS, GAIA, or pre-imaging)?

Bright-Source checking—are bright sources blocked by MSA config.?

Parallels

- Do parallels exceed data rate limitations?
- Are parallel and NIRspec exposures and dithers in sync?
- Verify-Only TA not allowed with parallels

Dithers, Nods, and Mosaics

- IS TA necessary?
- Can mosaics be executed at any orient?

Backgrounds–Are offset background measurements linked (target groups)?

Leakcal—Are leakcal exposures necessary to correct for MSA print-through?

Exposure Parameters

- Is IRS2 readout used as recommended?
- Is there unnecessary switching between IRS2 and IRS readout patterns?

MIRI MRS Checklist (abridged)

Target Acquisition

- Proper motions should be entered for all objects. This is crucial for proper TA.
- Are moving targets properly specified?
- No TA on extended sources!

Dithers

- Is DITHER=NONE selected anywhere? If so, is it justified?
- Is a dither type selected in the Exposure Parameters pane?
- If the dither is an extended-source pattern, is there a dedicated sky observation linked to the exposure?
- If the MRS EXTENDED property is set to 'YES' or 'UNKNOWN' in the target editor pane, is an EXTENDED source dither pattern used?
- If the number of points in the dither pattern is <4, is it justified?

Mosaics

- Is the Extended source dither pattern optimized for ALL channels? If not, FOV of channels 1 and 2 may not overlap.
- Is mosaicking used to circumvent dither patterns? If so, is it justified?

Backgrounds–Are dedicated backgrounds properly linked to the science observations?

MRS wavelength sub-bands—If more than one wavelength sub-band (A/B/C) is requested, are they correctly specified?

Exposure Parameters

- Is FAST mode readout used? If not, is it justified?
- If the number of groups is <5, is it justified?
- Will exposures cause saturation in any active modes?

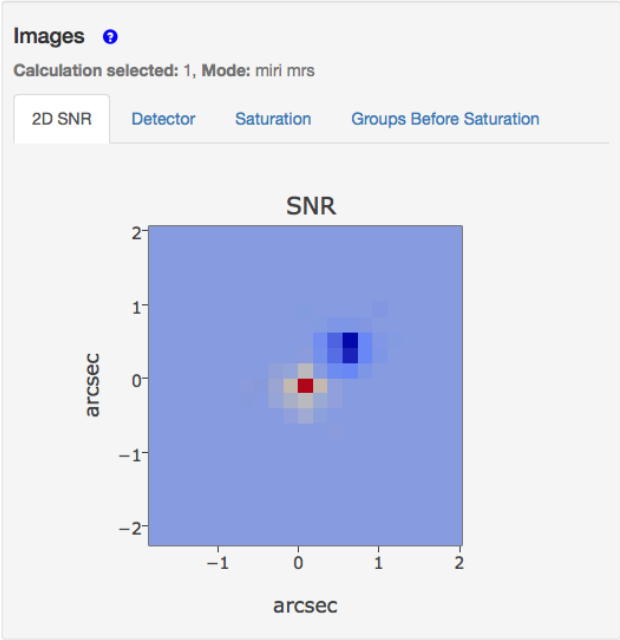
Is simultaneous imaging specified, using FULL array? Does the estimated data volume exceed limits?

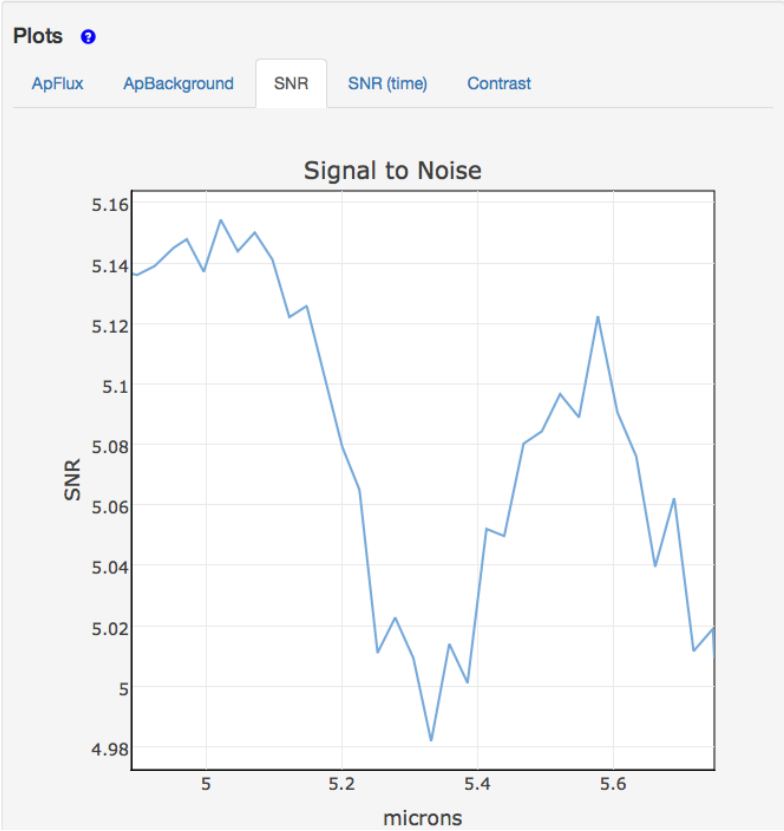
Feasibility Studies with ETC

ETC Feasibility example: MIRI point source

Point Source parameters

- Total flux or magnitude
- Spectrum
  - Continuum
  - Emission lines
- Background Strategy

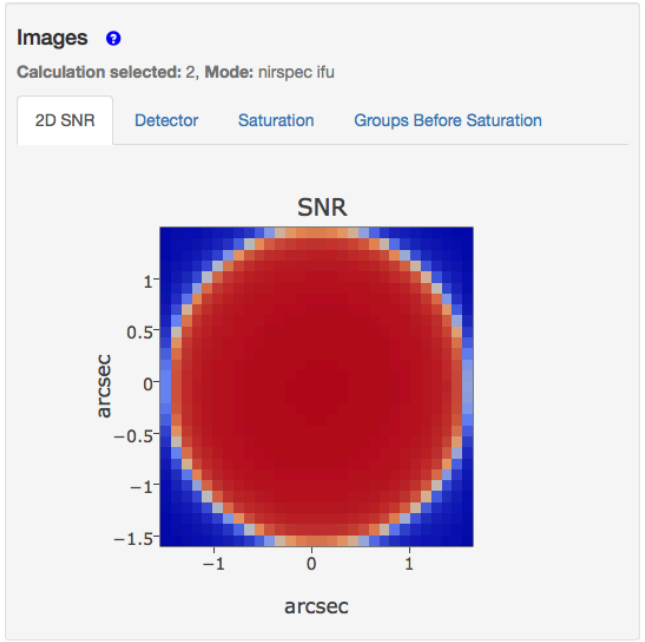


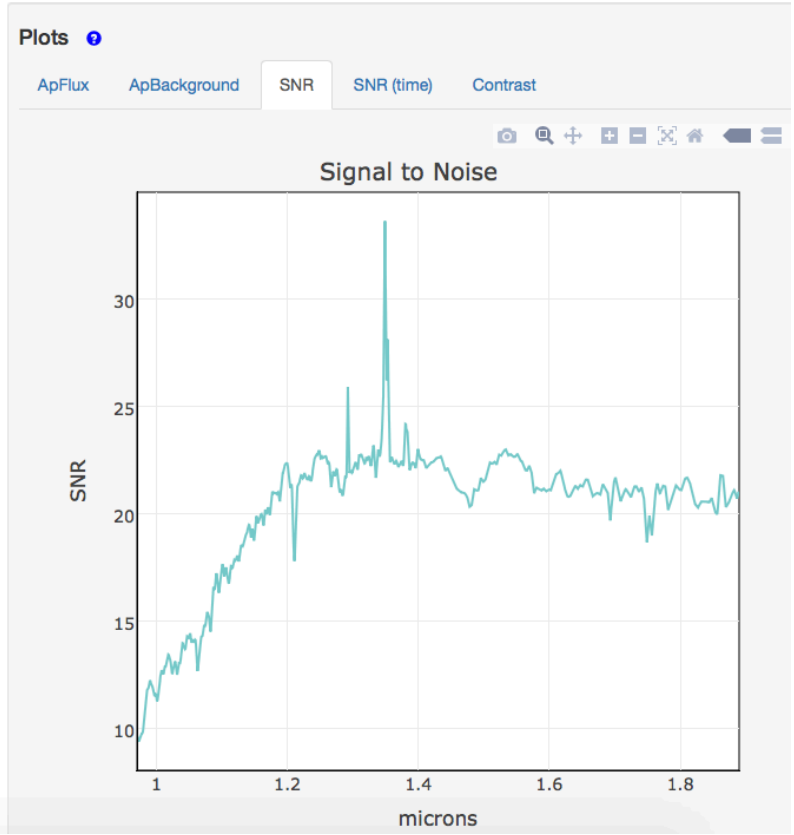


ETC Feasibility example: NIRSpec extended source

Extended Source parameters

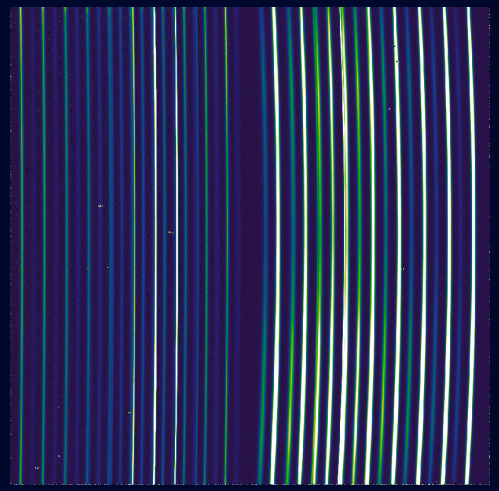
- Total flux or magnitude
- Source extent or profile
- Covering fraction
  - Consider source structure on 0.1 arcsec scale
- Spectrum
  - Continuum
  - Emission lines
- Background strategy





MIRI Simulated Data

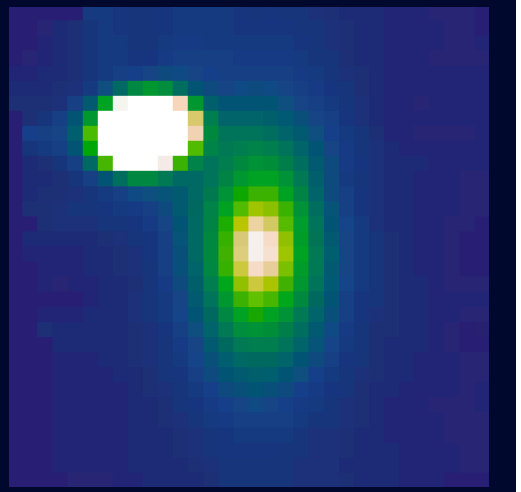
Simulations: MIRI MRS (z=0)



Detector Slope Data

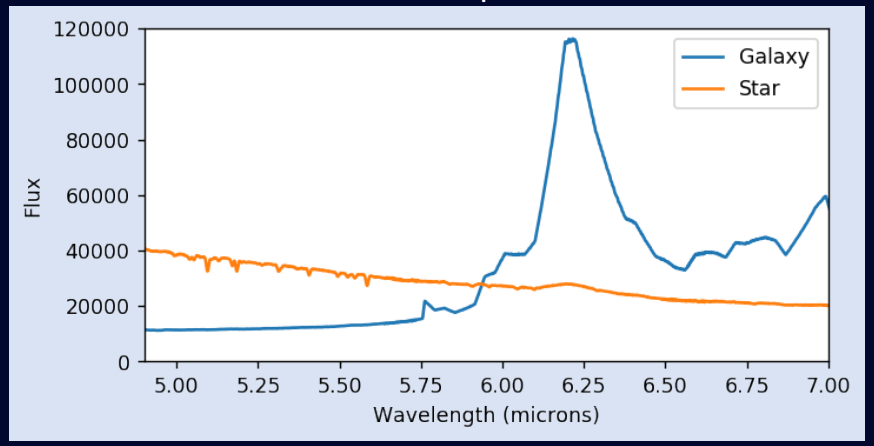
Comprehensive tools available:
'mirisim' simulation software
+
JWST calibration pipeline

Ch1A/B/C simulation with G0V star and Sersic model with NGC 5953 spectrum



Pipeline Cube

Extracted Spectra



Courtesy:
D. Law

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Hands-On Exercise: Design MIRI and NIRSpec Observations

Hands-on Exercise

1) Create MIRI MRS and NIRSpec IFU 1x2 mosaics in APT for the following scene:

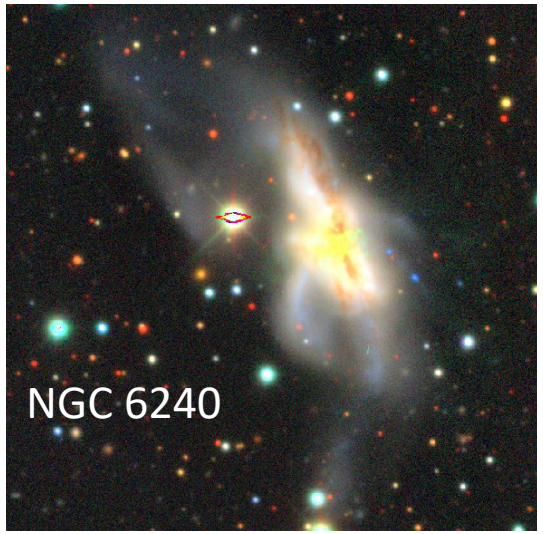
   LIRG Active Galactic Nucleus: NGC 6240

   Check for duplicates (GTO program 1265: MIRI MRS, MIRIM, and NIRSpec IFU)

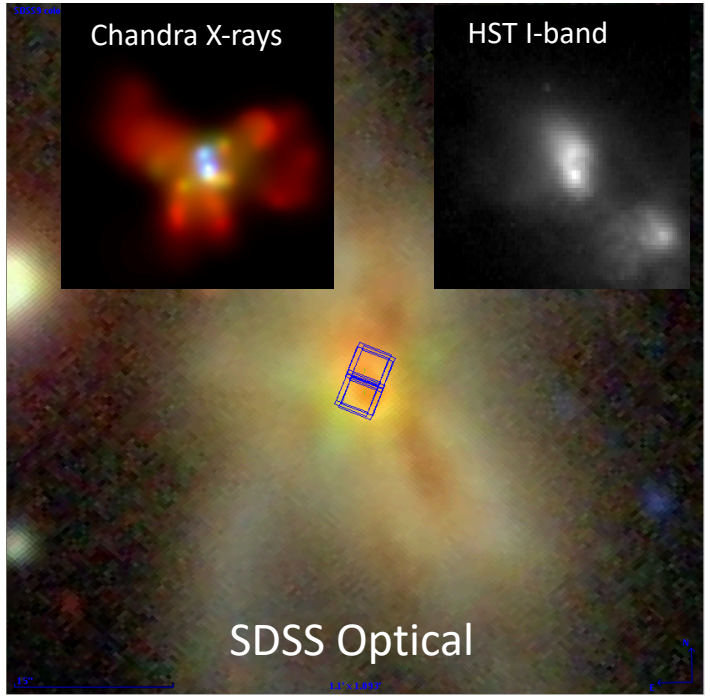
   Science Goals:

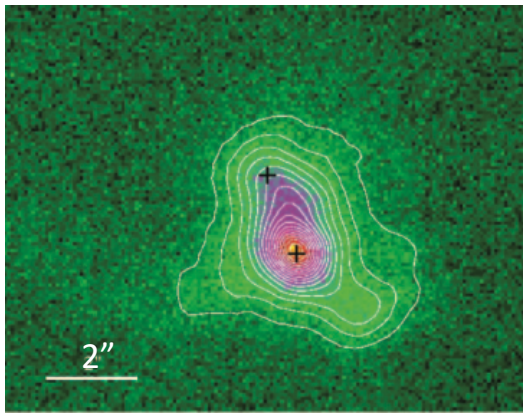
   1) Measure kinematics of the extended H2 1-0 S(0) 2.1 μm emission line
   2) Map star formation in the 2 nuclei (point sources) using PAH 8μm feature

2) Determine exposure times for your observations using ETC.

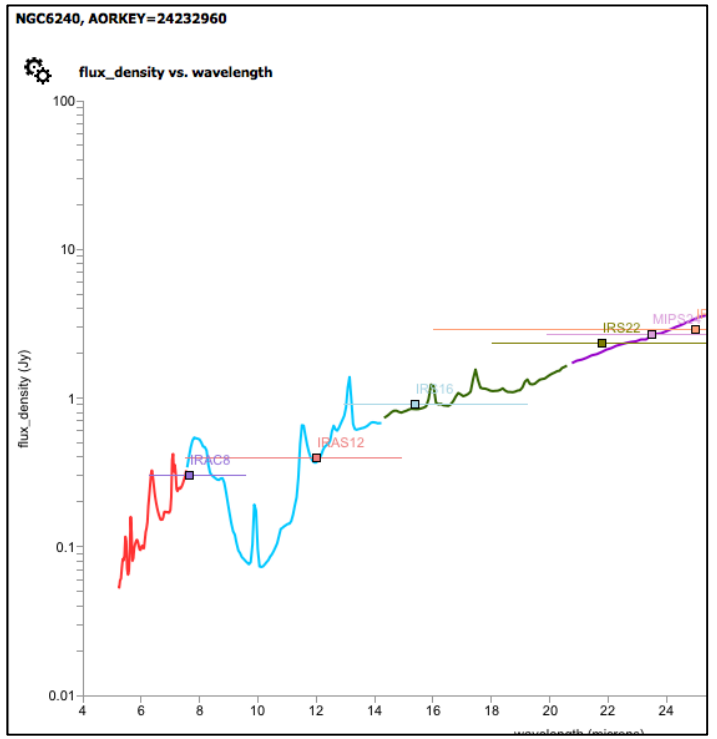


NGC 6240 (LIRG/AGN at z=0.02448)





Bogdanovic+2003

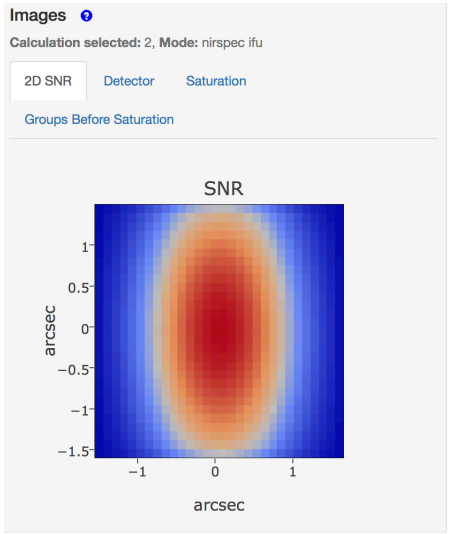


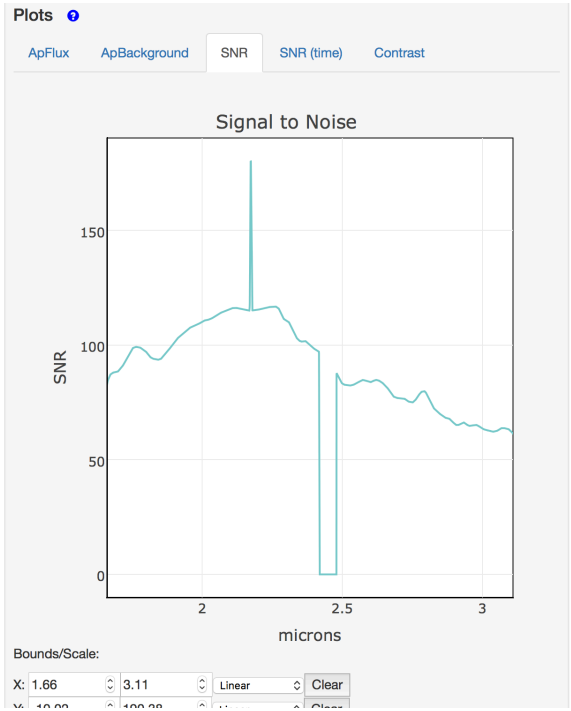
<u>Spatial scene:</u>
2 Nuclei sep: 1.6 arcsec
PAH and H_2 covering factor = ??

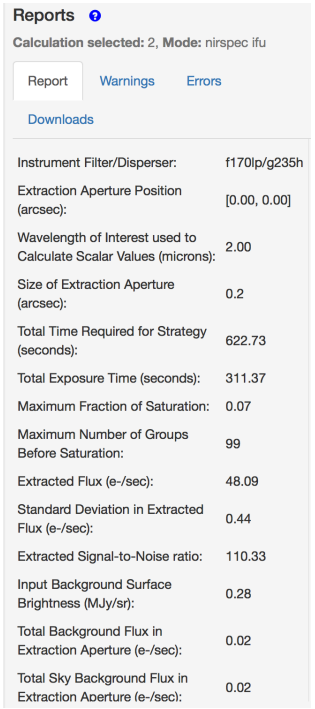
H_2 1-0 S(0) 2.12 µm line:
λobs = 2.1738 µm
Line Flux= 2E-13 erg cm^{-2} s^{-1}
FWHM= 400 km/s
Continuum within 5” radius:
33.7 mJy at 3.6 µm

<u>PAH 8 µm feature:</u>
Spitzer IRS 5-25 µm
(3.7” slit)
F_v = 0.6 Jy at 8 µm

NGC 6240 ETC Guidance—NIRSpec IFU



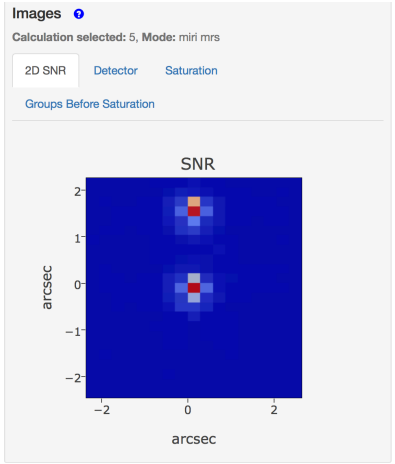


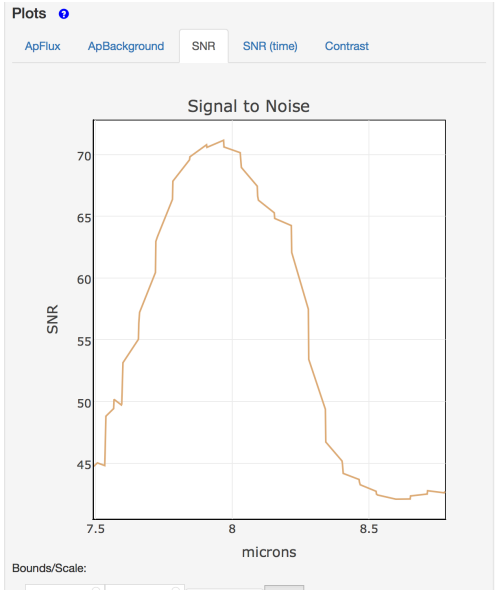


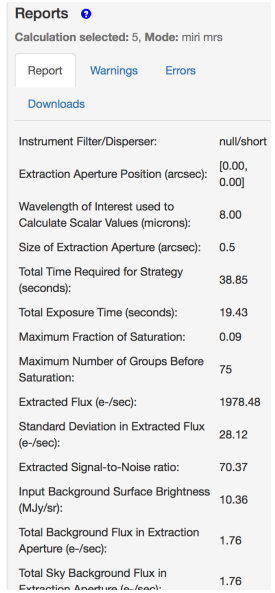
H_2 1-0 S(0) 2.12 µm line :

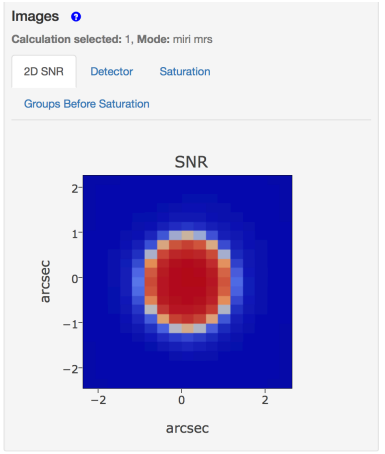
- Distribute line and continuum flux into (σ_x, σ_y) =0.5”x1” Gaussian ellipse
- 0.2” radius aperture, centered.
- Peak S/N per bin = 180
- For further investigation:
  - What is the S/N in the continuum-subtracted spectrum?
  - How far out in velocity are the emission line wings visible?

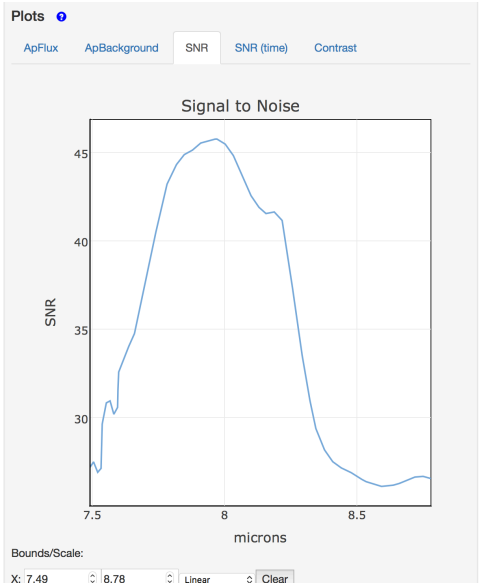
NGC 6240 ETC Scene Guidance—MIRI MRS

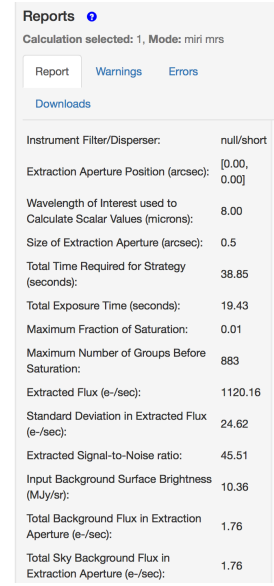












PAH 8 µm feature (Version 1):

- Split flux into 2 equally point sources separated by 1.6”
- 0.5” radius aperture on S. nucleus
- Peak S/N=71

PAH 8 µm feature (Version 2):

- Flat, extended source with 1” radius
- 0.5” radius aperture
- Peak S/N = 46