



**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

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The background of the slide is a deep space photograph showing a dense cluster of stars of various sizes and colors, ranging from small white dots to larger, more luminous blue and yellow stars. Interspersed among the stars are several large, dark, irregular shapes representing interstellar dust and gas clouds.

# Introduction

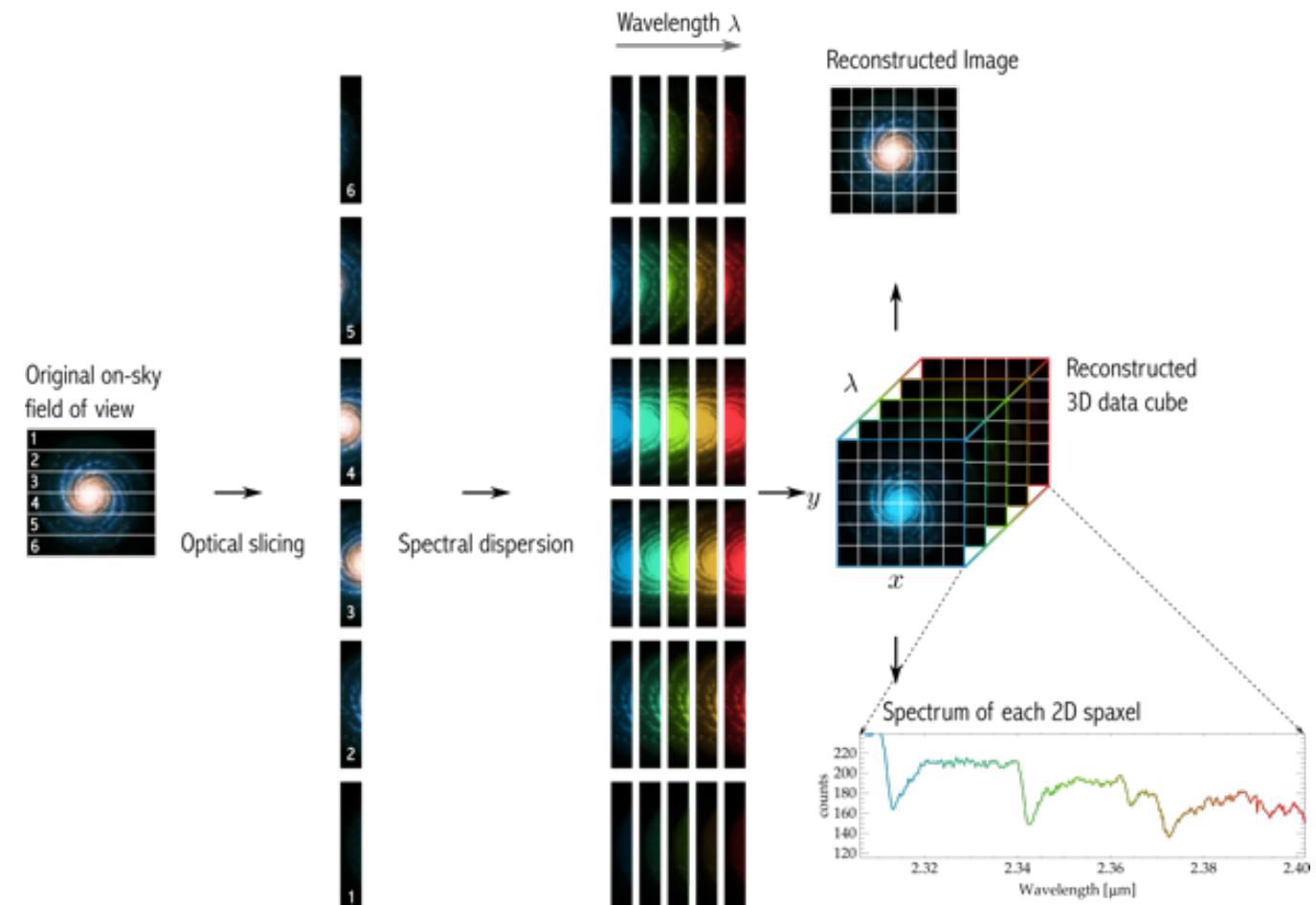
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# Integral Field Spectroscopy

## Image Slicing

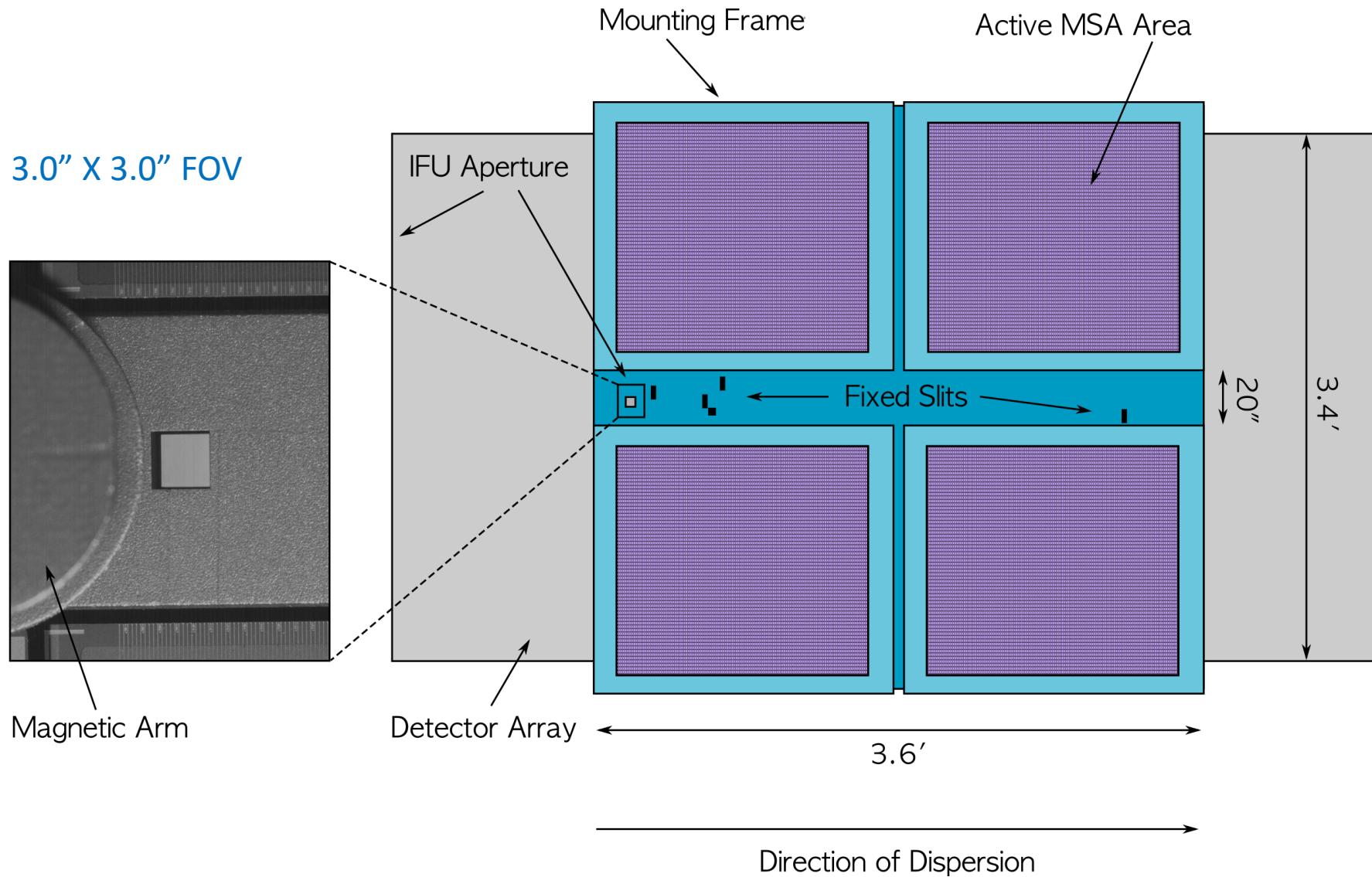
- NIRSpec and MIRI use Slicers
- Slices are dispersed in wavelength
- Signal recorded on detector
- Pipeline constructs cube from slices



From N. Luetzgendorf



# NIRSpec IFU Spectroscopy





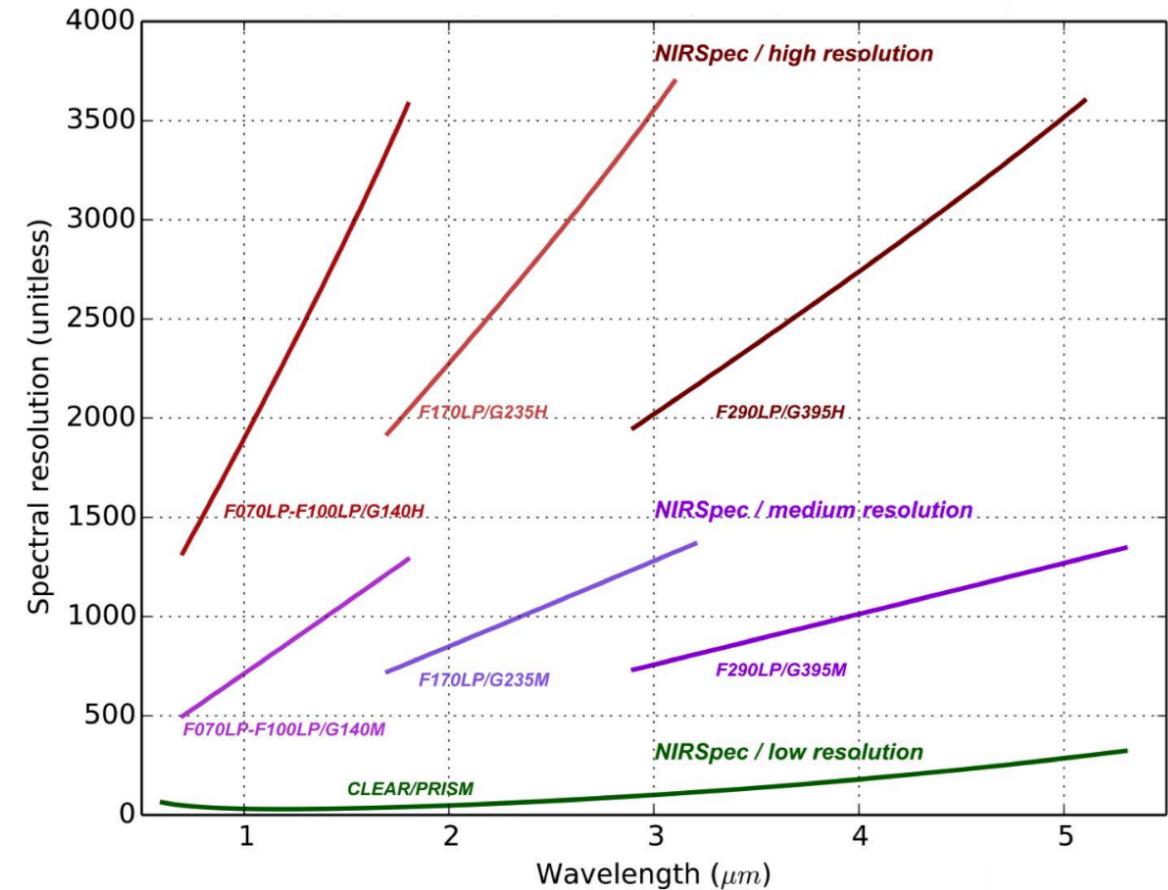
# NIRSpec IFU Wavelength Coverage

## Gratings

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

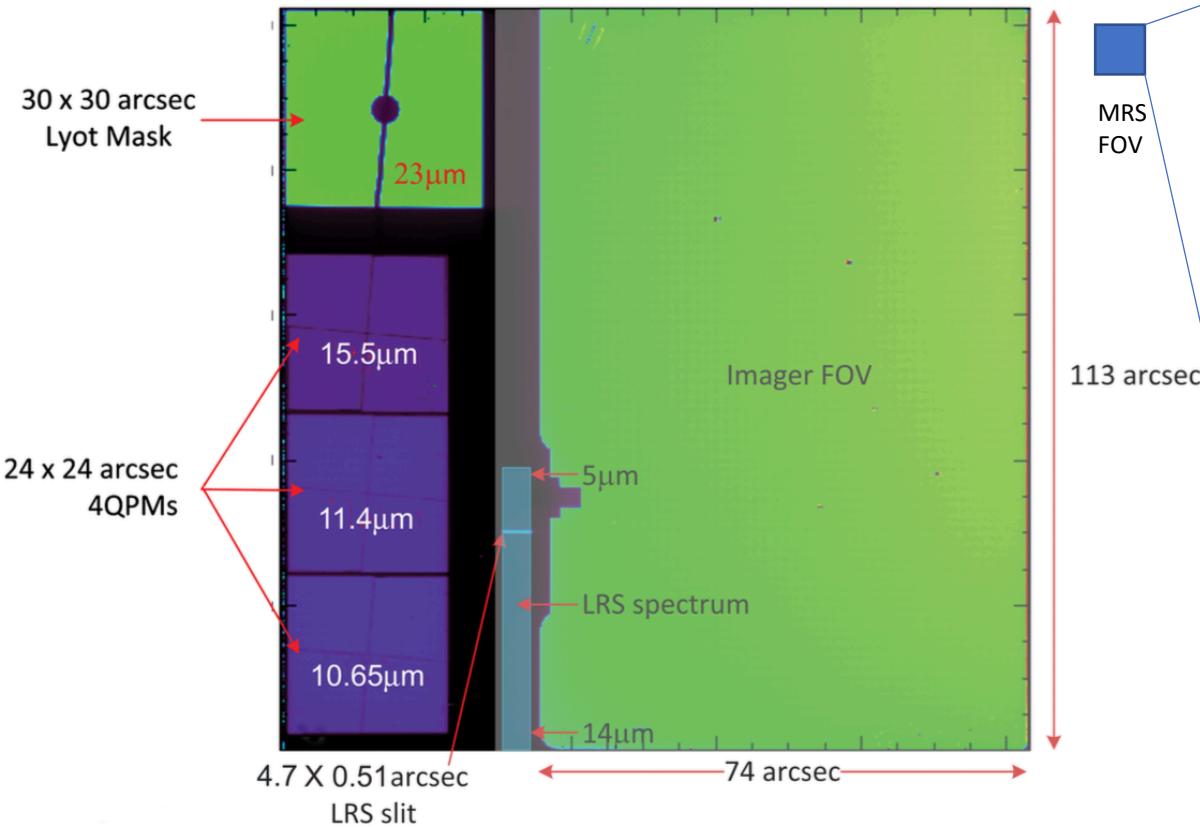
Filters paired with dispersers

e.g. F170LP/G235H

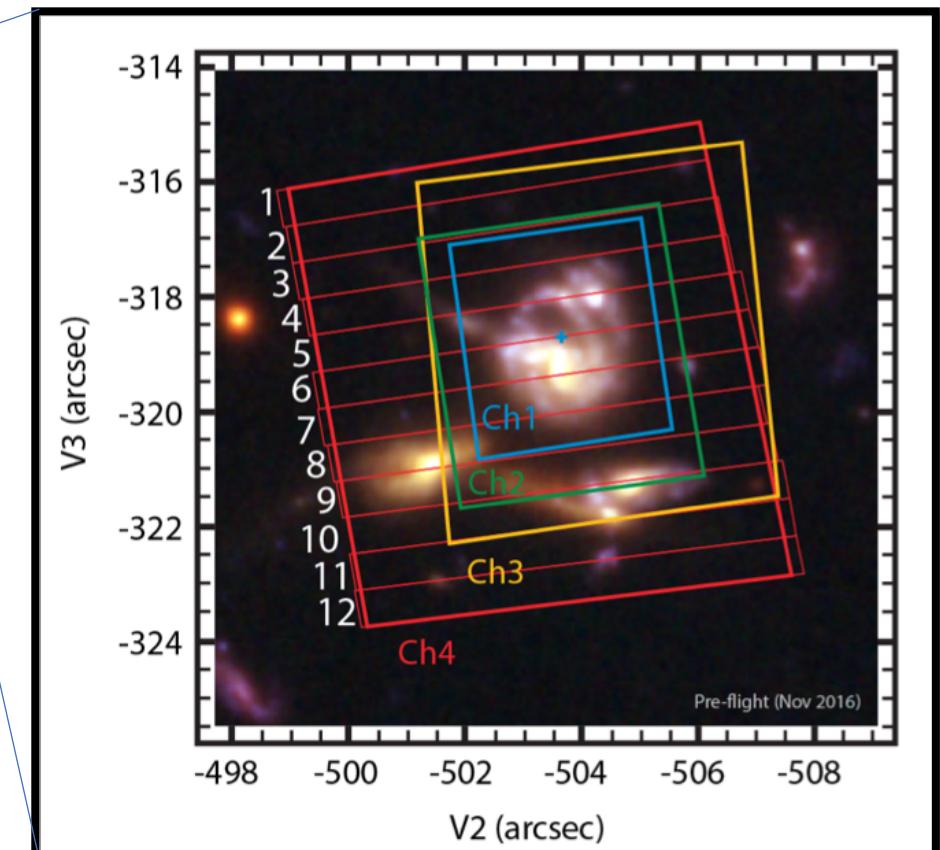




# MIRI Medium Resolution Spectroscopy (MRS)



MIRIM: MIRI Imager



MRS: Medium Resolution Spectrometer

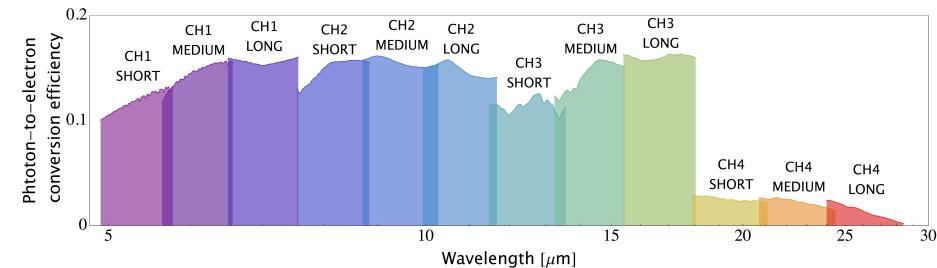
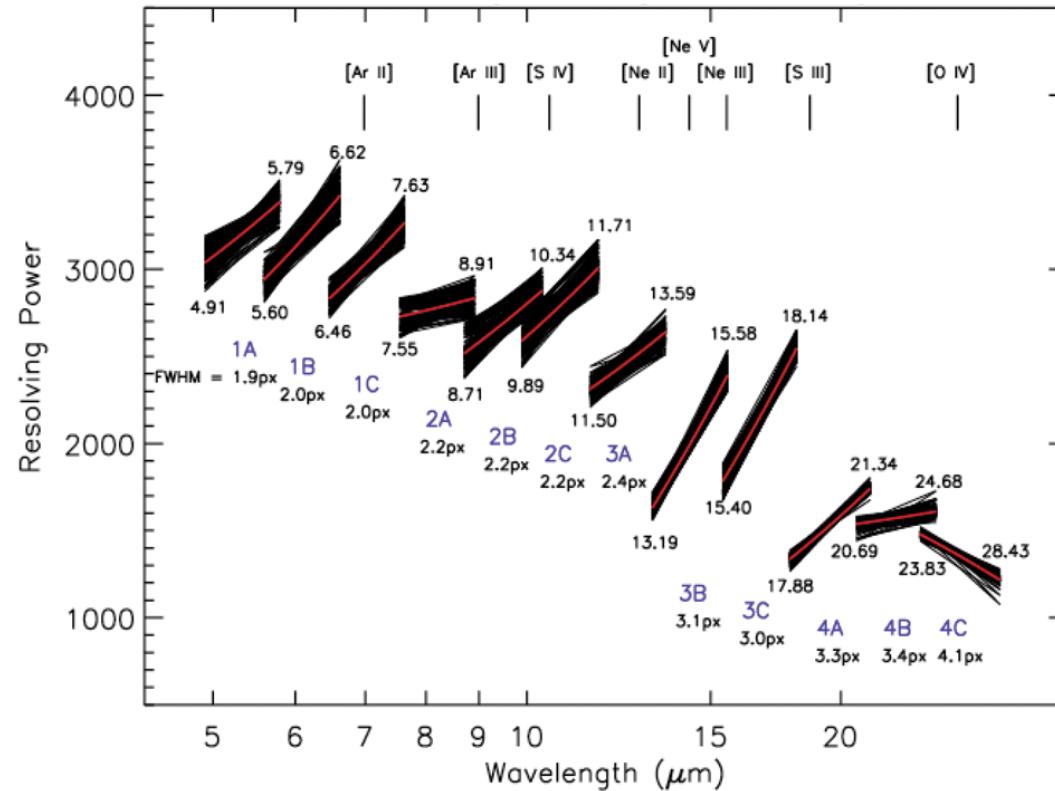


# MIRI MRS Wavelength Coverage

## 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.



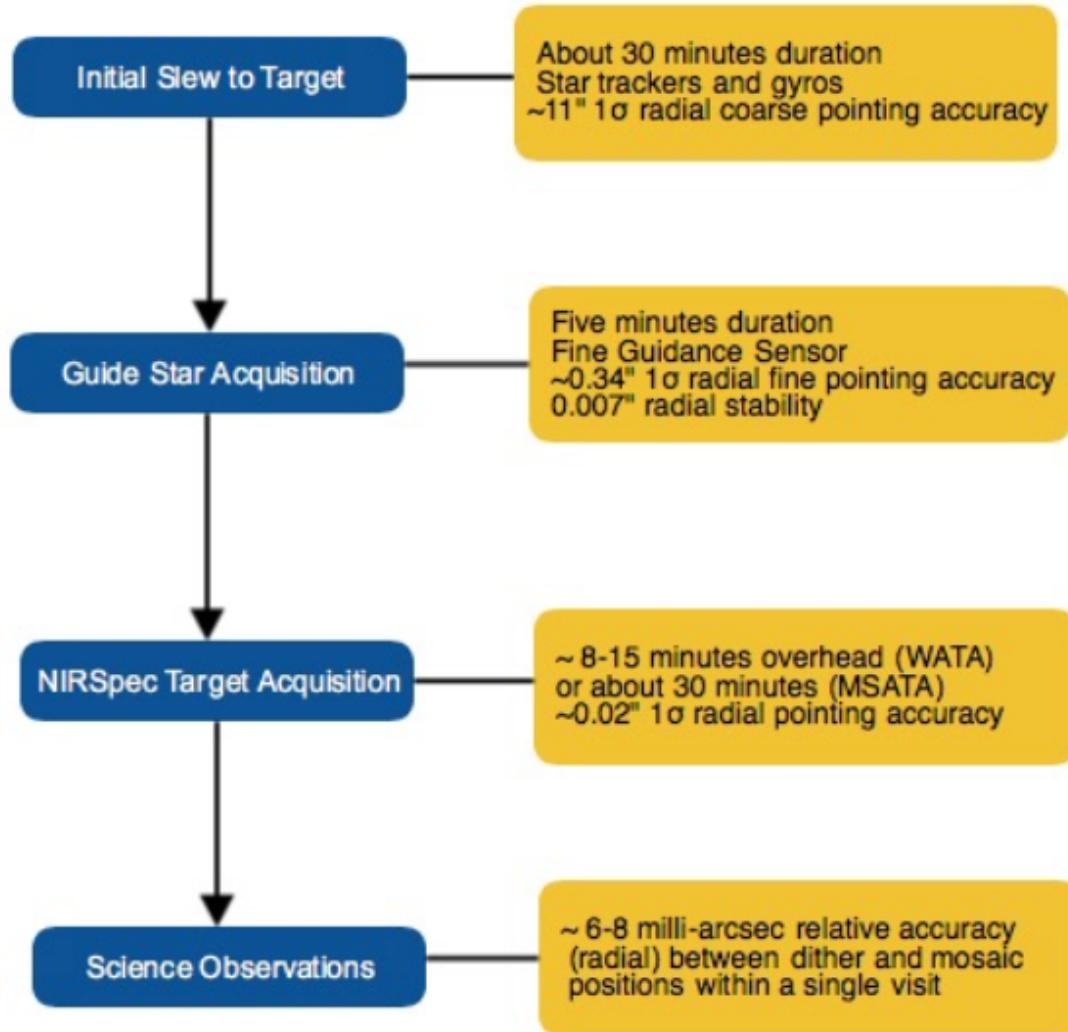
The background of the slide features a deep space scene with numerous small, glowing stars of varying colors (blue, white, yellow) scattered across a dark navy blue background. In the center-left, there is a prominent, large nebula with intricate, wispy structures in shades of blue, purple, and orange. A few bright, multi-pointed stars are visible in the upper left and upper right corners.

# Observation Planning with APT

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# NIRSpec IFU Target Acquisition





# NIRSpec IFU Target Acquisition

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## Methods

- NONE: JWST FGS pointing accuracy (radial  $\sigma = 0.34''$ )
- WATA (radial  $\sigma = 20$  mas, 11-18 minute overhead)
  - Limited by bright (e.g. 2MASS) reference star availability
- MSATA (radial  $\sigma = 20$  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

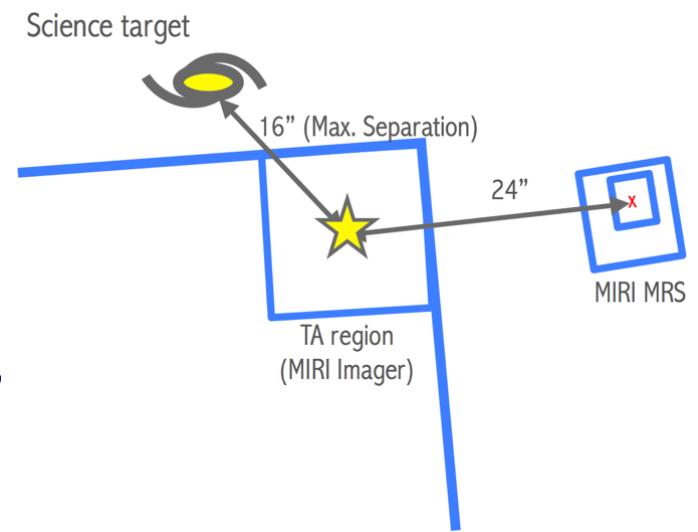
- Ref star must not have brighter point source within  $2''$
- WATA ref star coordinate absolute accuracy 150 mas
  - $38''$  visit-splitting limitation
  - $J = 11.9\text{-}25.7$  AB mag, depending on filter and readout
- MSATA: recommend accurate JWST or HST pre-imaging
  - $K = 19.5\text{-}25.7$ 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



# MIRI MRS Target Acquisition

## Methods

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

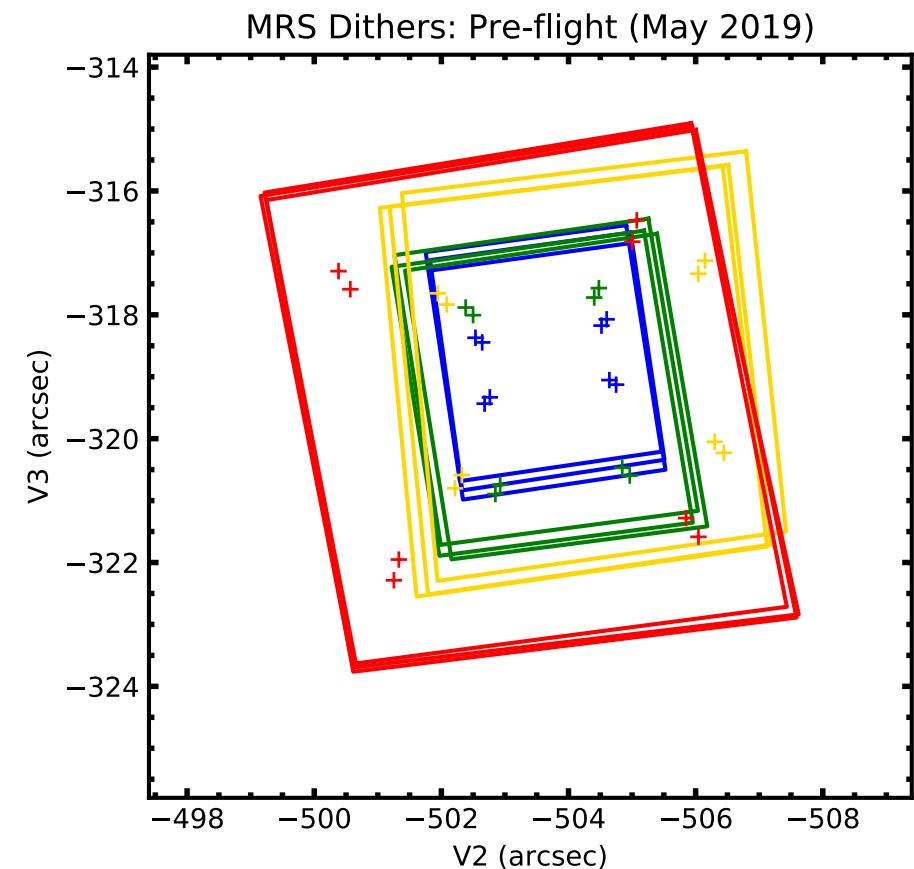
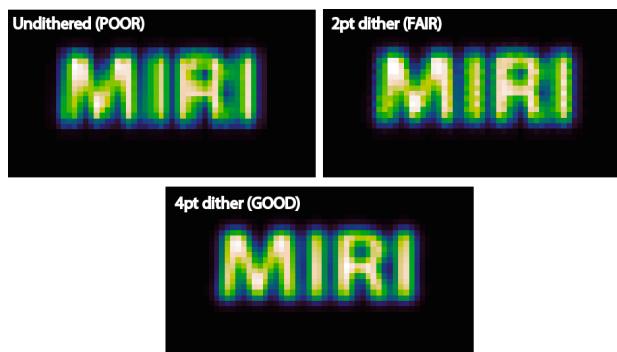




# MIRI MRS Dithering

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 43° for Point source
- 2-pt dither pattern
- 4-pt dither pattern
- 4-pt ALL preferred for point or extended sources.

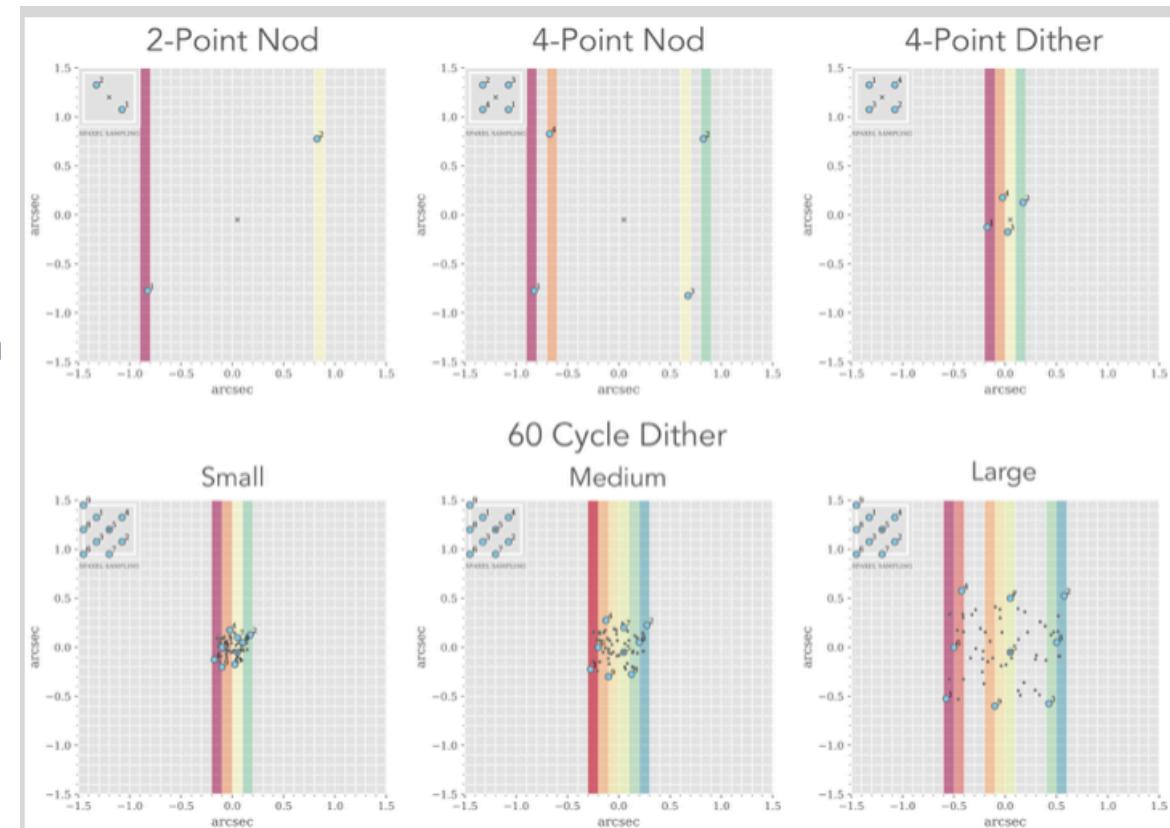




# NIRSpec Dithering and Nodding

## 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 (*preferred*)
    - ▶ 1.6" box
  - TA recommended so nod remains in-scene
- **Dither** = small offset for detector defect mitigation
  - 4-point dither
    - ▶ 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

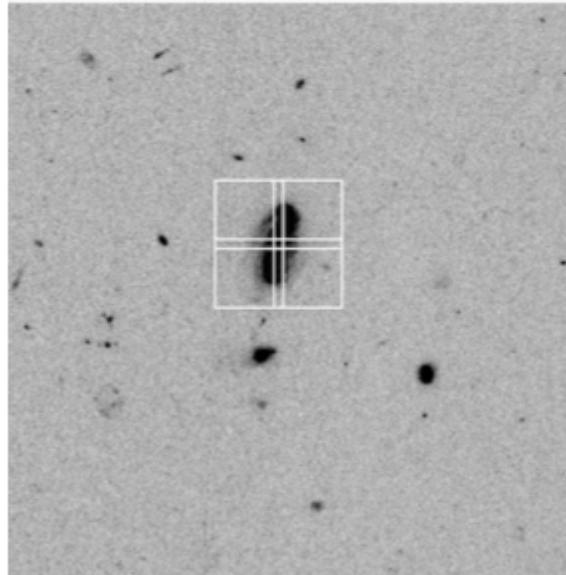
## Target groups

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

## MOSAIC

(Extending Coverage, Regular)

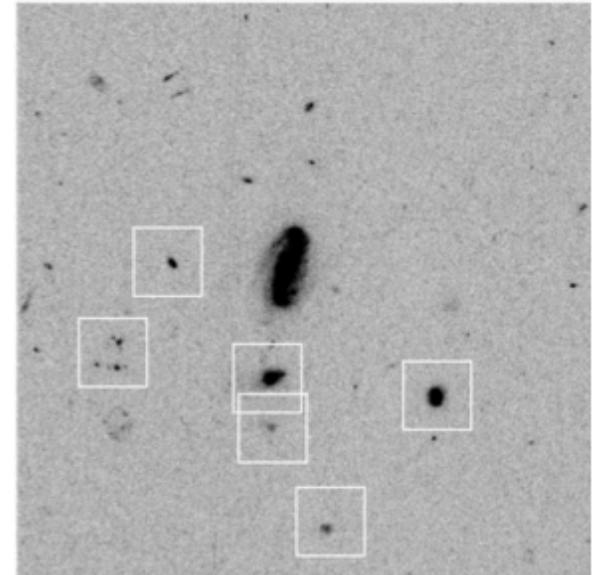
Available in the mosaic menu



## TARGET GROUPS

(Proximity Targets, Irregular)

Available in targets menu





## Offset Background Observations

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### 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

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## Readout

- SLOW mode
  - Current default for MRS
  - Fewer detector artifacts and slightly lower noise
  - Limits data rate when including MIRIM or parallels
- FAST mode
  - Available for bright targets
  - May be advantageous for expected high CR-rates (stay tuned)

## Groups

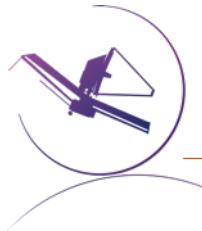
- 5 or more recommended for calibration (or switch to FAST)

## 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

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## Readout

- IRS<sup>2</sup>
  - 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

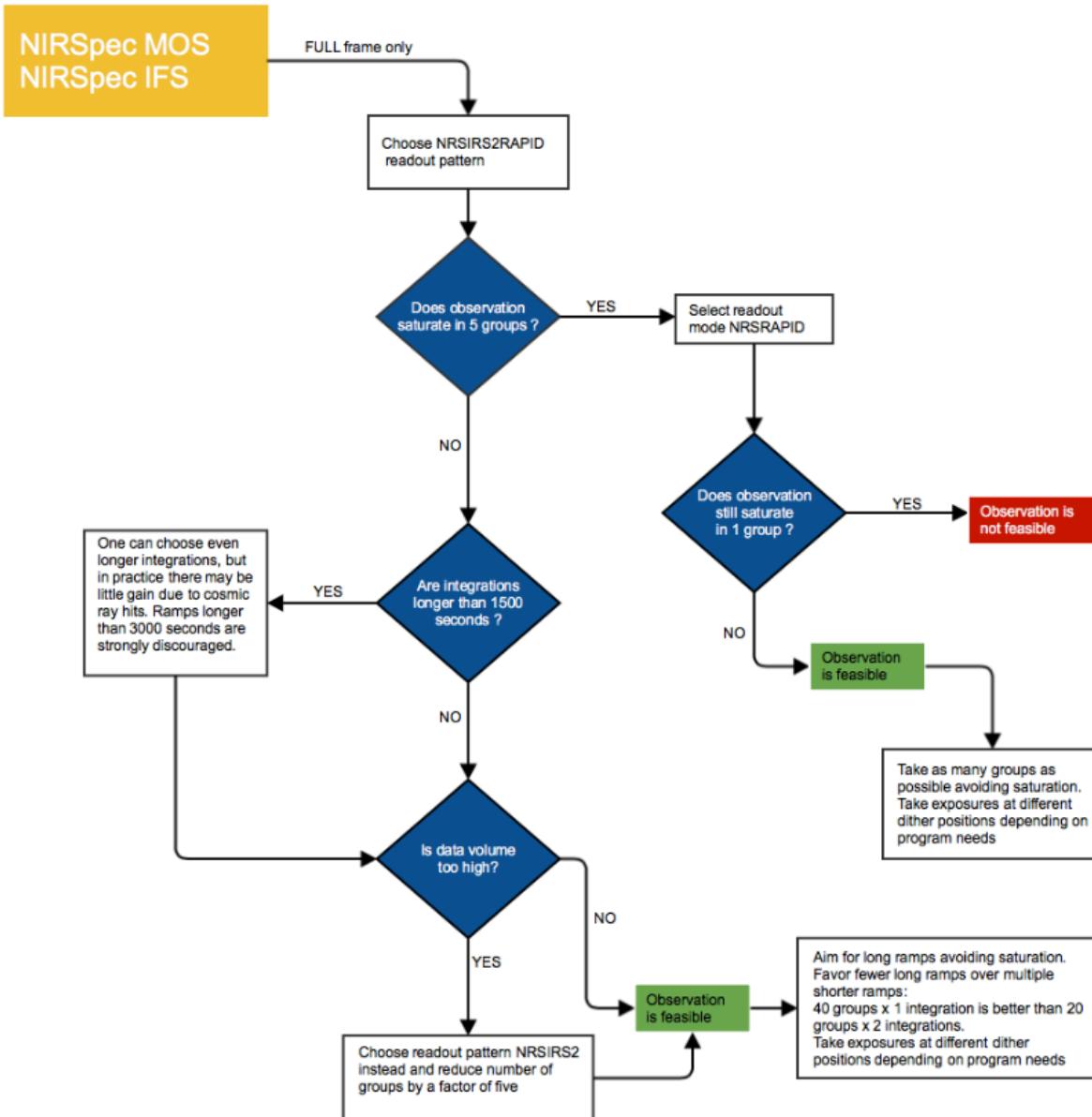
- <1500 sec recommended to mitigate cosmic rays

## 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

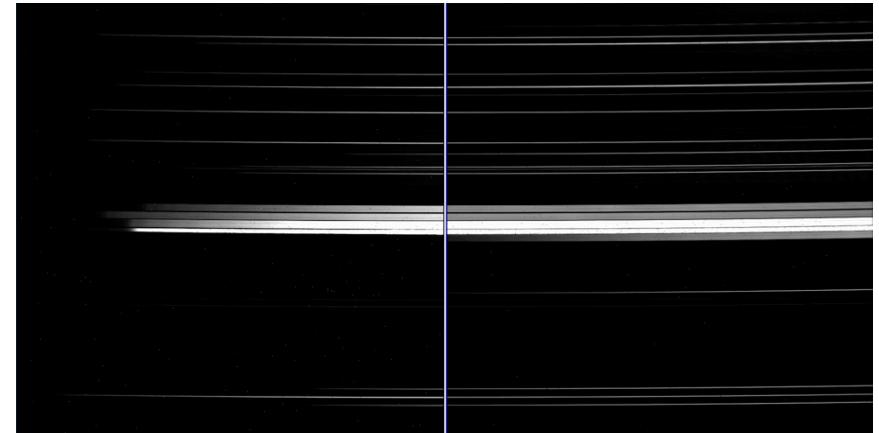
- Stars in open MSA shutters or bright star print-through
- Print-through from diffuse backgrounds (<3-10%)

Guidance on when Leakcal observations are necessary

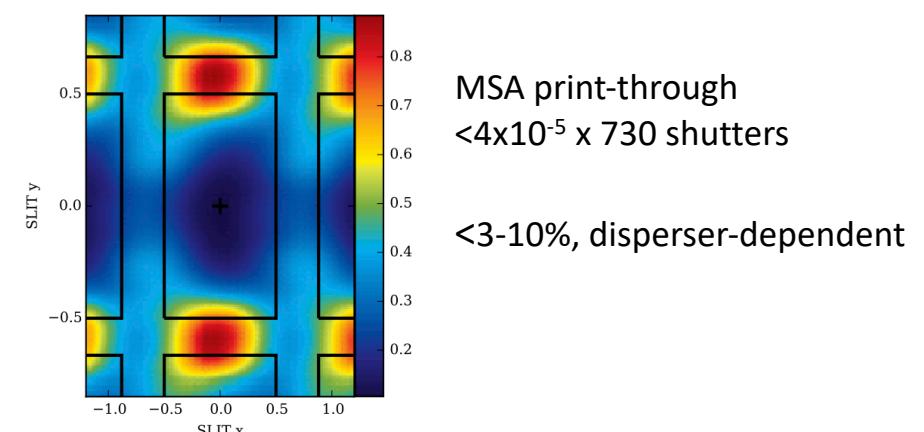
- Depends on source vs. spoiler signal
  - Print-through important for stars > 500x brighter than target
- Crowded stellar field
- Bright structured background (e.g. nebulae)

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  
 $<4 \times 10^{-5} \times 730$  shutters

<3-10%, disperser-dependent

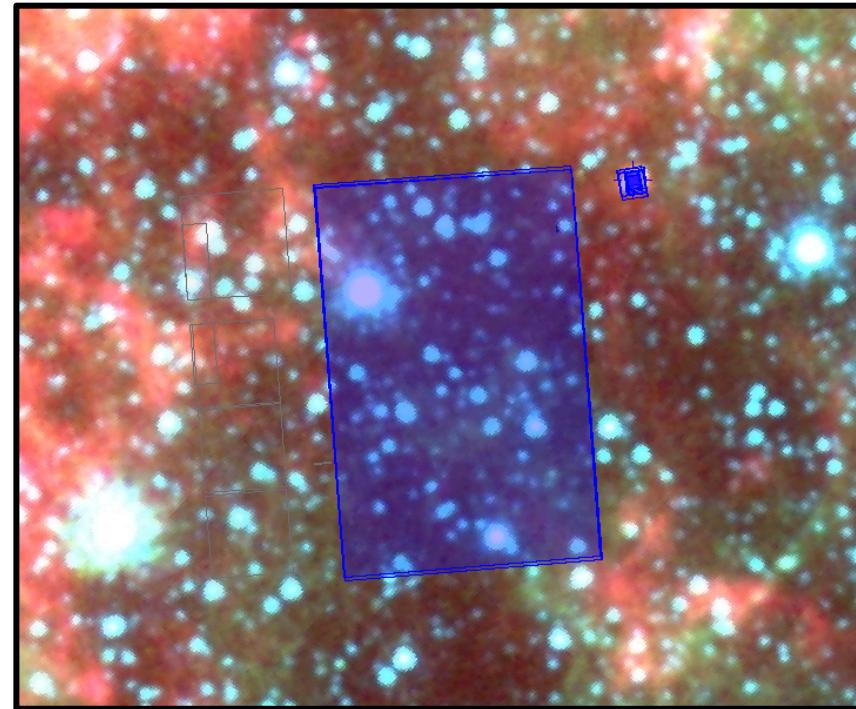


# MIRI MRS Simultaneous Imaging

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

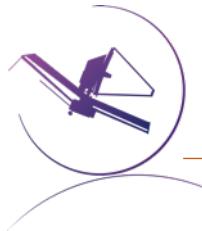
## Why is it useful?

- 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)

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## 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)

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## 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 SLOW 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

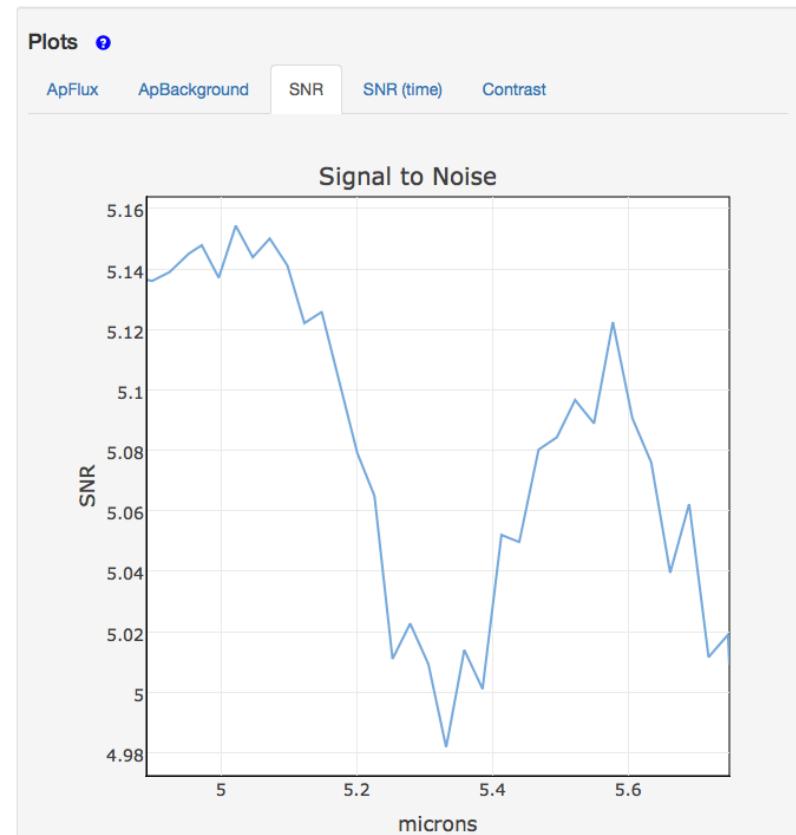
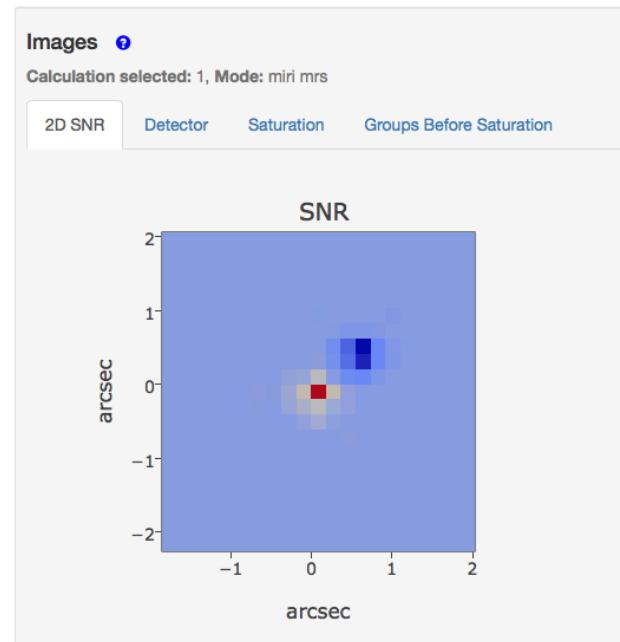
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# ETC Feasibility example: MIRI point source

## Point Source parameters

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

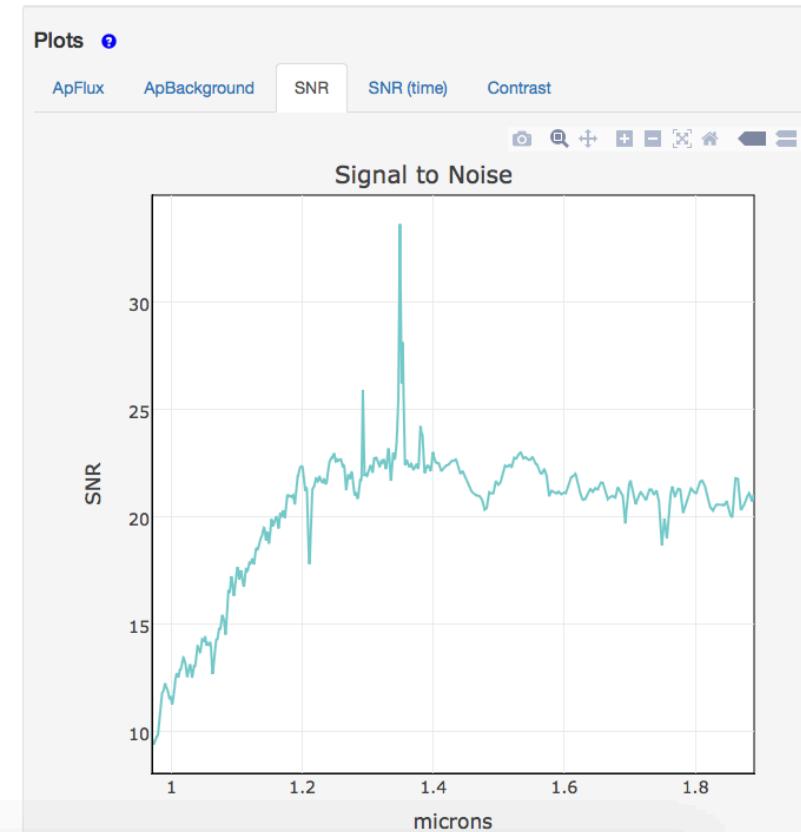
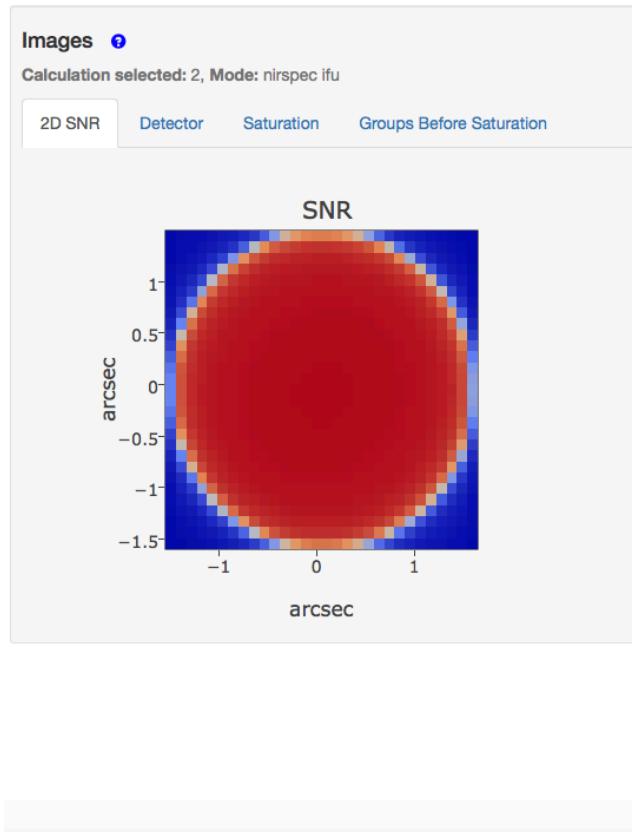




# ETC Feasibility example: NIRSpec extended source

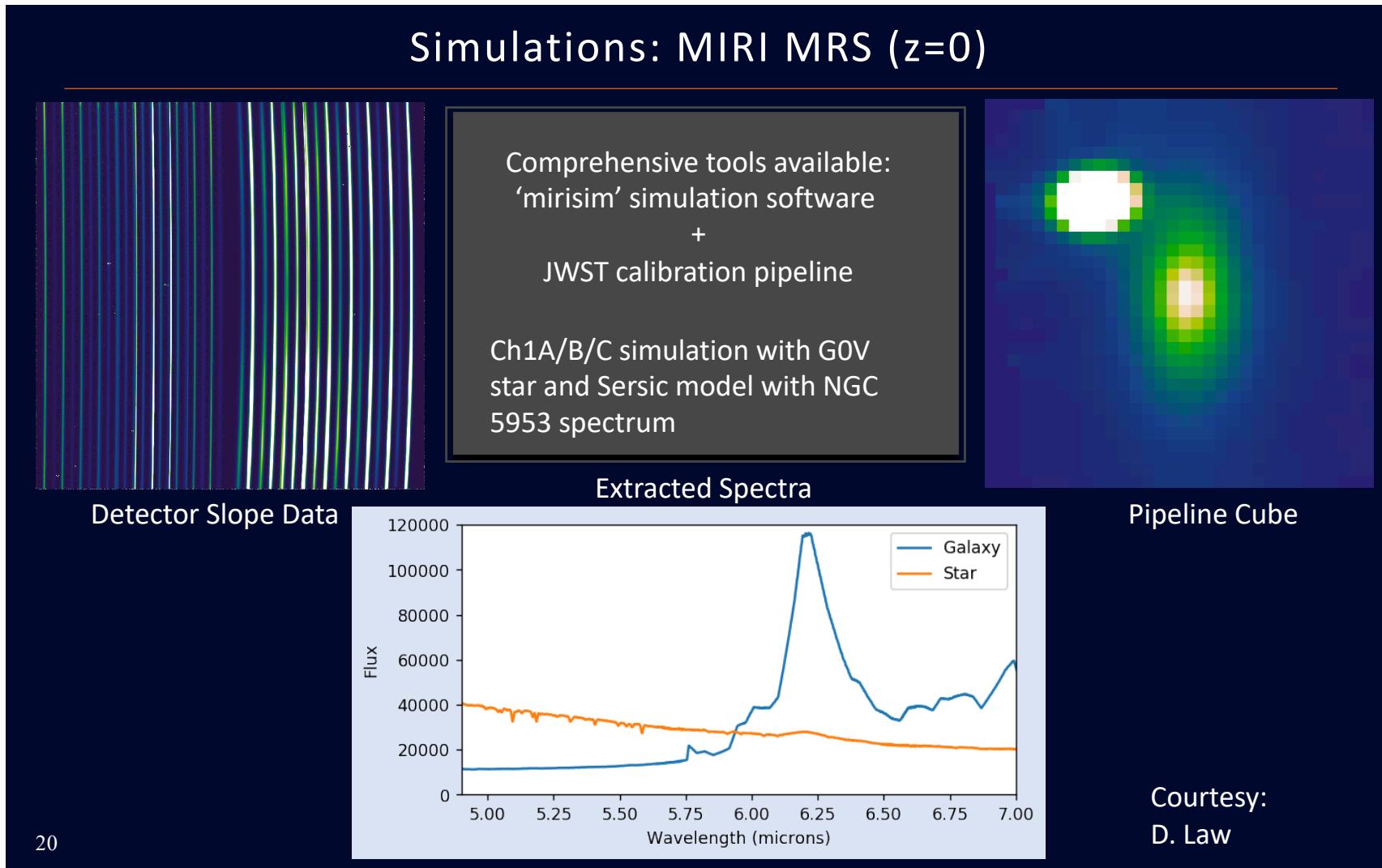
## Extended Source parameters

- 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



# Hands-On Exercise: Design MIRI and NIRSpec Observations

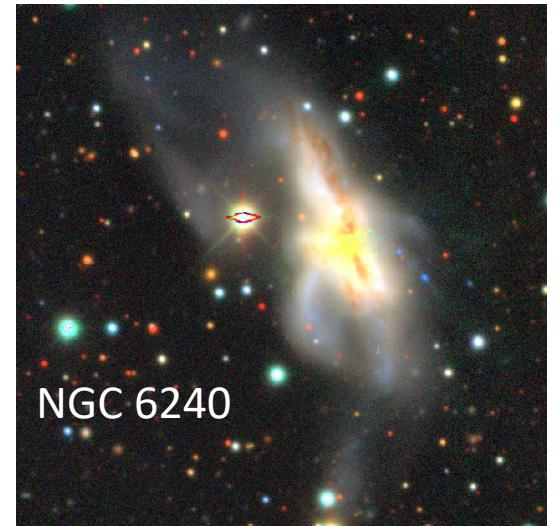
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## Hands-on Exercise

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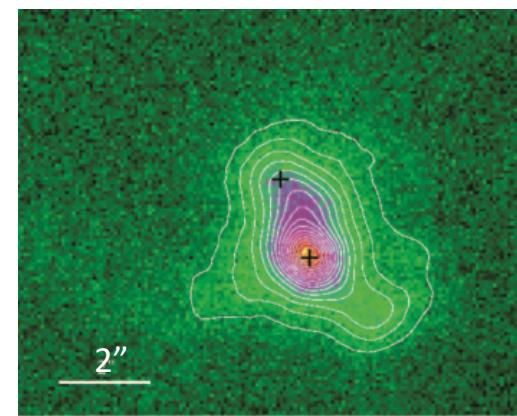
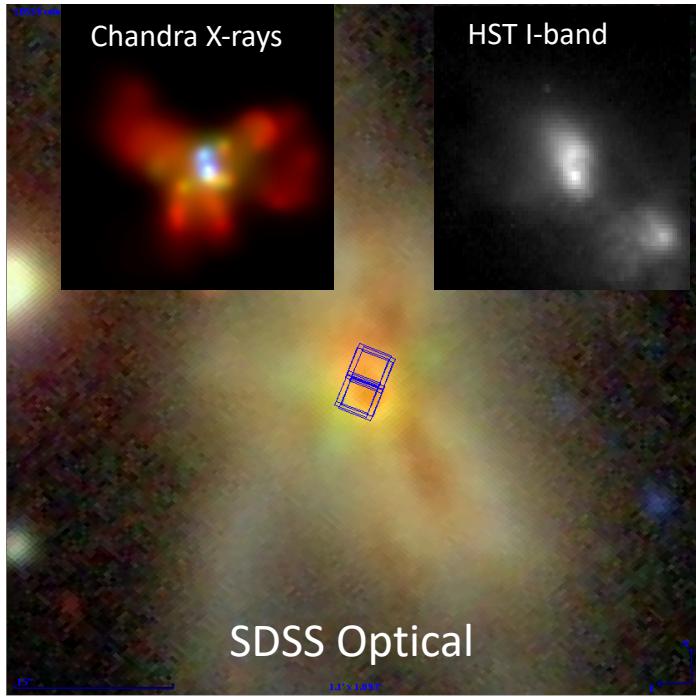
- 1) Create MIRI MRS and NIRSpec IFU 1x2 mosaics in APT for the following scene:  
LIRG Active Galactic Nucleus: NGC 6240  
Check for duplicates (GTO program 1265: MIRI MRS, MIRIM, and NIRSpec IFU )  
Science Goals:
  - 1) Measure kinematics of the extended H<sub>2</sub> 1-0 S(0) 2.1 μm emission line
  - 2) Map star formation in the 2 nuclei (point sources) using PAH 8μm feature
  
- 2) Determine exposure times for your observations using ETC.



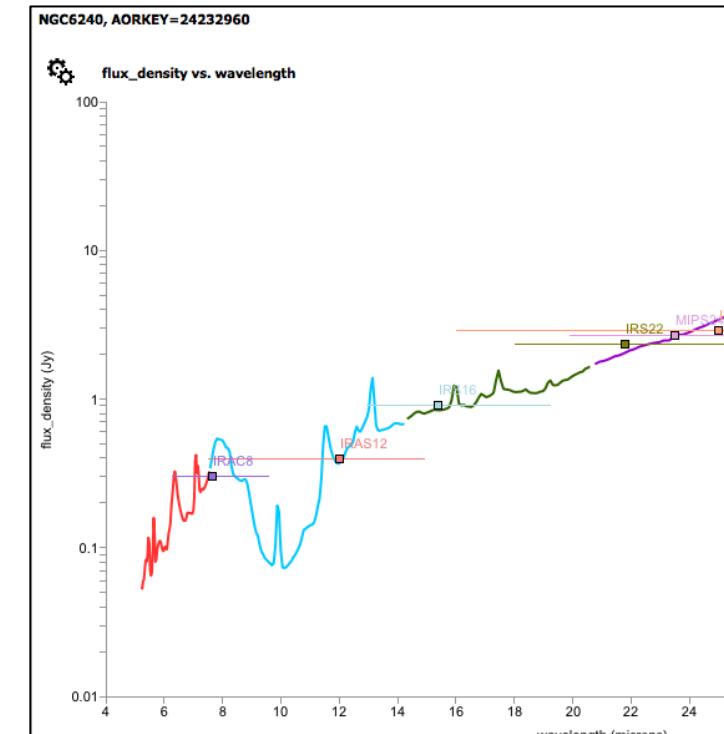
NGC 6240



# NGC 6240 (LIRG/AGN at $z=0.02448$ )



Bogdanovic+2003



## Spatial scene:

2 Nuclei sep: 1.6 arcsec

PAH and H<sub>2</sub> covering factor = ??

## **H<sub>2</sub> 1-0 S(0) 2.12 $\mu$ m line:**

$\lambda_{\text{obs}} = 2.1738 \mu\text{m}$

Line Flux =  $2 \times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$

FWHM = 400 km/s

Continuum within 5'' radius:  
33.7 mJy at 3.6  $\mu$ m

## PAH 8 $\mu$ m feature:

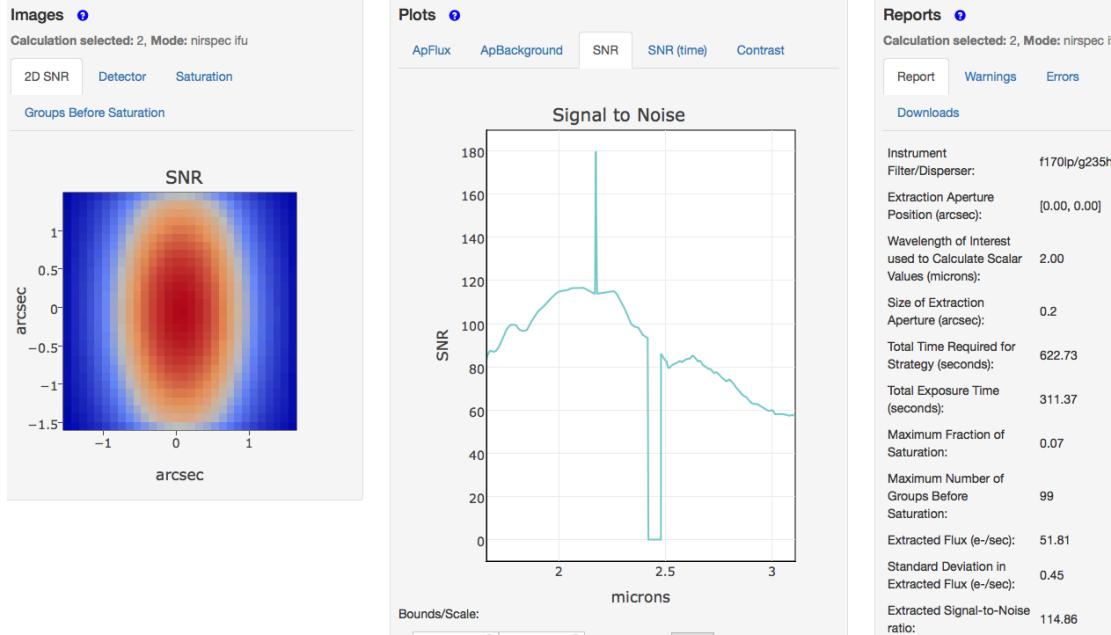
Spitzer IRS 5-25  $\mu$ m

(3.7'' slit)

$F_v = 0.6 \text{ Jy}$  at 8  $\mu$ m



# NGC 6240 ETC Guidance—NIRSpec IFU

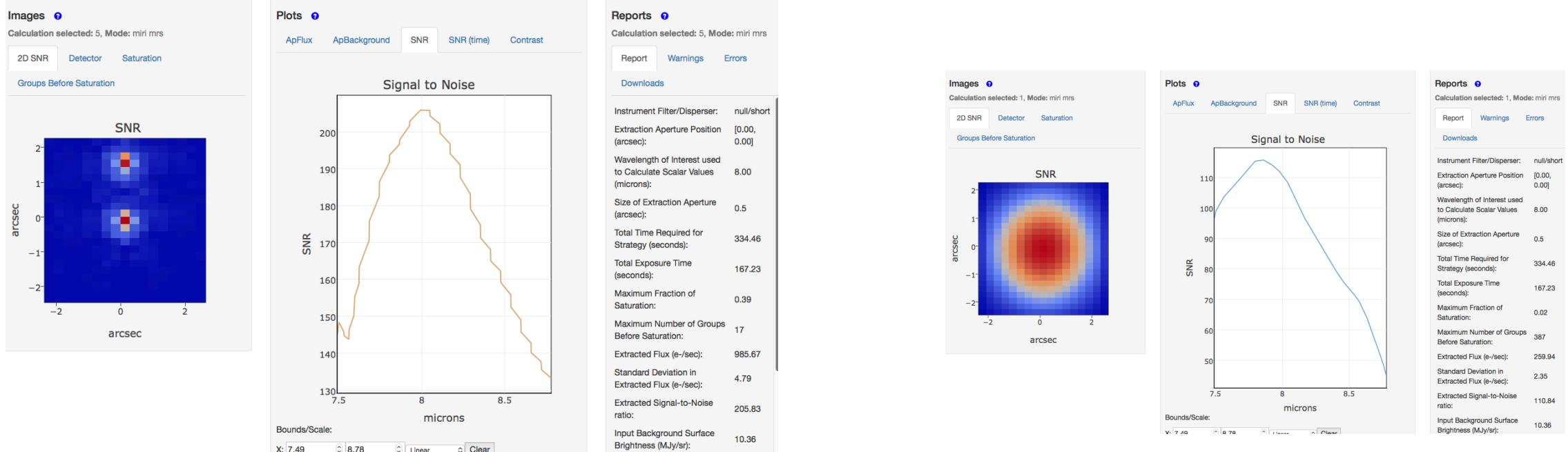


## H<sub>2</sub> 1-0 S(0) 2.12 μm line :

- Distribute line and continuum flux into  $(\sigma_x, \sigma_y) = 0.5'' \times 1''$  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=205

## PAH 8 μm feature (Version 2):

- Flat, extended source with 1" radius
- 0.5" radius aperture
- Peak S/N=115