
Overview of the NIRSpec Multi-Object Mode
observing strategies, issues and tips
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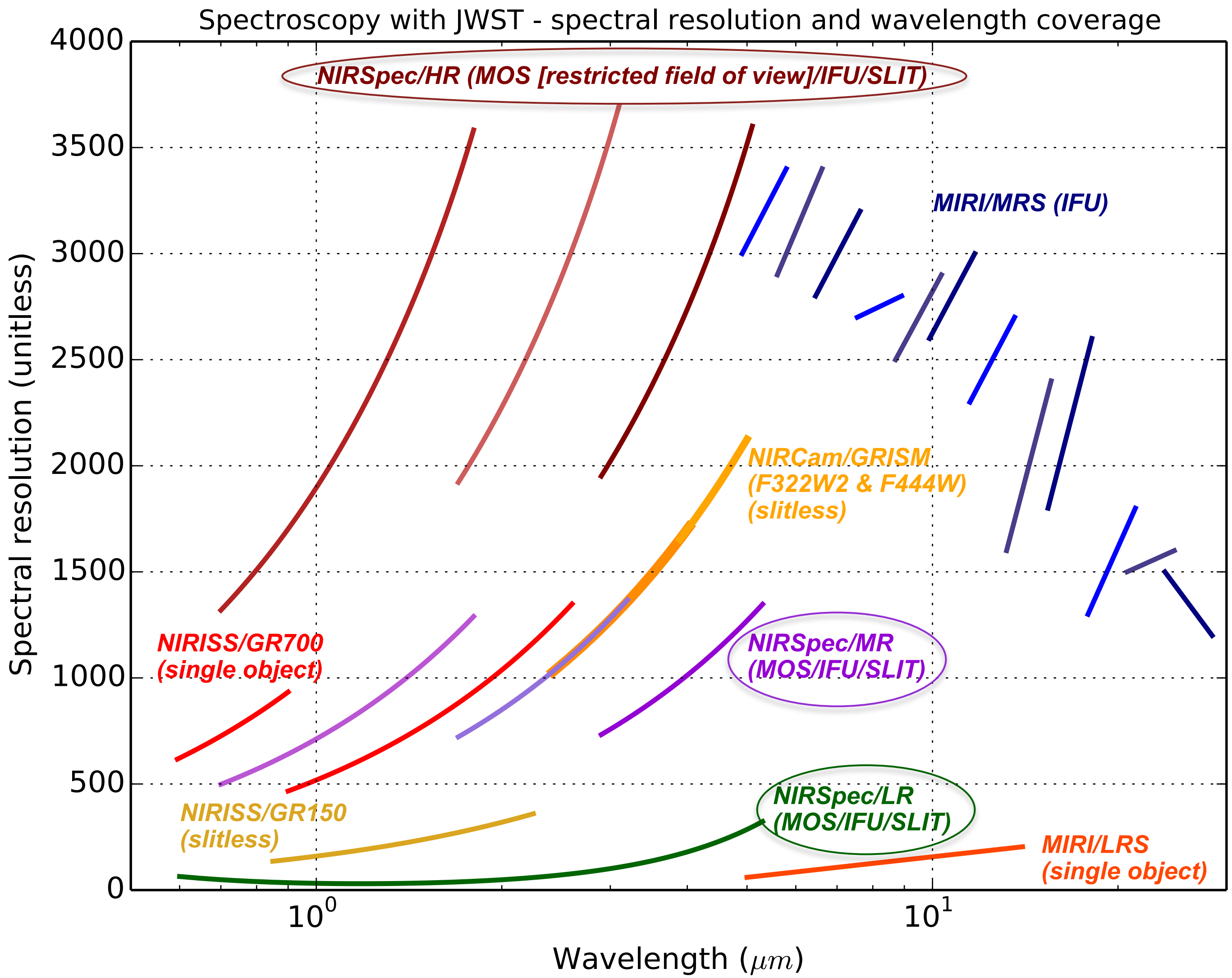
on behalf of the NIRSpec GTO team

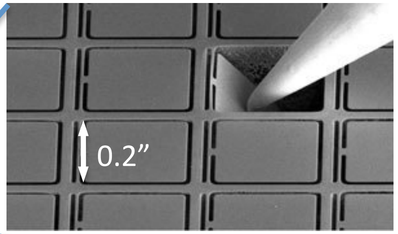
NIRSpec spectral resolution and wavelength coverage:

3 high resolution gratings (R~2700)

3 medium resolution gratings (R~1000)

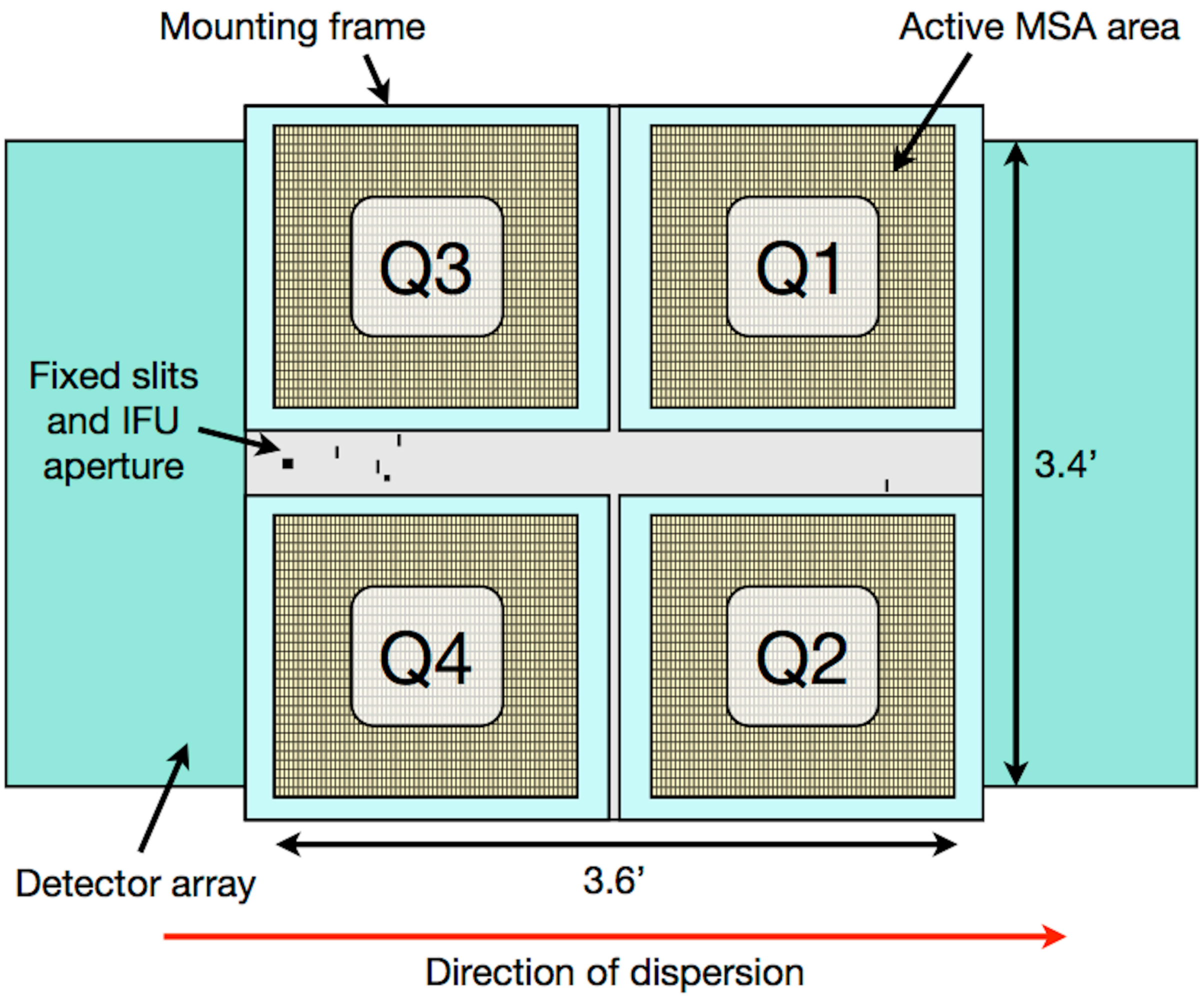
1 low resolution prism (R~100)





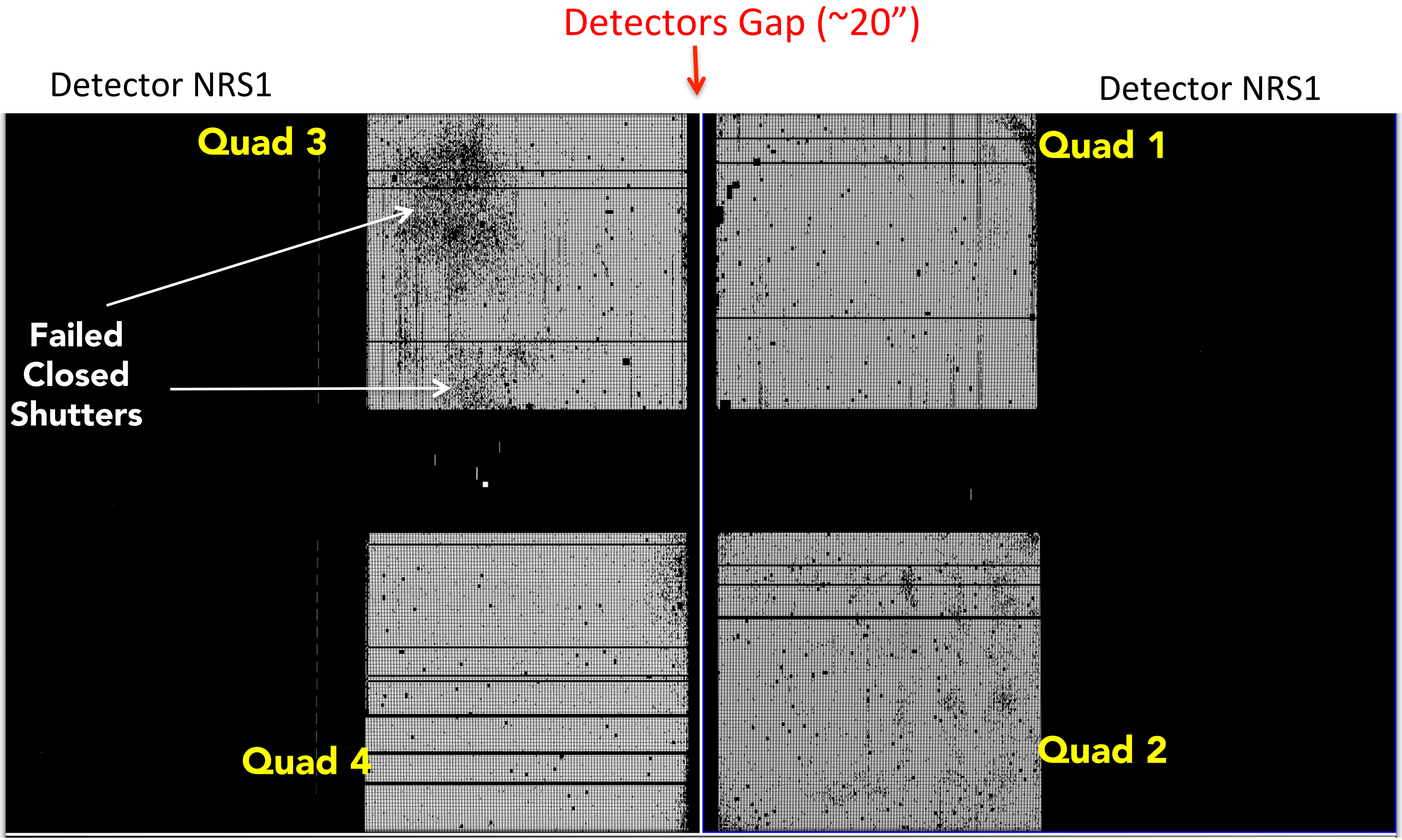
Micro Shutter Array

4 quadrants, each with 171 rows of 365 shutters, totaling ~250,000 shutters
Each shutter is 0.46” high x 0.2” wide
(dispersion direction)



Note:
it is a **RIGID ARRAY**
⇒ implications
for observing plan
(as we’ll see)

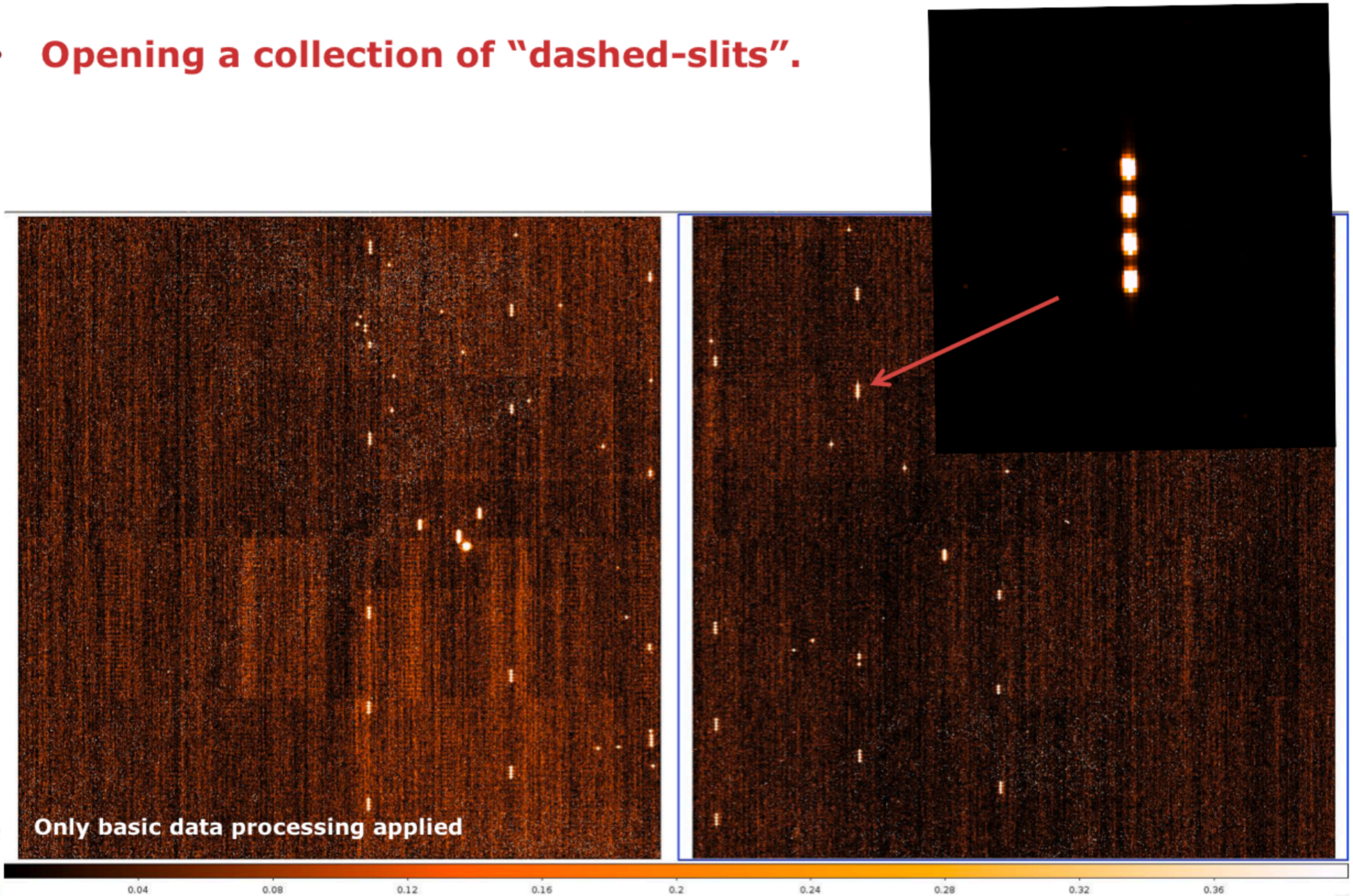
MSA images of uniform illumination with "all" shutters open



All dispersing elements can be used...

Example of MOS test data

- **Opening a collection of "dashed-slits".**

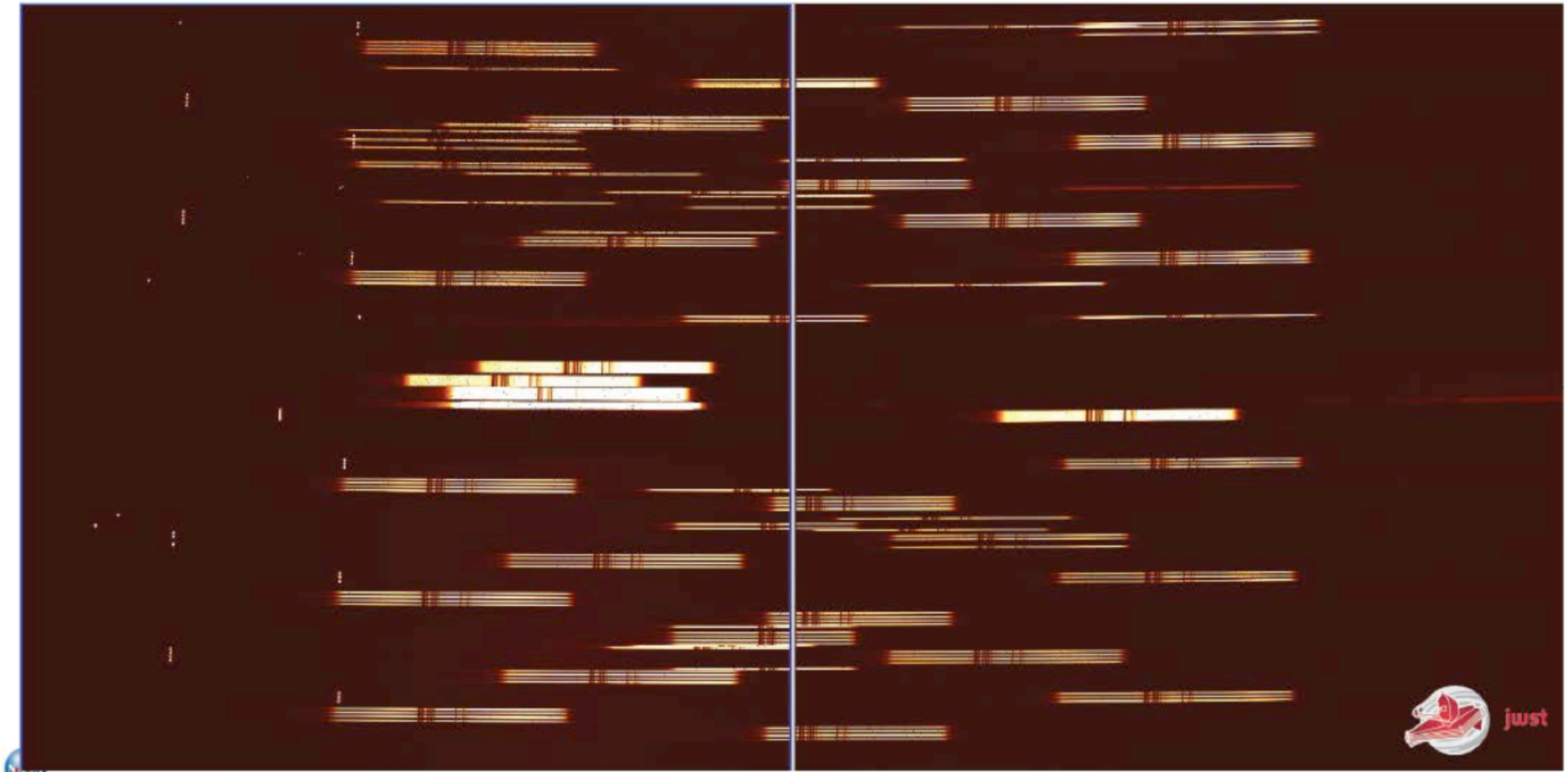


Data obtained before the replacement of the detectors by new ones with much improved cosmetics!

JWST/NIRSpec Example of MOS data

- **And getting spectra...**

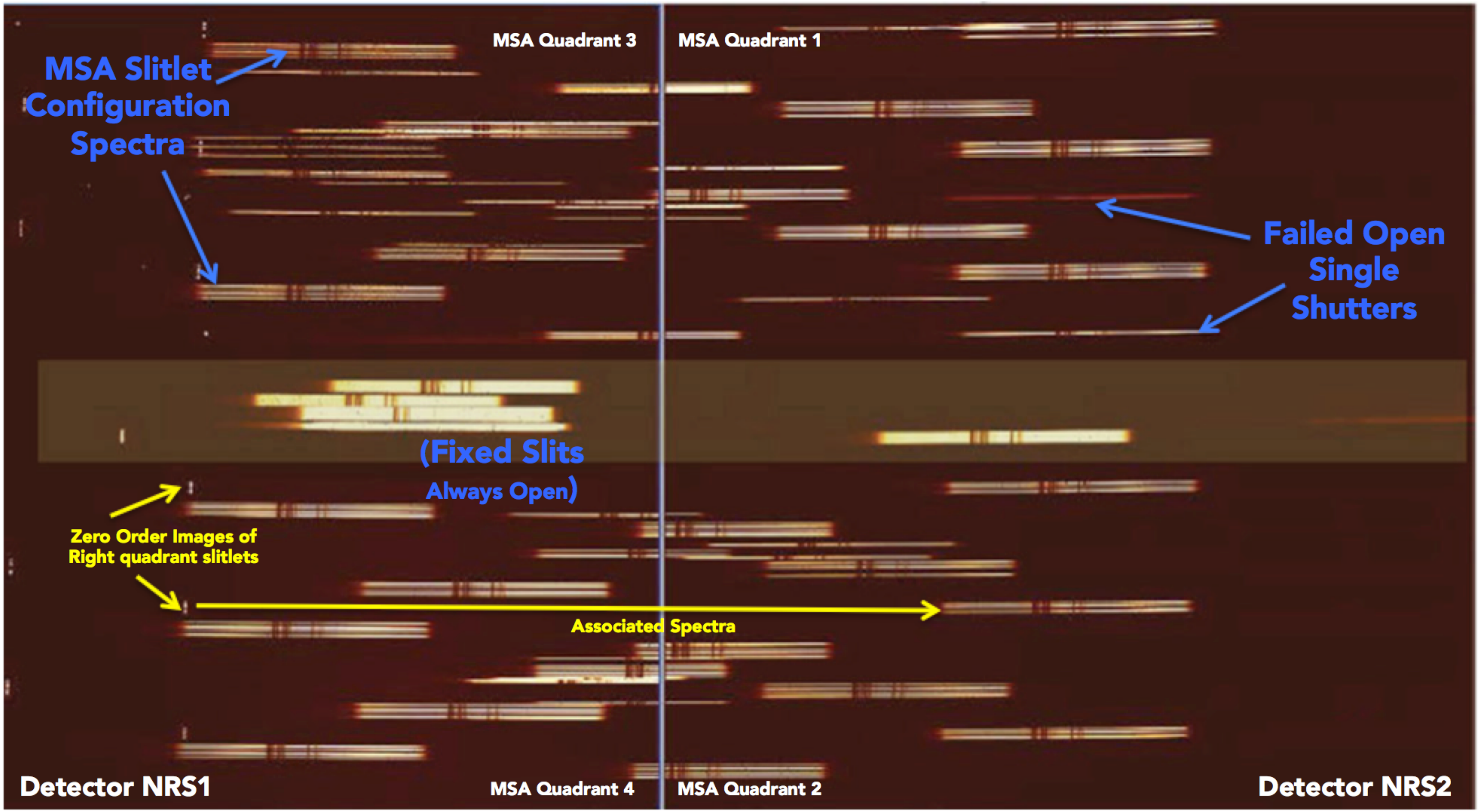
G140M configuration.
1.3-1.7 micron source with absorption lines.



JWST/NIRSpec - FM2 cyrogenic test campaign 01/2013

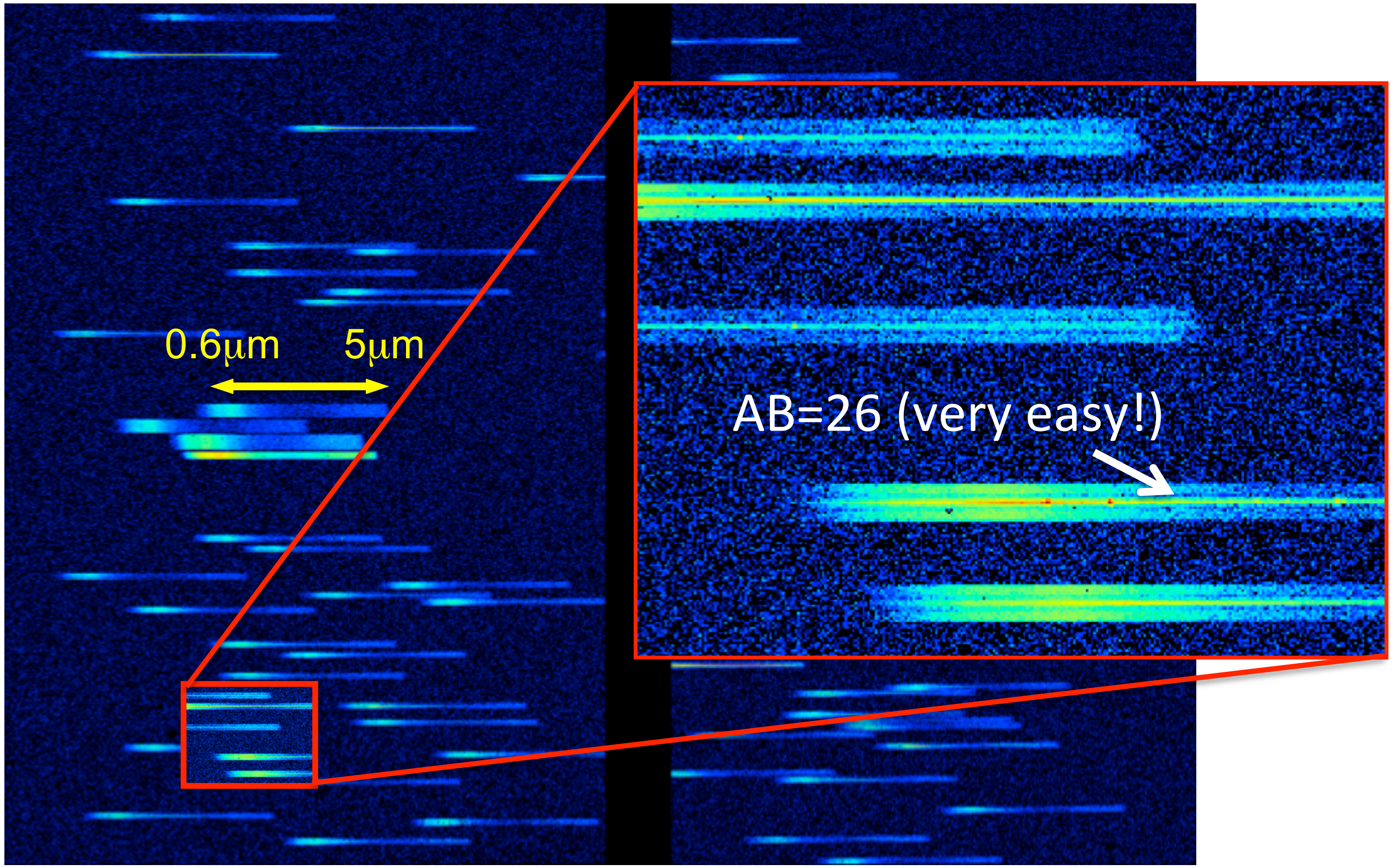
JWST/NIRSpec
Example of MOS data

zoom in

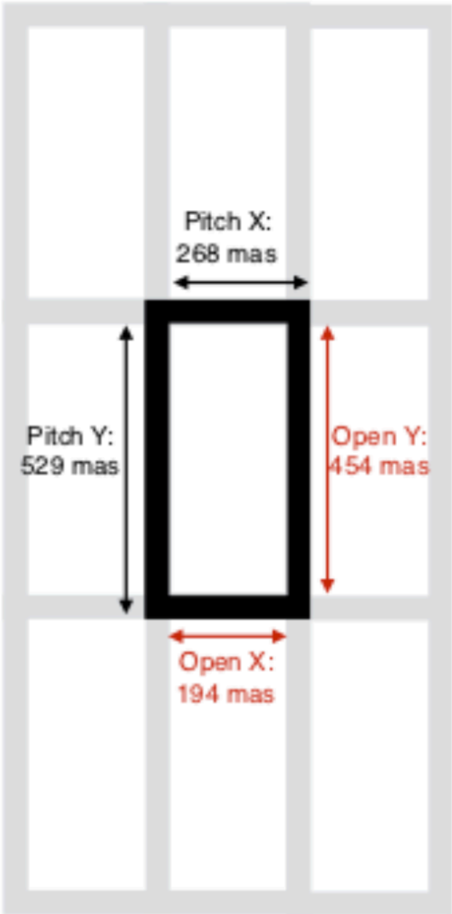


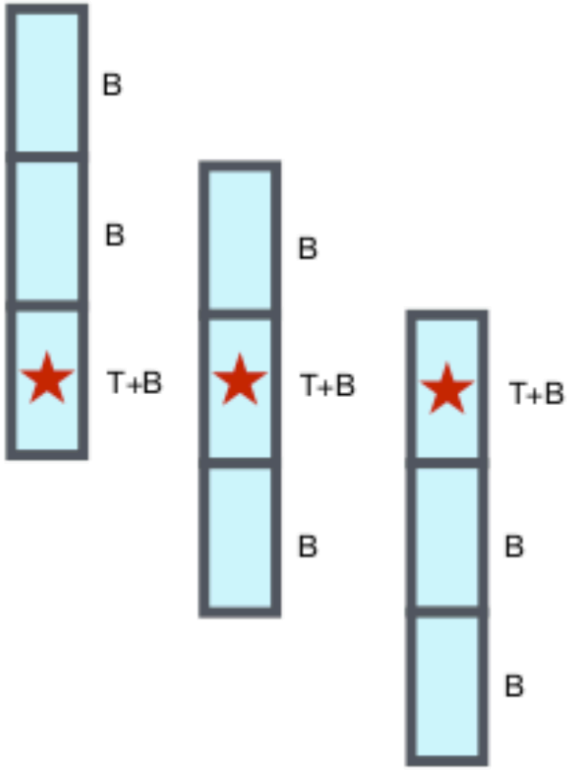
Simulation of exposure in the Hubble Deep Field 20 min

R=100



In general each target (especially for faint ones) will have associated a set of **3 shutters forming a slitlet** and the telescope will **nod** targets on the three shutters for background subtraction (more/less shutters per slitlet can be selected depending on target size and brightness)





Courtesy:
P. Jakobsen

All dispersers can be used

Example with **R=100**
Short spectra => typically 4 spectra can be accommodated in one row without overlaps

Courtesy:
P. Jakobsen

Example with **R=1000**
Typically one spectrum can be accommodated in one row without overlaps (or less, given that spectra are curved)

Note that most spectra have a gap
-> need an offset by ~20" to recover this gap

At **R=2700** spectra are ~2.7 times longer
most of them are truncated (on the blue side)
The extent of truncation depends on the target location on MSA

Planning challenge:

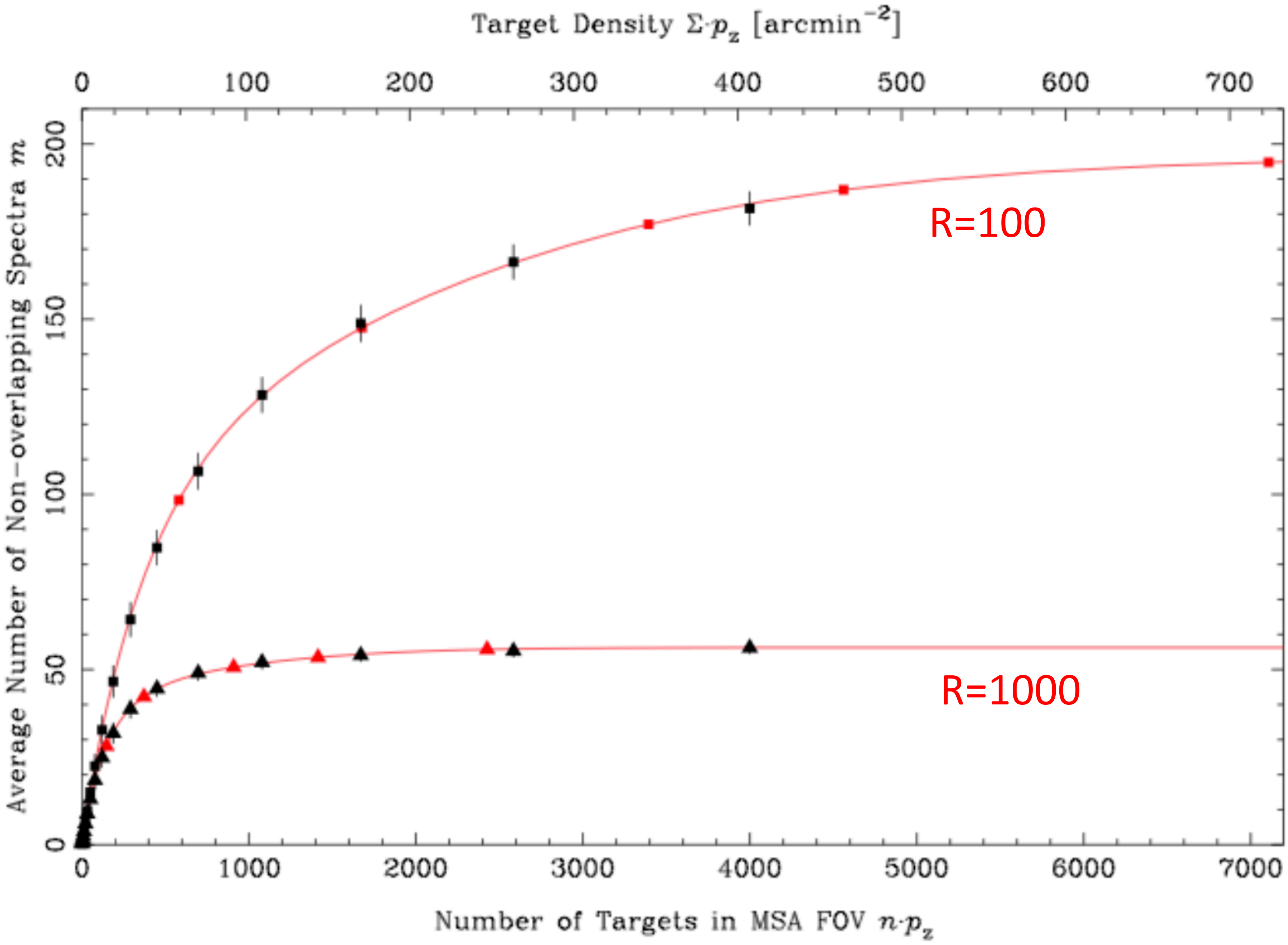
- **Rigid MSA structure**
  => cannot center simultaneously all targets:
  have to find a compromise
  -> **“acceptance zone”** within shutter footprint
- Avoid **failed closed** shutters
- **Avoid spectra overlap**
- Avoid overlap with **failed open** shutters

Planning challenge

-> **MPT:**

1) given a **roll angle** and set of **"primary" targets** optimizes
   the pointing and MSA configuration to maximize the number
   of targets observed
   -> **typically ~ 30% of the primary target can be accommodated**

2) opens the other shutters on as many **"filler targets"** as possible
   -> **final efficiency** (number of spectra obtained per pointing)
   depends on density of targets
   (at least ~200 $arcmin^{-2}$ to decently exploit the MSA)



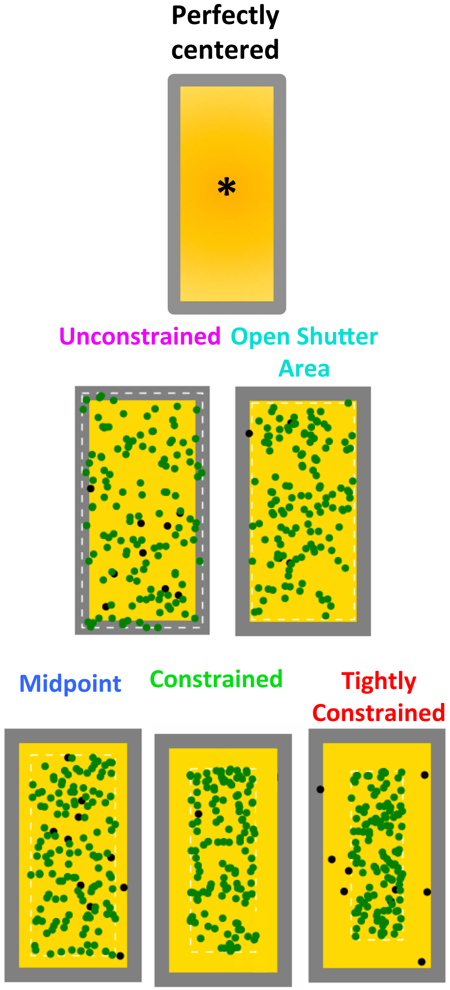
courtesy: P. Jakobsen

Key Planning Parameters in MPT:

courtesy: D. Karakla

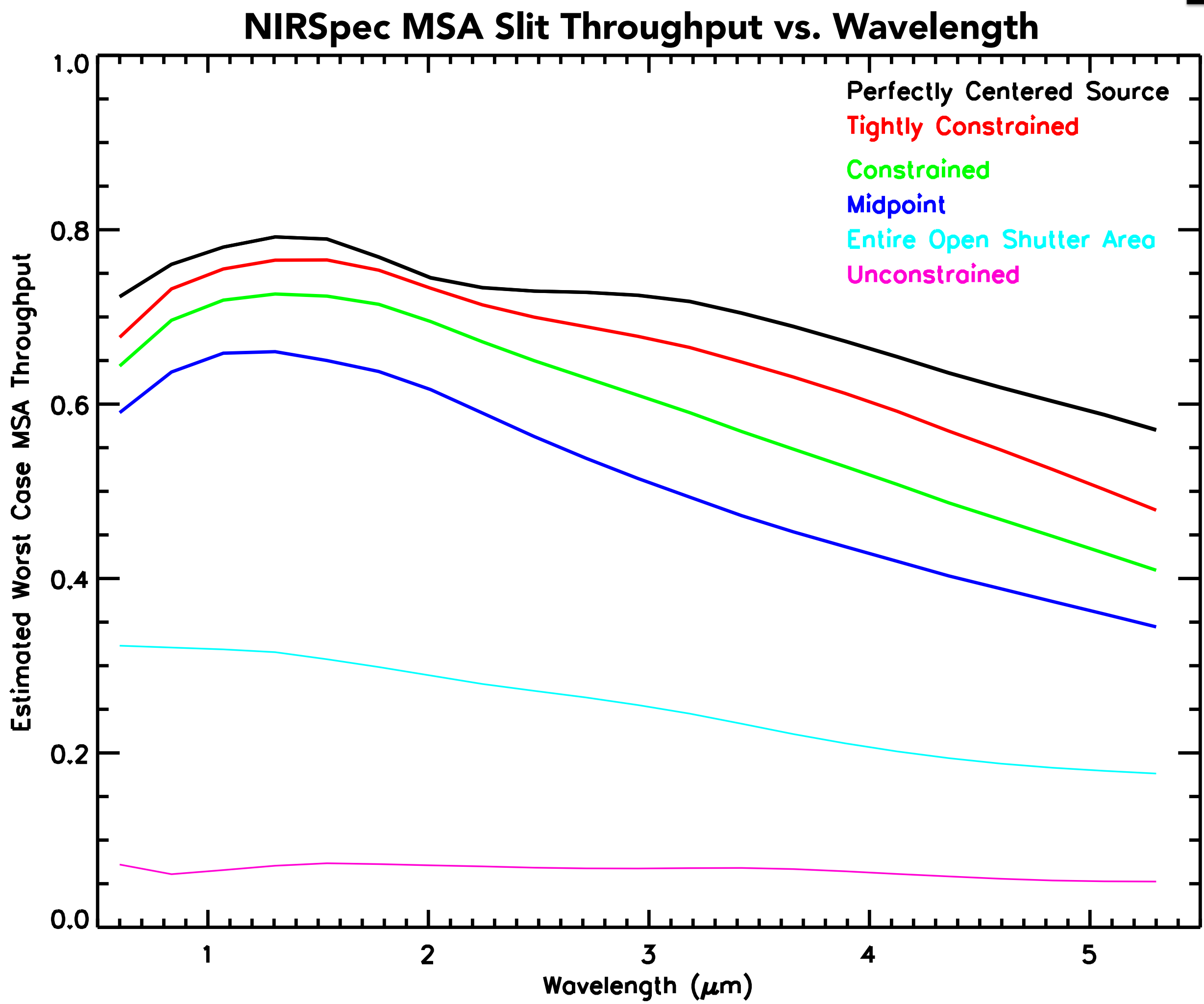
Slitlet Shape & Shutter Margin (aka "Acceptance Zone")

- **Shutter margin** to limit slit losses (5 choices):



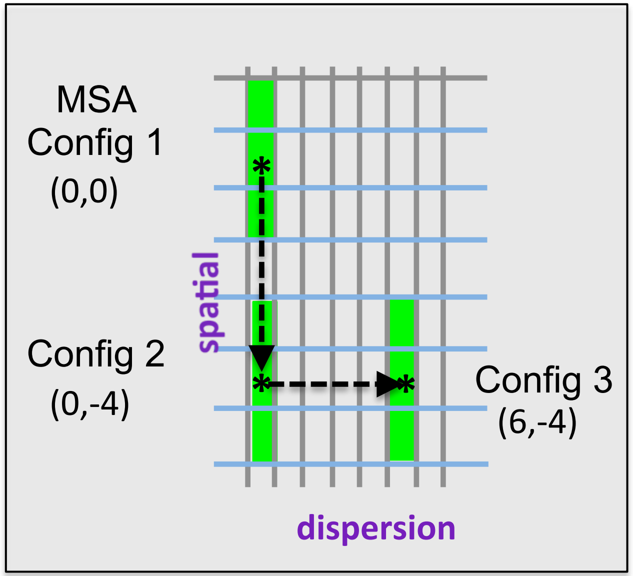
Shutter Planning Constraints

- **Slitlet shape** (can be 1, 2, 3, or 5 shutters)



Key Planning Parameters in MPT: Dithers

Fixed dithers: Translate MSA config pattern to new dither point.



SMALL dithers only! <~ 10 arcsec

Flexible Dithers: Large dithers
e.g. to cover the detectors gap

- Because of distortions requires MSA reconfiguration

  Typically only 30-50% of the targets can be retrieved in the new MSA configuration

adapted from D. Karakla

courtesy: D. Karakla

Output and Plan Assessment Tools

There are some nice built-in tools to help assess plans:

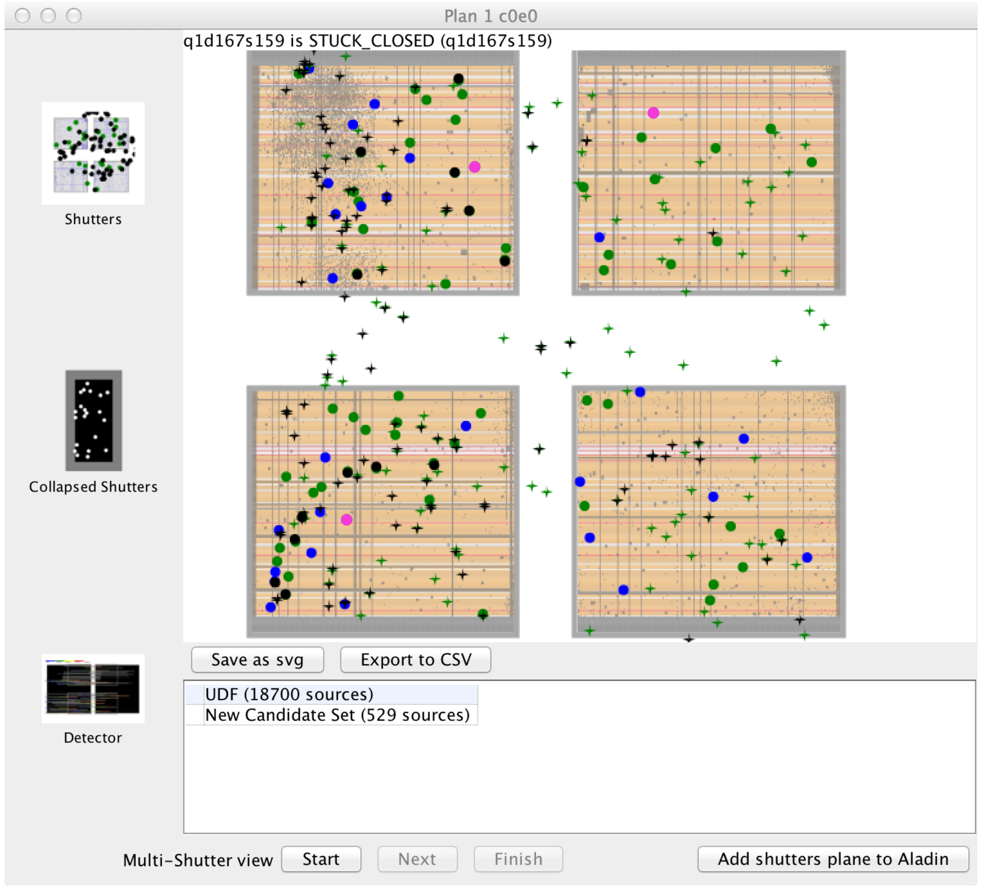
- Different **Exposure views**

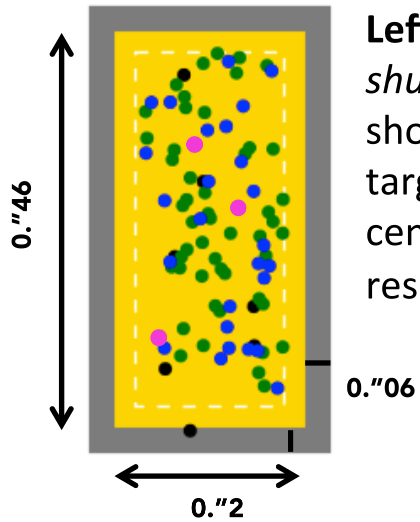
Green=Primaries
Blue=Fillers
Black=contaminants

MSA Shutter View

Collapsed Shutter View

Right: *MSA shutter view*. Targets are shown on a sketch of the MSA for one exposure.

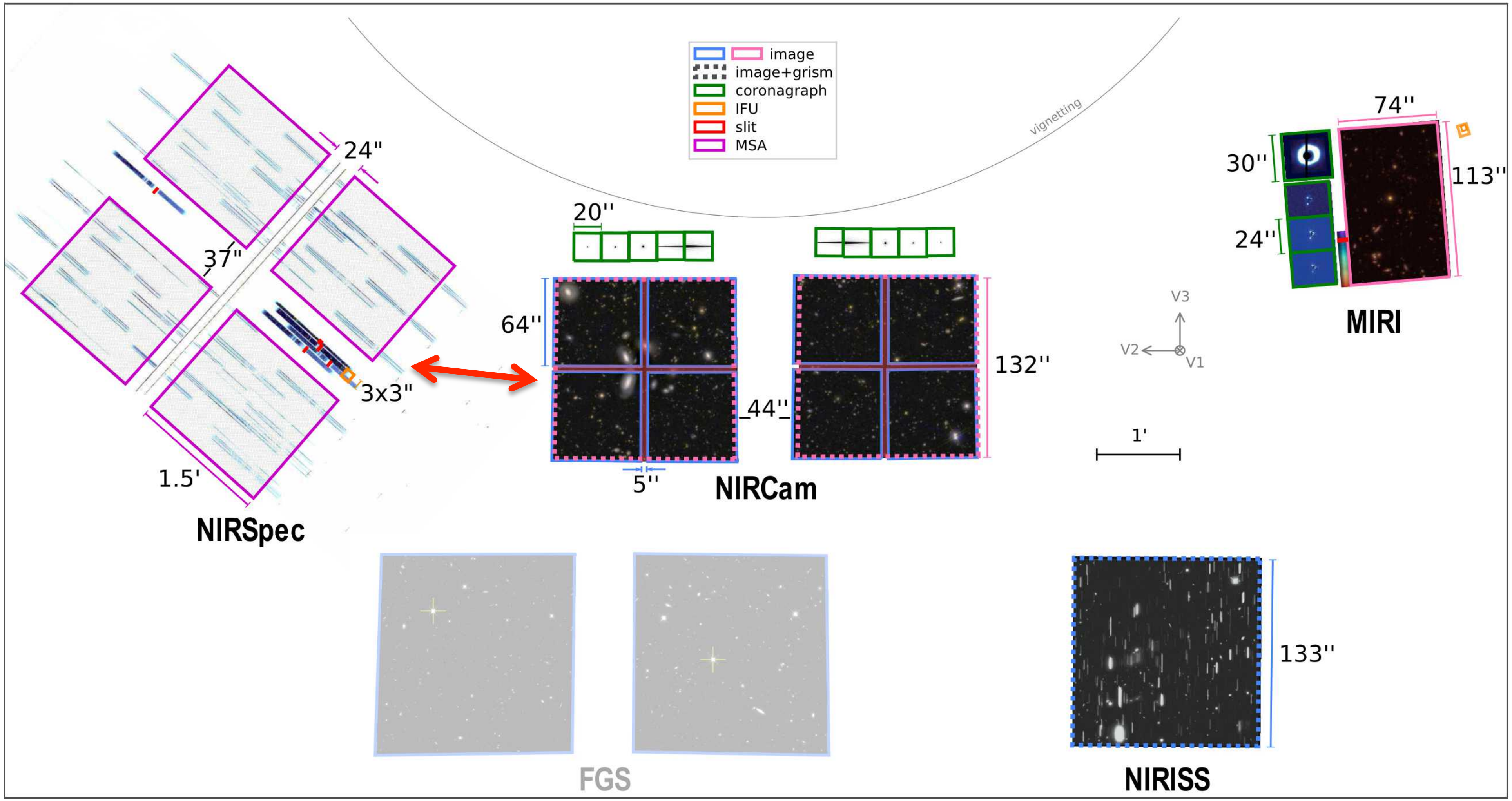




Left: *Collapsed shutter view* showing target centering results

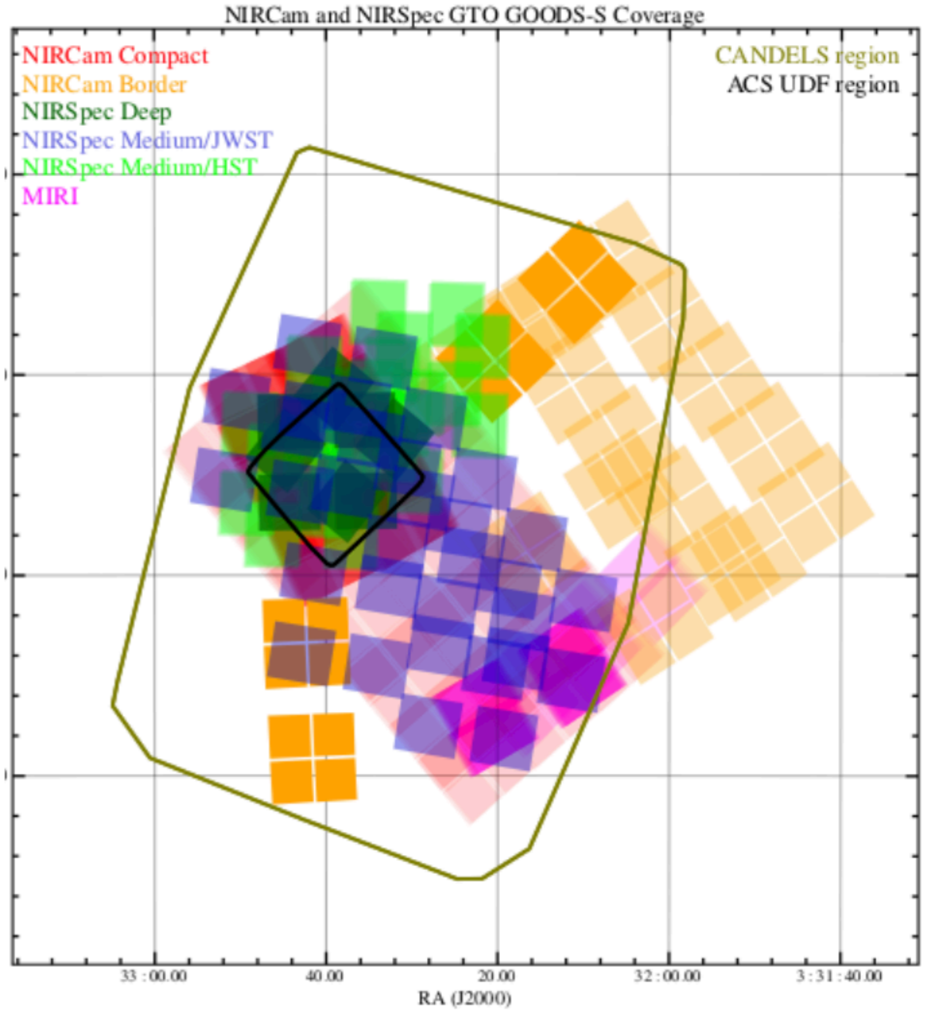
JWST focal plane

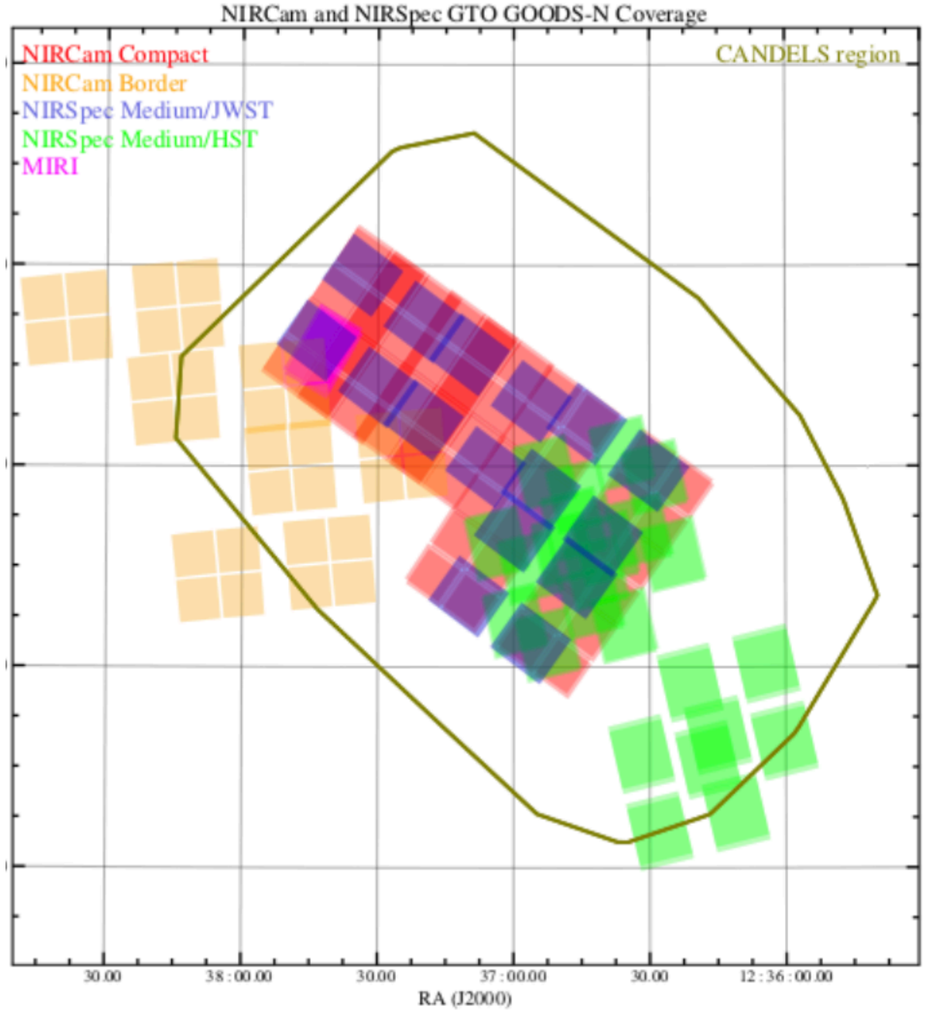
In Cycle 1 NIRSpec only allowed coordinated parallel:
NIRSpec MSA mode with NIRCam
("pure" parallels many more combinations)

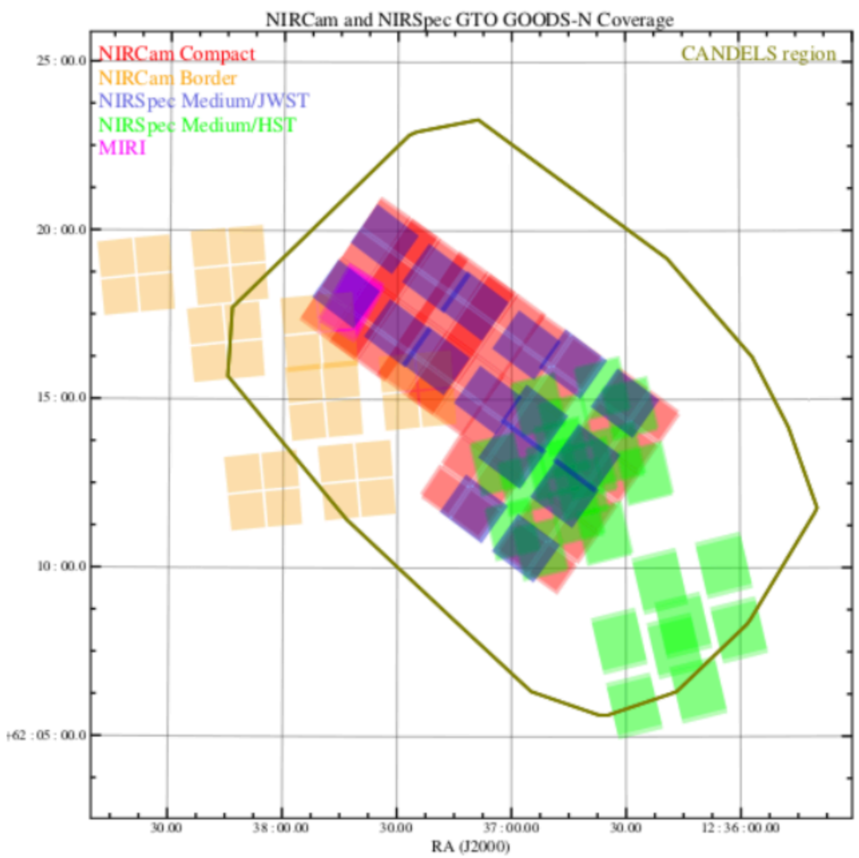


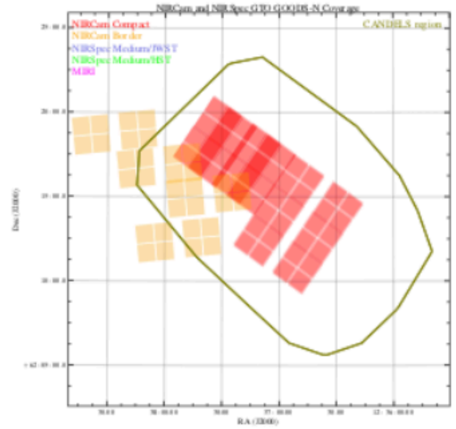
Example of NIRSpec MSA programme in parallel with NIRCam: GTO in the GOODS fields

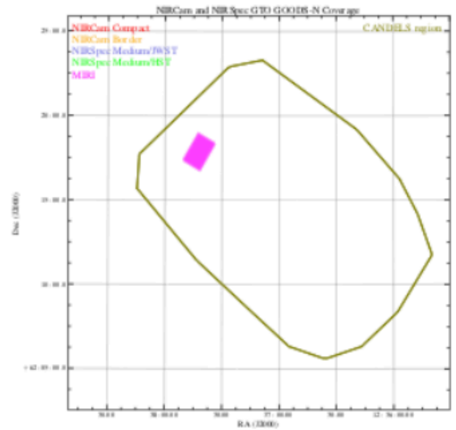
Now focus on GOODS-N (simpler)







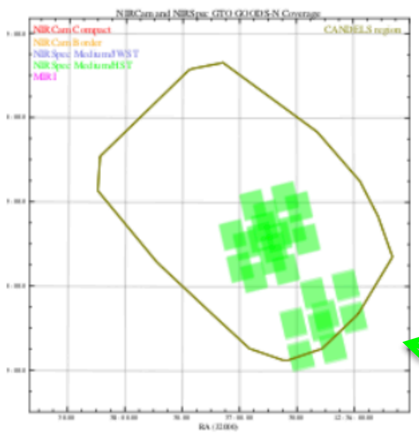


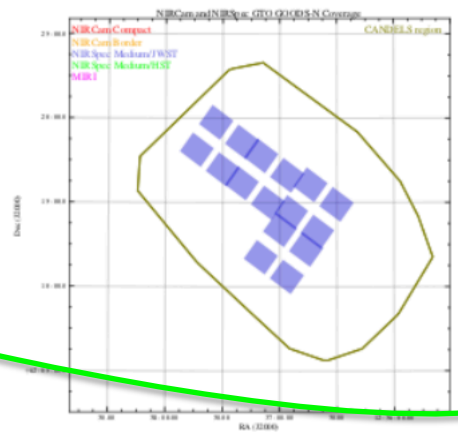


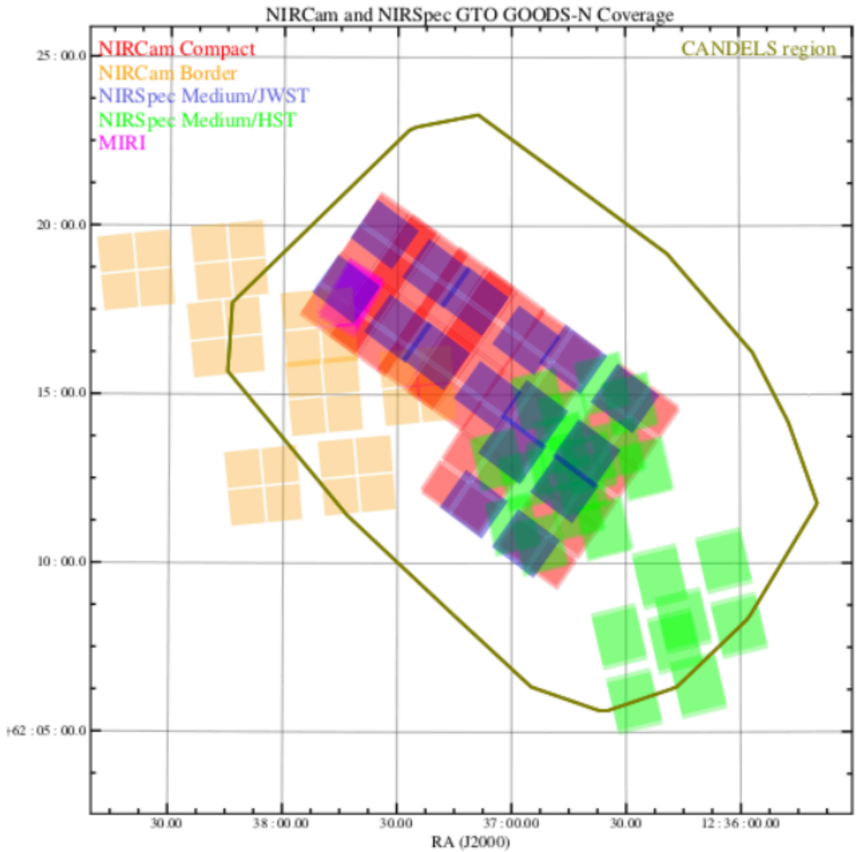
NIRCam-prime

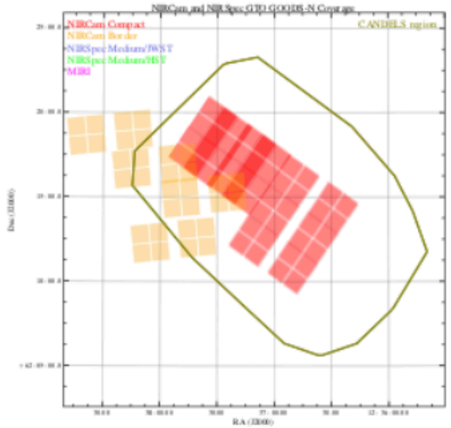
7 pointings

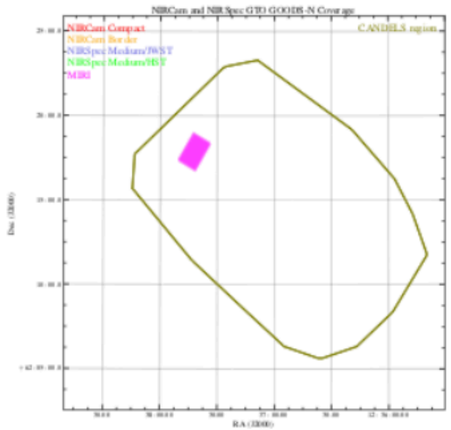
6 in have NIRSpec in parallel (HST preimaging) of which 6 overlap with the same NIRCam pointings











NIRCam prime

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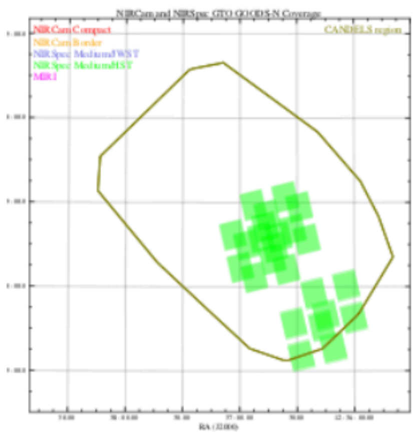
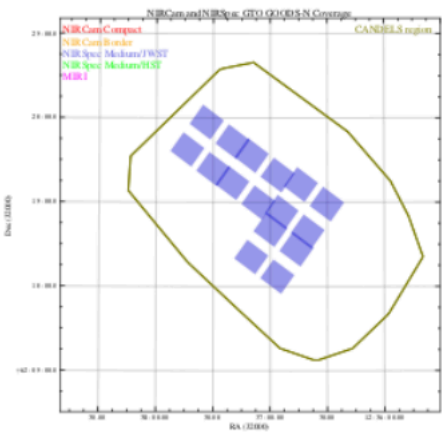
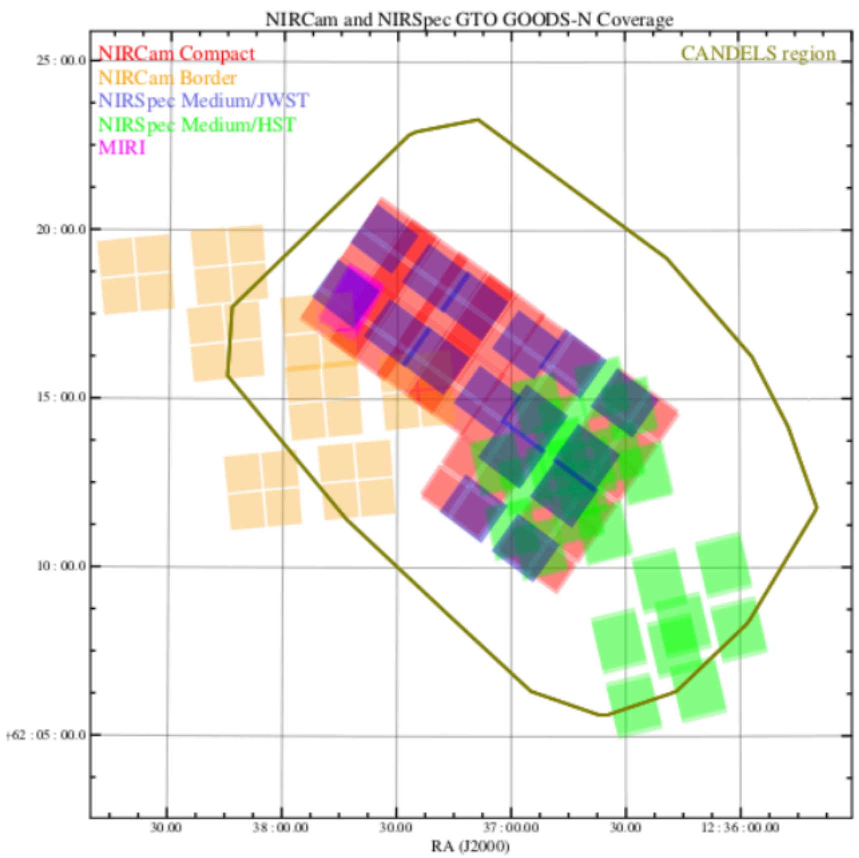
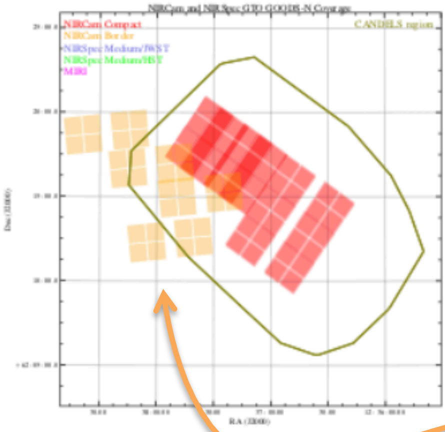


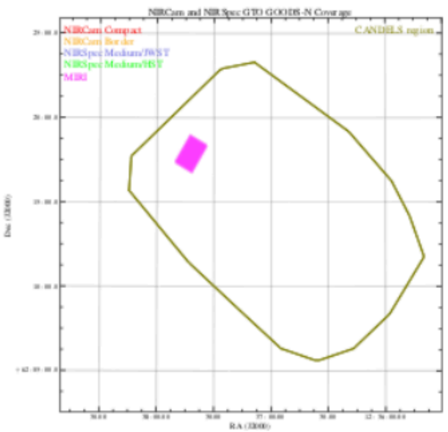


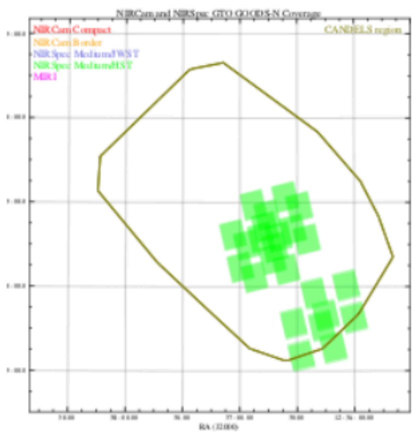
Coordinated exposures per pointing:

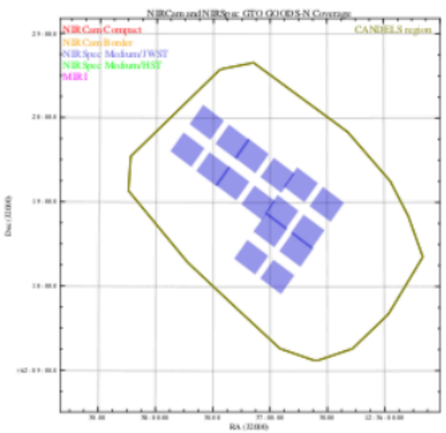
	2.3hr	2.3hr	2.3hr	2.3hr
NIRCam: SW:	F090W -	F115W -	F150W -	F200W
LW:	F227W -	F356W -	F410M -	F444W
NIRSpec:	PRISM -	PRISM -	G235M -	G395M





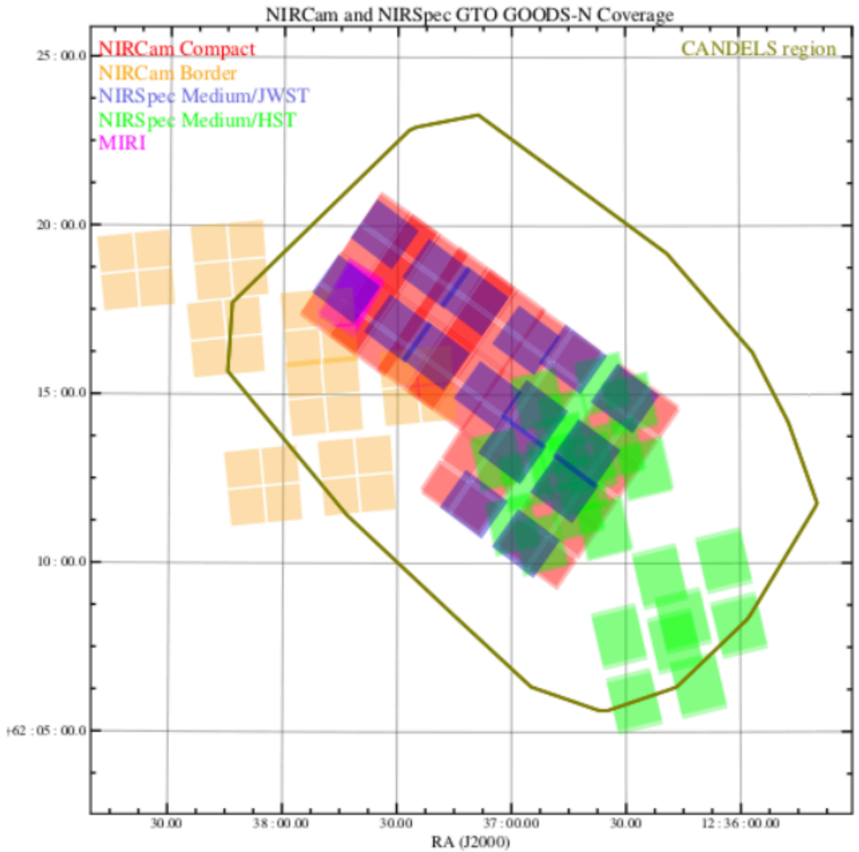


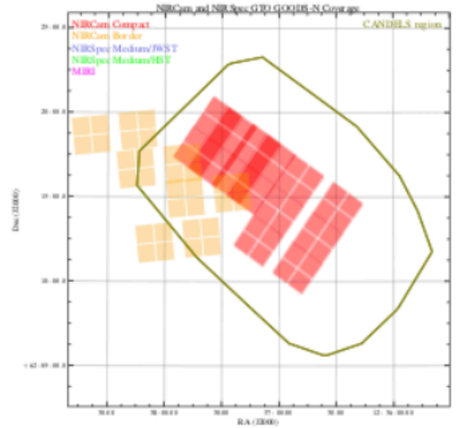


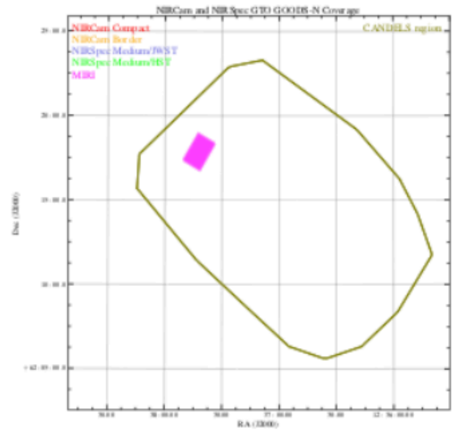


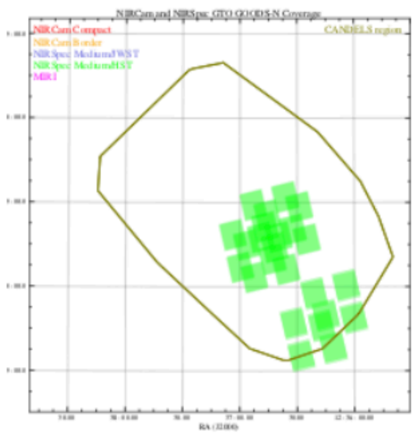
NIRSpec-prime
4 pointings
(on previous NIRCam pre-imaging)

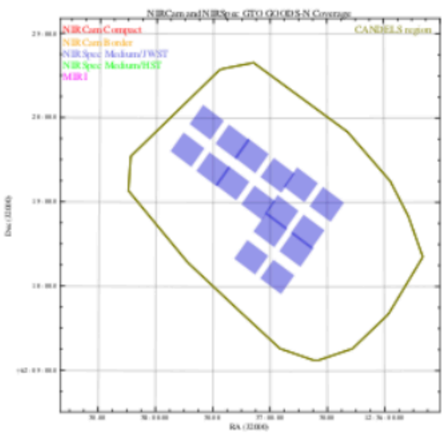
NIRCam in parallel











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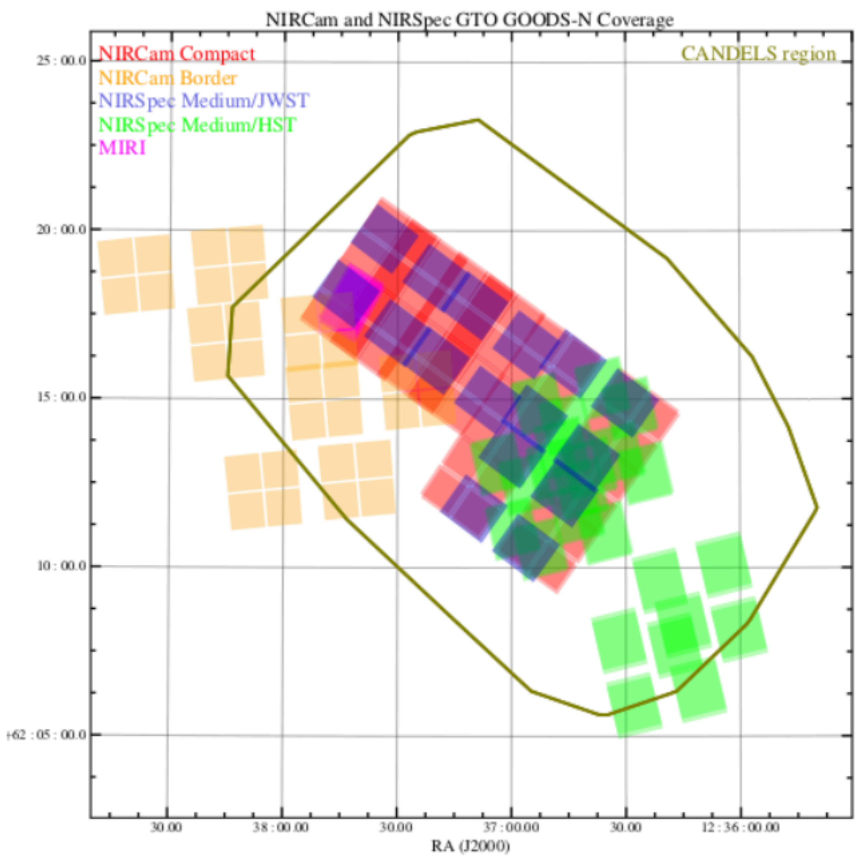
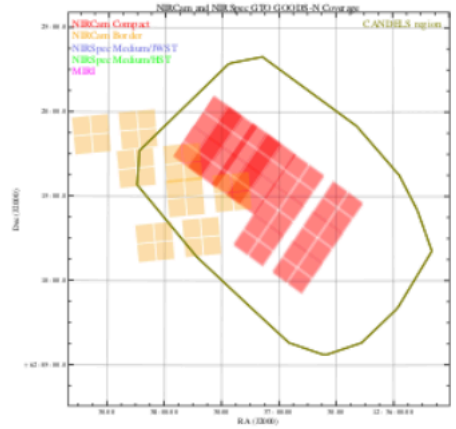
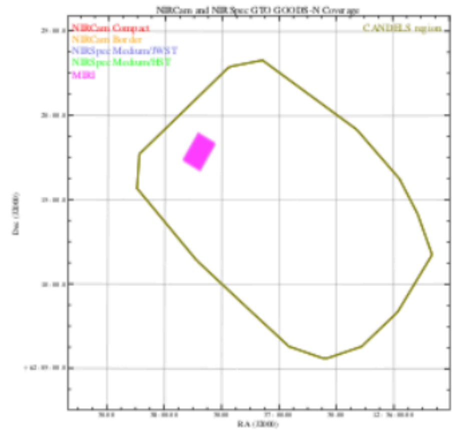
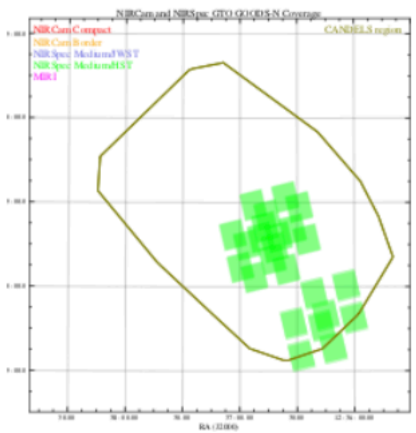
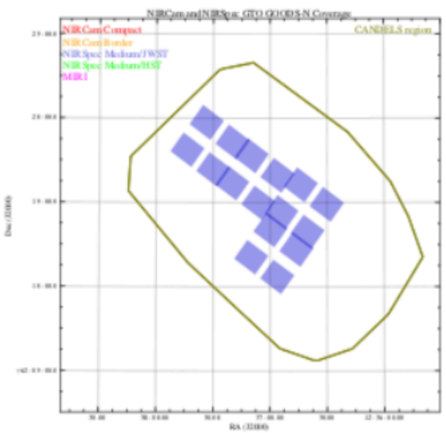
	2.3hr	2.3hr	2.3hr	2.3hr	2.3hr
NIRCam:	SW: F070W - F090W - F115W - F150W - F200W				
	LW: F227W - F335W - F356W - F410M - F444W				
NIRSpec:	PRISM - G140M - G235M - G395M - G395H				











Rationale:

stellar continuum & redshift

nebular lines full band

kinematics

NIRSpec: PRISM - G140M - G235M - G395M - G395H

Similar (but bit more complex) for GOODS-S
Summary of pointings and times allocations

Subsurvey	Field	# Pointings	Obs Hours	Prime Hours	Parallel Hours
NIRCam:					
Deep/Compact	GOODS-S	4	183	232	—
Deep/Border	GOODS-S	2	133	—	148
Medium/Compact	GOODS-S	12[a]	84	121	—
Medium/Compact	GOODS-N	7[a]	49	75	—
Medium/Border	GOODS-S	8	95	—	134
Medium/Border	GOODS-N	4	47	—	66
Total					
NIRSpec:					
Deep/JWST	GOODS-S	1	55	74	—
Deep/HST	GOODS-S	1	55	74	—
Medium/JWST	GOODS-S	8	95	134	—
Medium/JWST	GOODS-N	4	47	66	—
Medium/HST	GOODS-S	6	42	—	65
Medium/HST	GOODS-N	6	42	—	65
Total					
MIRI:					
Deep/MIRI	GOODS-S	4	183	—	232
Medium/MIRI	GOODS-S	6	42	—	56
Medium/MIRI	GOODS-N	1	7	—	10
Total					

HST: spectra on HST-selected targets
JWST: spectra of NIRCam-selected targets

total prime time = 776 hours

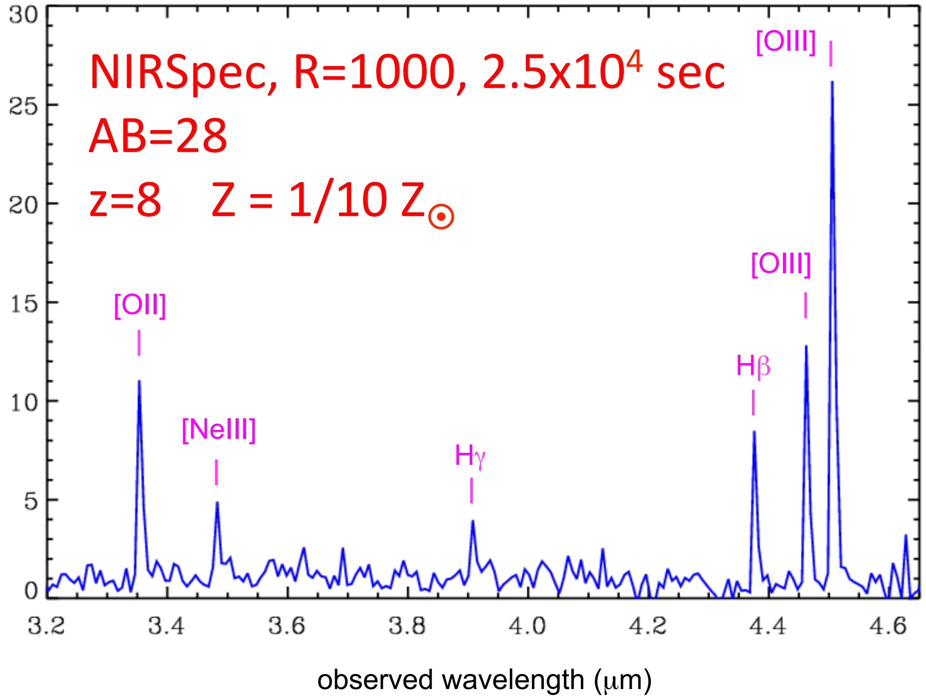
In case you're interested: summary of expected NIRSpec sensitivities and expected # targets

Subsurvey	# Targets	Exposure Times (Ksec) Prism	G140M	G235M	G395M	G395H
Deep/JWST	200	100	25	25	25	25
Deep/HST	200	100	25	25	25	25
Medium/JWST	2400	8.5	8.5	8.5	8.5	8.5
Medium/HST	up to 4800[a]	3.5	2.8	2.8	3.5	—

Subsurvey	Limiting Emission Line Sensitivity (10-σ; cgs units) Prism (2.5 μm)	G140M (1.2 μm)	G235M (2.5 μm)	G395M (4.5 μm)	G395H (4.5 μm)
Deep	8.5×10^{-19}	1.9×10^{-18}	9.3×10^{-19}	5.8×10^{-19}	8.1×10^{-19}
Medium/JWST	2.8×10^{-18}	3.4×10^{-18}	1.6×10^{-18}	1.0×10^{-18}	1.4×10^{-18}
Medium/HST	4.5×10^{-18}	6.8×10^{-18}	3.2×10^{-18}	1.7×10^{-18}	—

(additional tier "wide" in Candles fields not shown)

Expected quality of spectra in "deep" GOODS

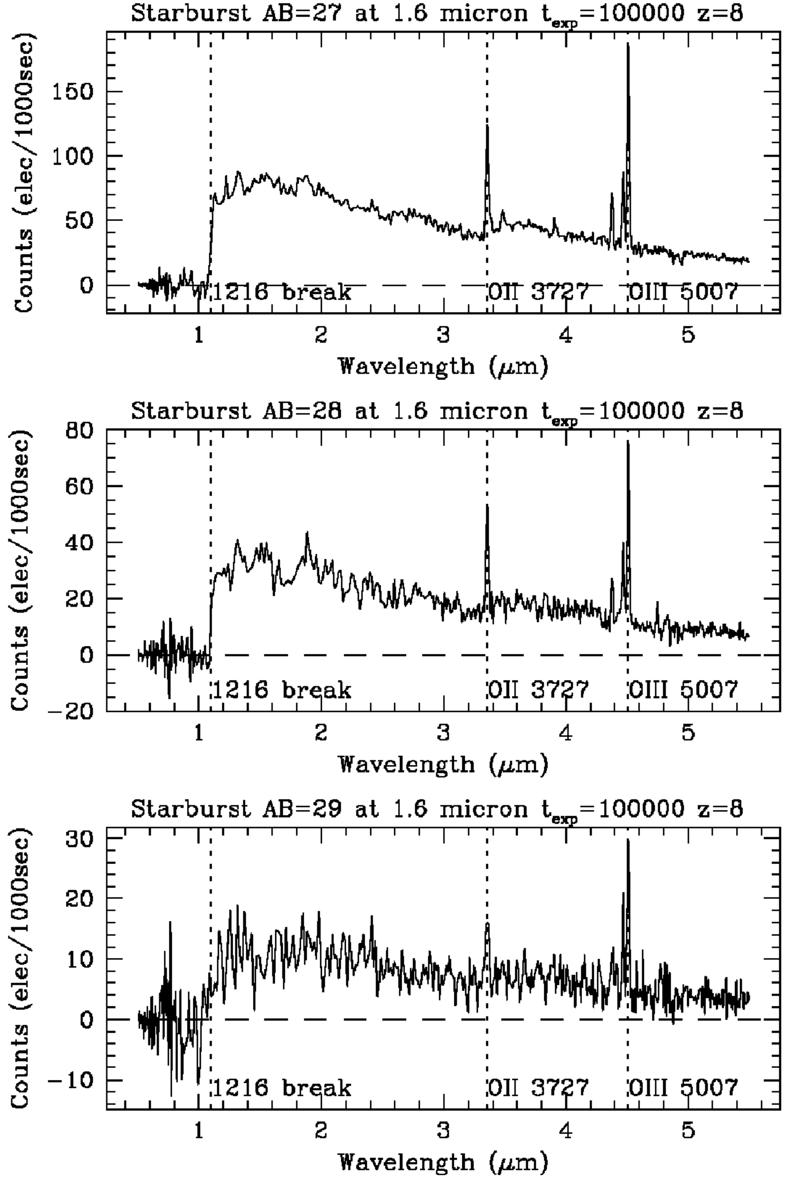


NIRSpec R=100, z=8, 10^5 sec
continuum easily detected

AB=27

AB=28

AB=29



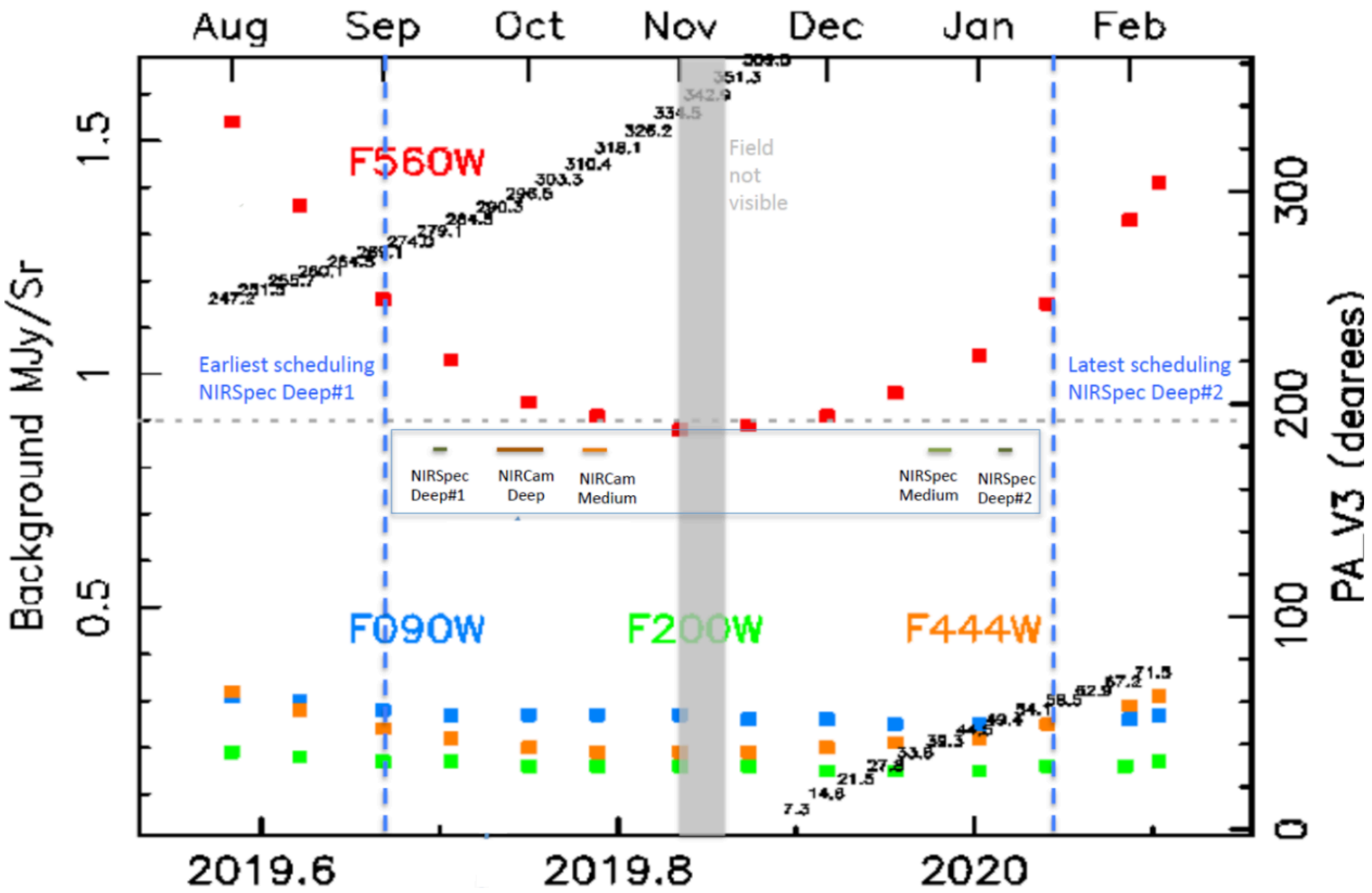
Retrival of stellar age, SFR, Mstar, SFH
extinction, metallicity, ...
+ extreme redshift machine

In case you're interested:
summary of NIRCam exposures, areas, exptected sensitivities

Subsurvey	Exposure Times (Ksec) F070W	F090W	F115W	F150W	F200W	F277W	F335M	F356W	F410M	F444W
Deep Compact	—	41.3	57.8	41.3	24.8	33.0	24.8	24.8	41.3	41.3
Deep Border	—	49.5	66.0	49.5	33.0	41.3	24.8	33.0	49.5	49.5
Medium Compact	—	6.9	6.9	5.6	5.6	5.6	—	5.6	6.9	6.9
Medium Border	5.7	11.3	11.3	8.5	5.6	8.5	5.6	5.6	11.3	11.3
Deep Average	—	60.5	80.8	59.3	38.8	49.1	30.9	38.8	60.5	60.5
Medium Average	6.7	11.7	11.7	9.1	7.5	9.2	6.7	7.5	11.7	11.7

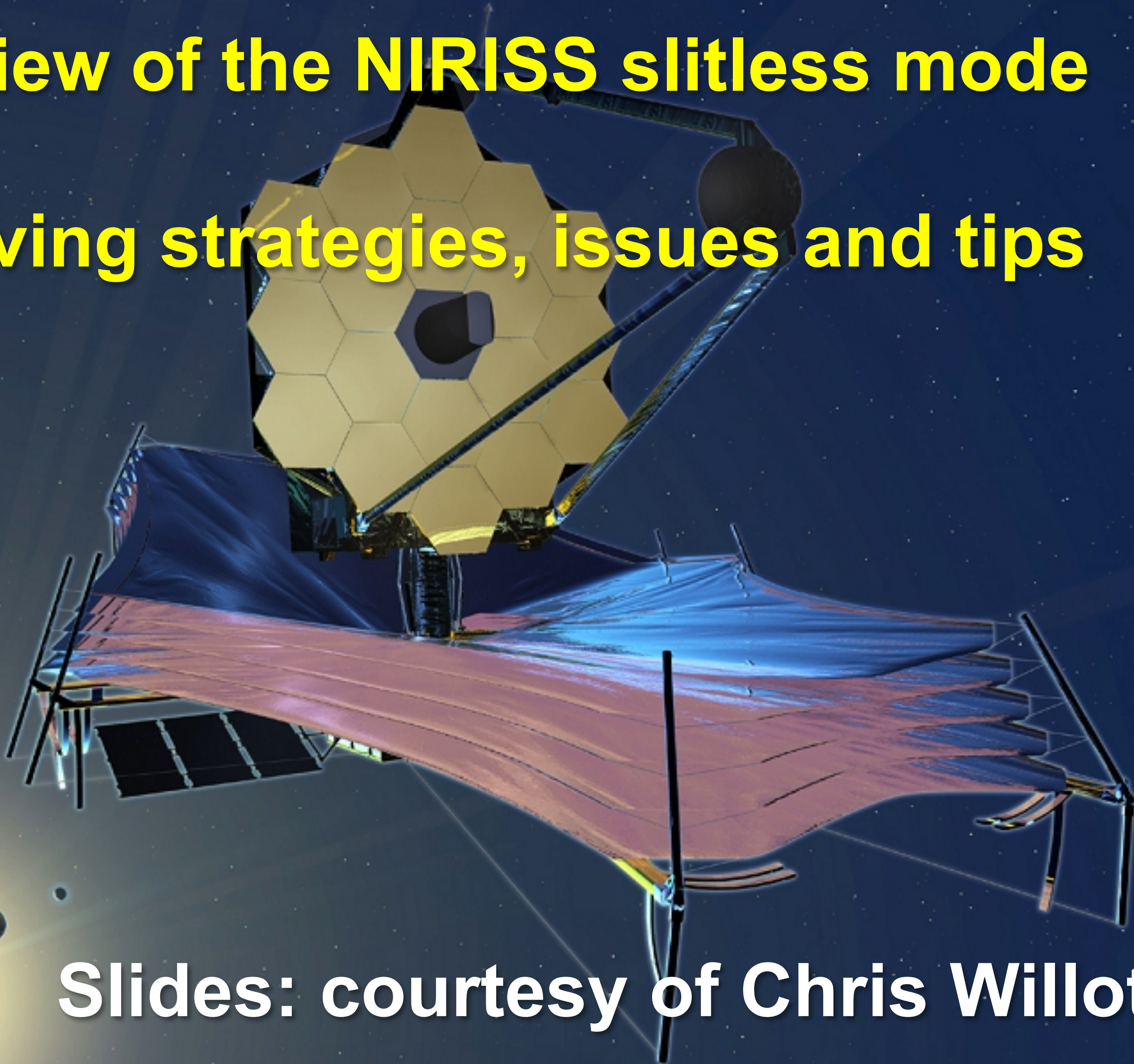
Subsurvey	Area □′	10σ Point Source Magnitude (AB) F070W	F090W	F115W	F150W	F200W	F277W	F335M	F356W	F410M	F444W
Deep	46	—	29.5	29.8	29.9	29.9	29.5	28.8	29.4	29.0	29.1
Medium	190	28.0[a]	28.6	28.8	28.9	29.0	28.6	28.0[a]	28.6	28.1	28.3

Proposed scheduling for GOODS-S given by constraints on roll angle and also background (note, for spectroscopy the latter relevant only at R=100)



Overview of the NIRISS slitless mode

observing strategies, issues and tips



Slides: courtesy of Chris Willott

Galaxy Evolution with NIRISS Slitless Spectroscopy

NIRISS

NIRISS images a 2.2'x2.2' field with a single H2RG 2048x2048 pixel detector.

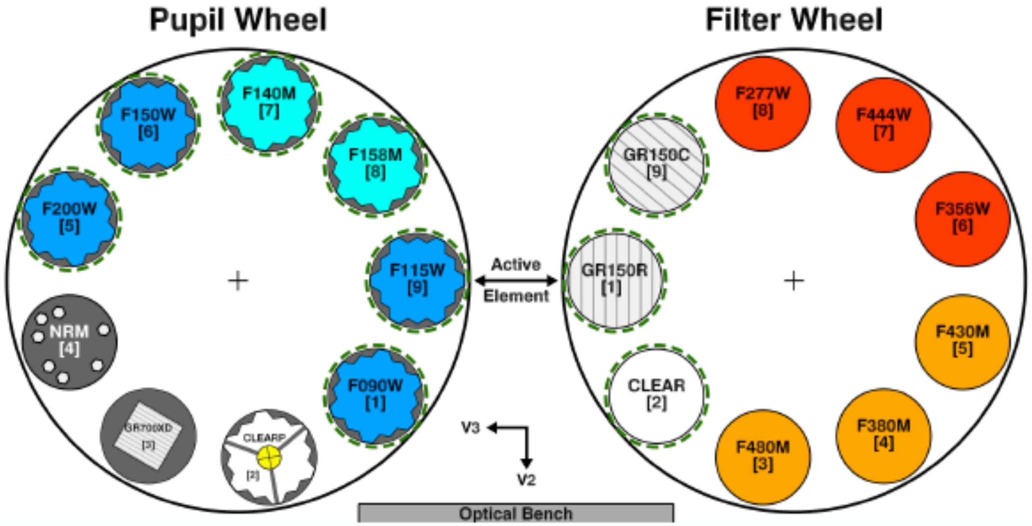
Selection of pupil wheel and filter wheel elements determines the observing mode:

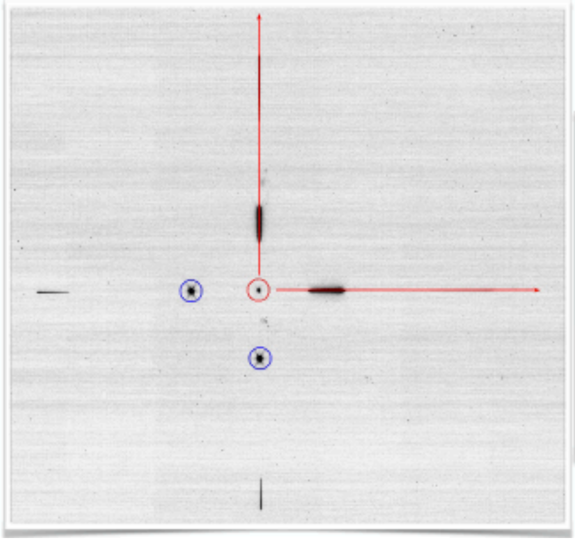
- ✦ Wide-Field Slitless Spectroscopy (WFSS)
- ✦ Single Object Slitless Spectroscopy (SOSS)
- ✦ Aperture Masking Interferometry (AMI)
- ✦ Imaging

For WFSS choice of six blocking filters that limit wavelength range.

GR150R and GR150C orthogonal grisms to mitigate contamination.

Direct image required for object position/ wavelength solution and contamination modelling.





ISIM CV3 NIRISS test data of both grisms and direct image overlaid

NIRISS Operations

JWST-STScI-004466
SM-12

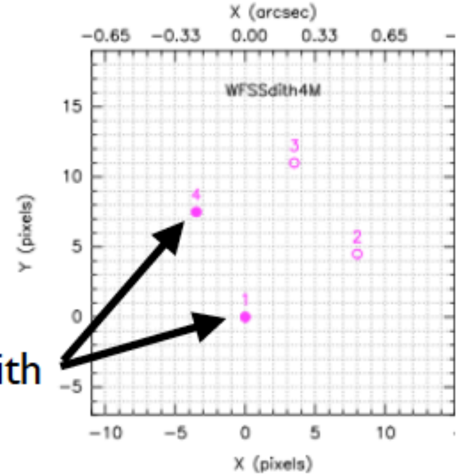
The NIRISS pixel size of 0.065 arcsec per pixel does not fully sample the JWST short-wave PSF.

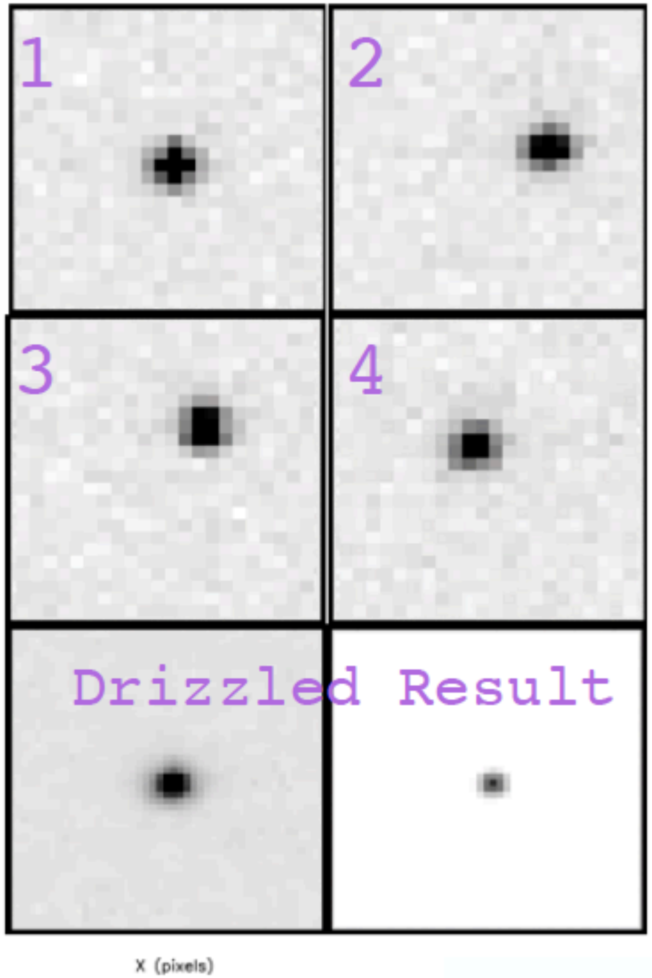
Dithering to recover spatial sampling, plus mitigate effects of bad pixels and flat-field errors is mandatory for the WFSS, AMI and Imaging modes.

WFSS grism and direct imaging dither sequences use N+0.5 pixel offsets to put objects on different pixels and perform half-pixel sub-sampling.

Dither sequence grism and direct reconstructed images will have 4080x4080 pixels with pixel scale 0.0325 arcsec per pixel.

Filled symbols show locations with direct images as well as grism.



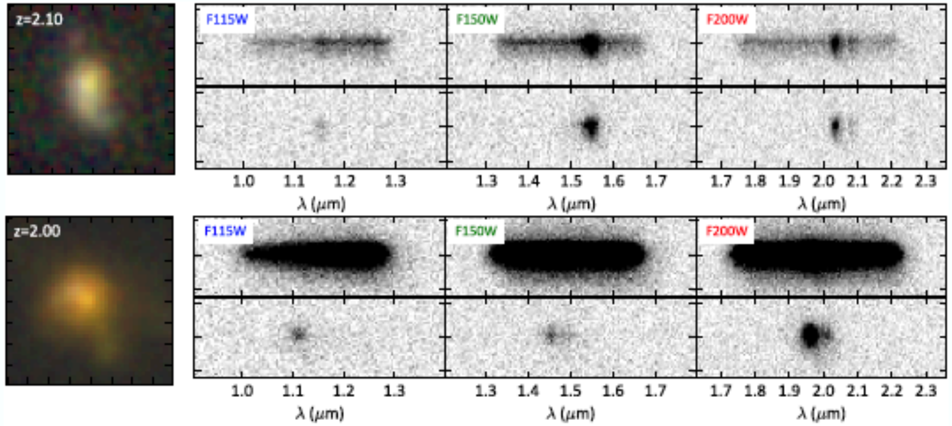


NIRISS WFSS Data

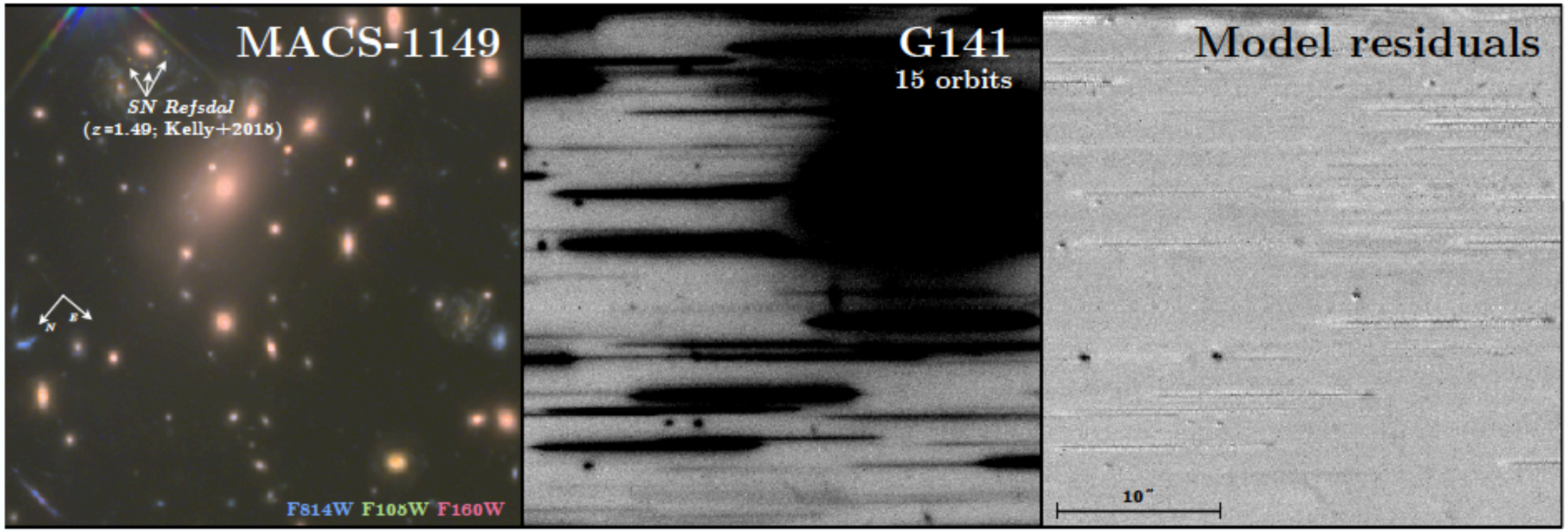
One of the most exciting uses of NIRISS WFSS is to map emission lines.

Requires modelling and subtraction of source continuum.

Modelling of all sources in the field is best, especially in crowded fields.



JWST pipeline + analysis software (e.g. the grizli package of Gabe Brammer) are available to help.



CANUCS Observing Plan

The survey emphasizes two **unique features** of **WFSS** with **NIRISS**:

- **Very high multiplex factor**: The NIRISS detector has space for 5000 WFSS spectra if optimally packed, assuming the typical object spans 8 pixels in the spatial direction (0.5") and 100 pixels in the dispersion direction. Therefore a deep survey in a relatively crowded field has very high efficiency for getting > 1000 spectra at once.

- **Spatially-resolved emission lines**: Modelling and subtracting the continuum spectrum leaves a map of the emission lines. We will use stellar continuum and emission line maps to study the distribution of stars, metals, dust, star formation and AGN activity in galaxies. By utilizing gravitational lensing we probe lower luminosity galaxies and smaller spatial scales than in the field.

CANUCS Observing Plan

Field Layouts

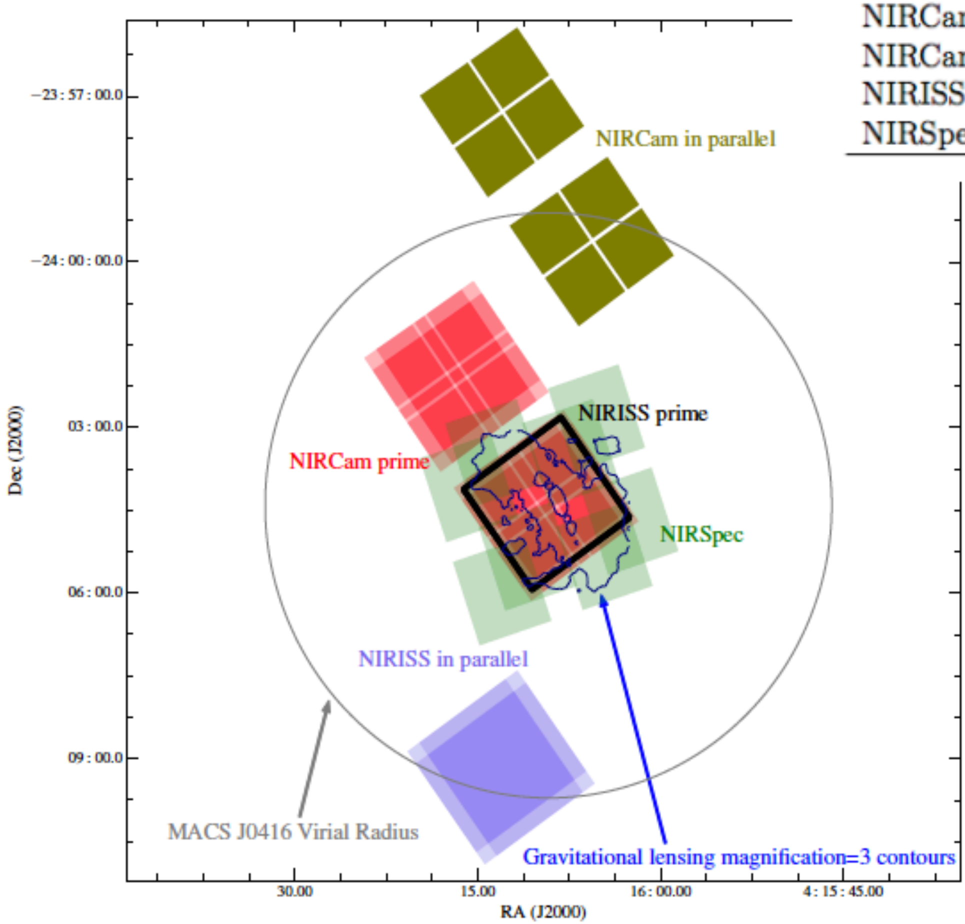


Table 1: Summary of Observations per Cluster

Instrument	Mode	Prime?	#Configs	Exp. Time (h)	Tot. Time (h)
NIRISS	WFSS	Prime	6	20.8	26.0
NIRCam	Image	Prime	4	7.2	12.0
NIRCam	Image	Parallel	6	20.1	–
NIRISS	WFSS	Parallel	4	6.9	–
NIRSpec	MOS	Prime	2	1.6	3.5

CANUCS Targets

Table 2: Target List.

Cluster	RA	DEC	Redshift	Survey	*JWST* Visibility Period
Abell 370	02:39:52.8	-01:34:36	0.375	HFF	24 Jul-16 Sep + 12 Dec-02 Feb
M0416.1-2403	04:16:09.4	-24:04:04	0.395	HFF	12 Aug-09 Nov + 27 Nov-22 Feb
M0417.5-1154	04:17:34.7	-11:54:32	0.443	RELICS	17 Aug-20 Oct + 26 Dec-24 Feb
M1149.6+2223	11:49:35.9	+22:23:55	0.543	HFF	19 Apr-15 Jun + 05 Dec-27 Jan
M1423.8+2404	14:23:47.8	+24:04:40	0.545	CLASH	13 May-24 Jul + 08 Jan-15 Mar

NIRISS+NIRCam NIRSpec

Cluster Selection Criteria

- High mass and large area (> 1 square arcmin) with high magnification.
- Critical curves that fit within the 2.2 arcmin field of NIRISS.
- > 10 degrees away from zodiacal plane.
- Little area lost to bright stars.
- $z > 0.35$ to avoid too much contaminating light from ICL and cluster galaxies.
- Well suited to cosmography, i.e. reasonable lensing mass distributions.
- Good data at other wavelengths, especially deep ACS for redshift fitting.

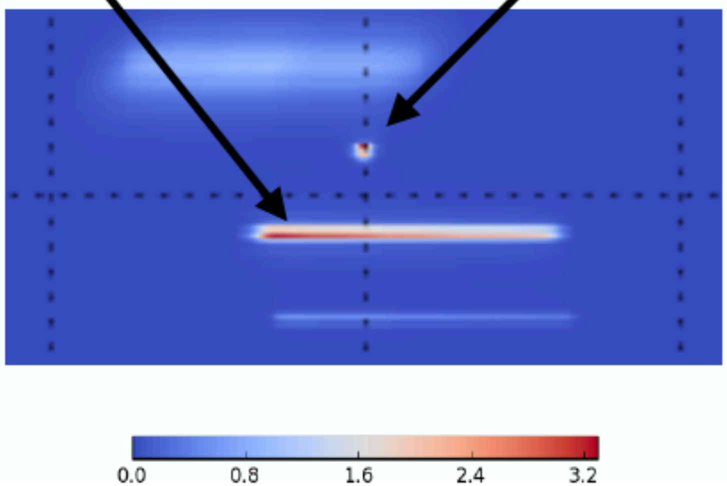
NIRISS WFSS Observing Plan

Largest component of our project is NIRISS WFSS for thousands of simultaneous galaxy spectra.

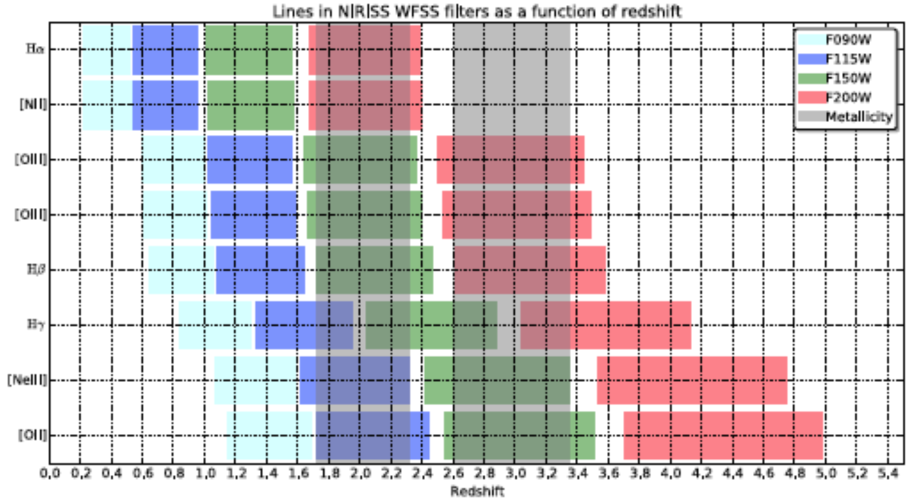
Total integration times per filter per grism of 3.2 hours (8 exposures of 1417s each).

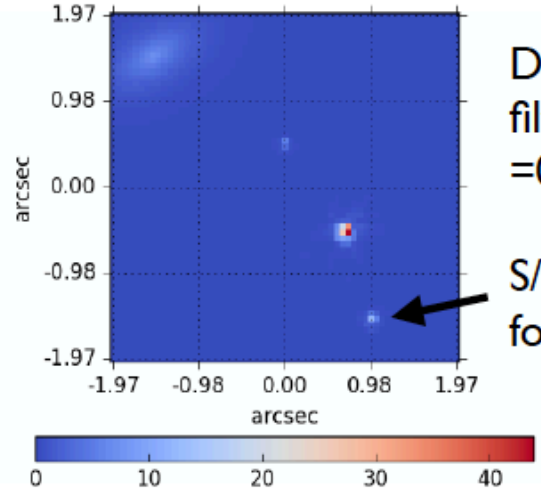
Reaches S/N ~3 per pixel continuum at AB=26.0 for a point source.

Emission line source with 3.5E-18 erg/s/cm² detected with peak S/N ~3.



Use three filters to get good emission line vs wavelength coverage: F115W, F150W, F200W





Direct image per filter integration time =0.6 hours (~10%).

S/N ~10 at AB=28.0 for a point source.

For more information please visit:

NIRSpec MSA mode

https://jwst-docs.stsci.edu/display/JTI/NIRSpec+Multi+Object+Spectroscopy

MPT-APT Tutorial (D. Karakla)

https://jwst.stsci.edu/news-events/events/events-area/stsci-events-listing-container/

NIRISS Wide Field Slitless Spectroscopy

https://jwst-docs.stsci.edu/display/JTI/NIRISS+Wide+Field+Slitless+Spectroscopy

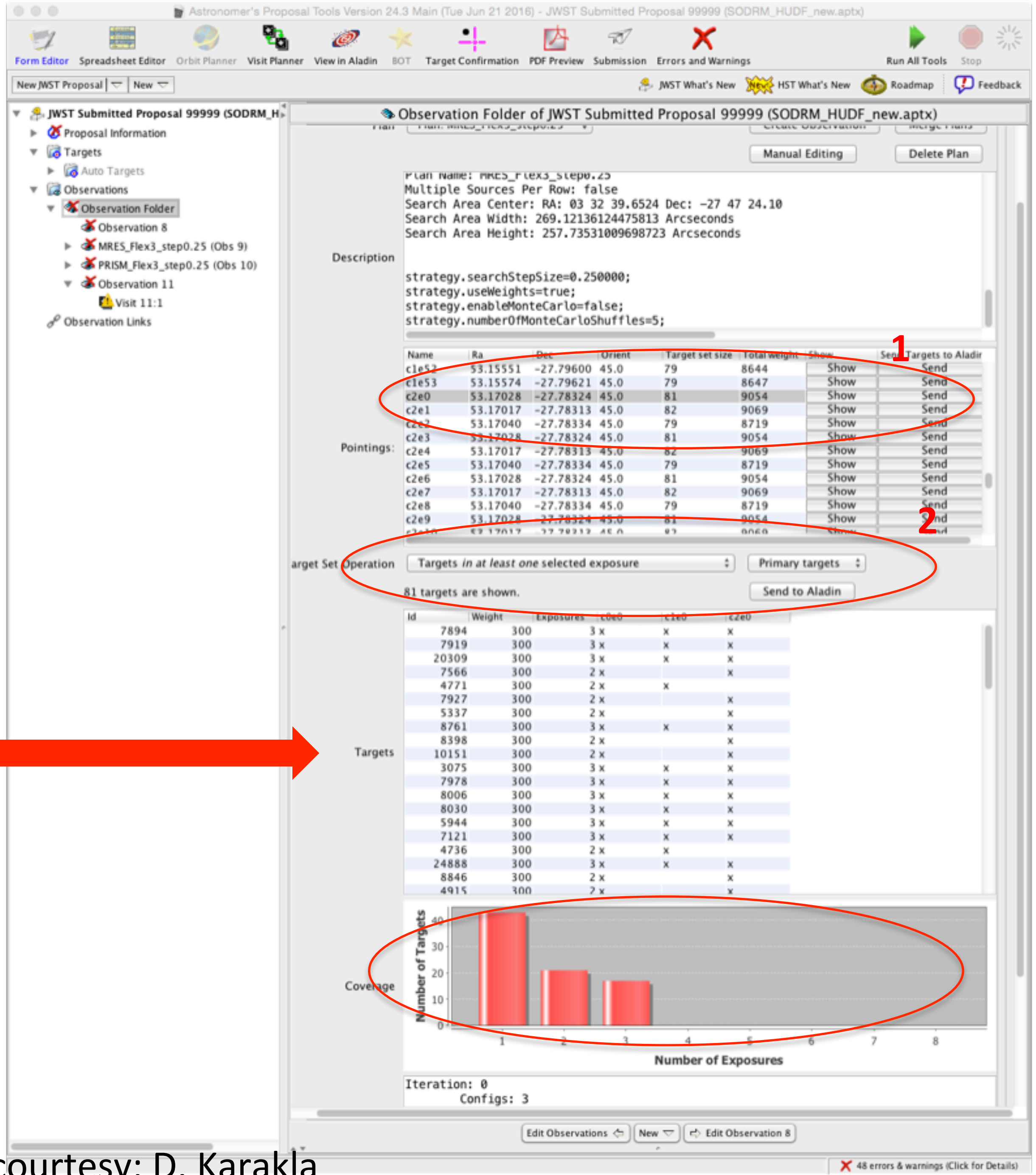
Spare slides

Review Plan Results

Ability **to**

1) **select one or more exposures** and
2) **filter plan results** to list primaries (or fillers or contaminants), or all observed sources.

- View successful targets in all selected exposures
- **Histogram** of targets from the selected and filtered results.



courtesy: D. Karakla

NIRISS Operations

NIRISS WFSS dithering strategy hard-coded in APT: direct ➜ N x grism ➜ direct

Patterns of N=2, 3, 4, 6, 8 steps with S/M/L spacing.

Dither sequences
can include one
or both grisms.