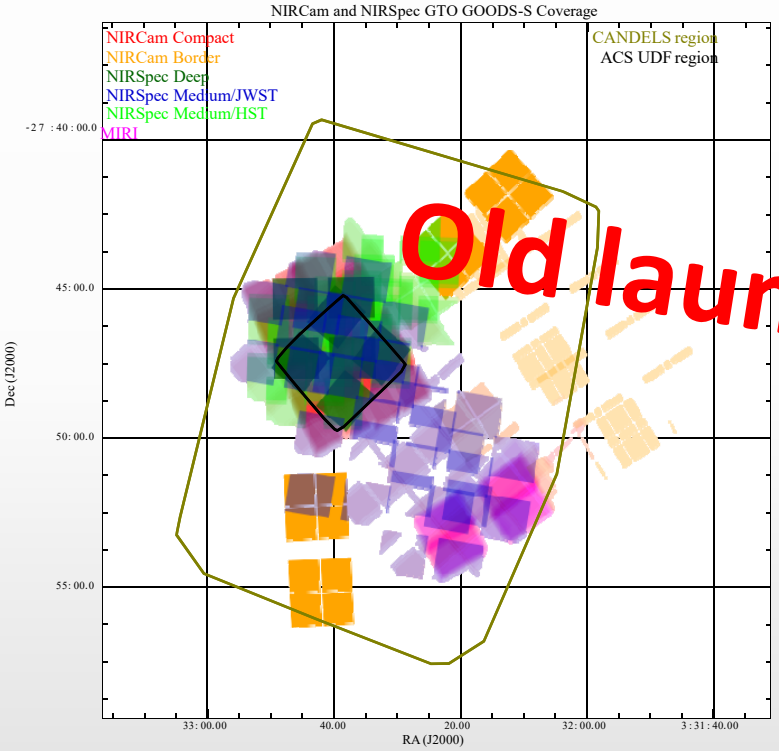
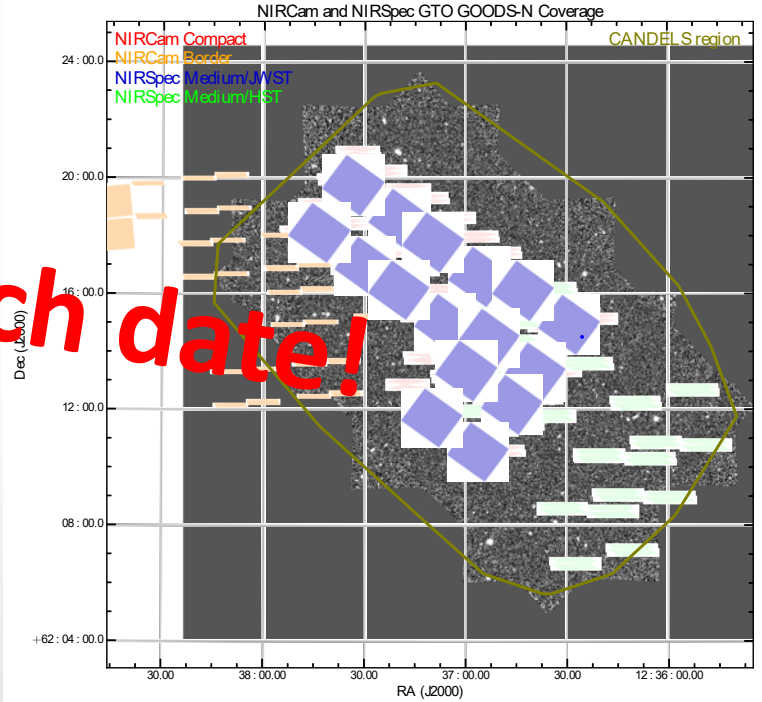
Deep Surveys with JWST: Answering Galaxy Evolution

Marcia Rieke, NIRCam PI

for the NIRSpec – NIRCam GTO Galaxy Assembly Collaboration





Old launch date!

Contributing Team Members: Stacey Alberts , Andrew Bunker, Stephane Charlot , Jacopo Chevallard , Alan Dressler , Eiichi Egami , Daniel Eisenstein , Ryan Endsley , Pierre Ferruit , Marijn Franx, Kevin Hainline , Peter Jakobsen , Emma Curtis Lake, Roberto Maiolino , Michael Maseda, Janine Pforr, Hans-Walter Rix , Brant Robertson, Renske Smit, Daniel Stark , Christina Williams , Christopher Willmer , Chris J. Willott

Overview: Program Science Goals

Study galaxy evolution from the first steps (z>10) through the end of the dark ages (7<z<9) and through the epoch of galaxy assembly (2<z<6):

1) Luminosity functions at the highest redshifts to test galaxy formation models
2) Test ΛCDM by finding the highest redshift galaxies and estimating their masses
3) Estimating the halo masses of these galaxies
4) Measure morphological parameters and assembly of stellar mass as a function of redshift
5) Measure metallicity as a function of redshift
6) Measure star formation histories
7) Learn about reionization from these galaxies
8) Look for surprises

And many more!

Data required:

Deep, multicolor imaging to provide galaxy samples including mid-infrared data to help with accurate mass estimations and increase discovery space

Spectra over 0.6 to 5 microns to enable measurement of redshifts, emission lines, metallicities, detailed spectral energy distributions

What Are the Elements of a Survey?

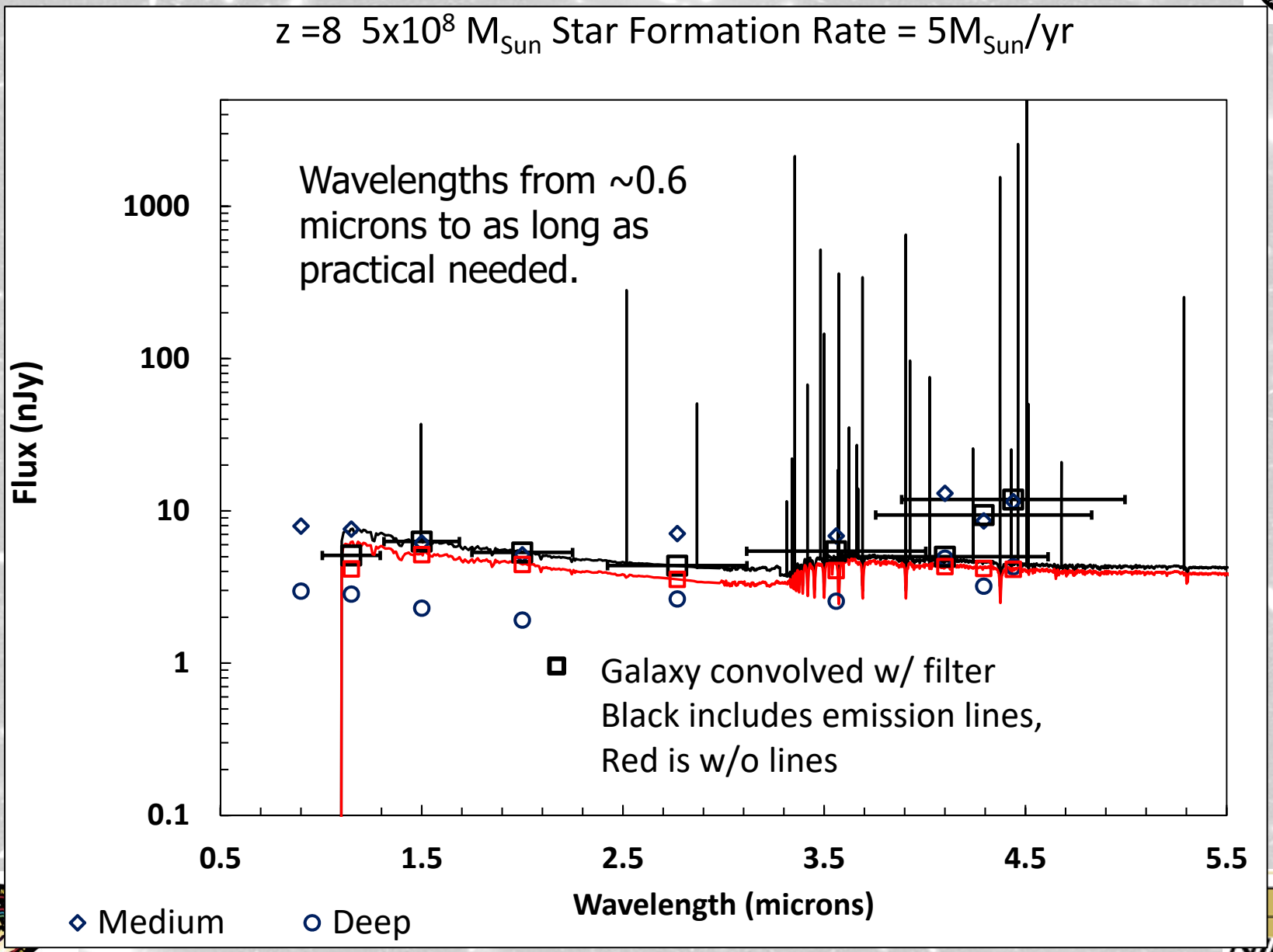
What data are needed to answer the questions posed?

- Characteristics of the sources to be detected
- Density of sources on the sky
- Observing strategies to yield good data in the face of noise sources and cosmic-rays
- Problems posed by multi-object spectroscopy using a fixed grid of slits

And then match to capabilities:

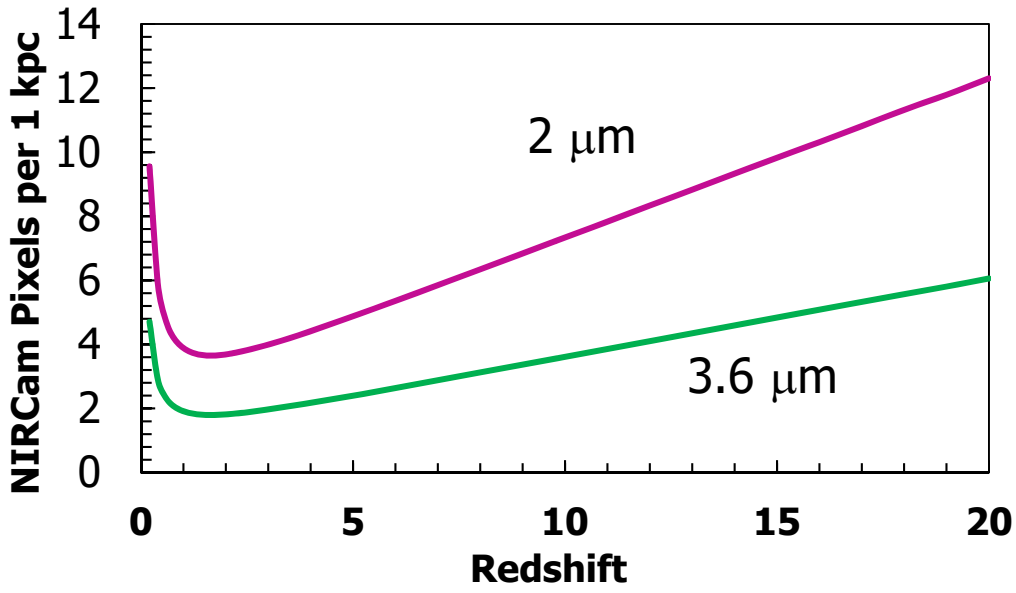
- What wavelengths are needed?
- What spatial resolution is needed?
- What sensitivity is required?
- What area needs to be covered?
- How many spectra are needed?

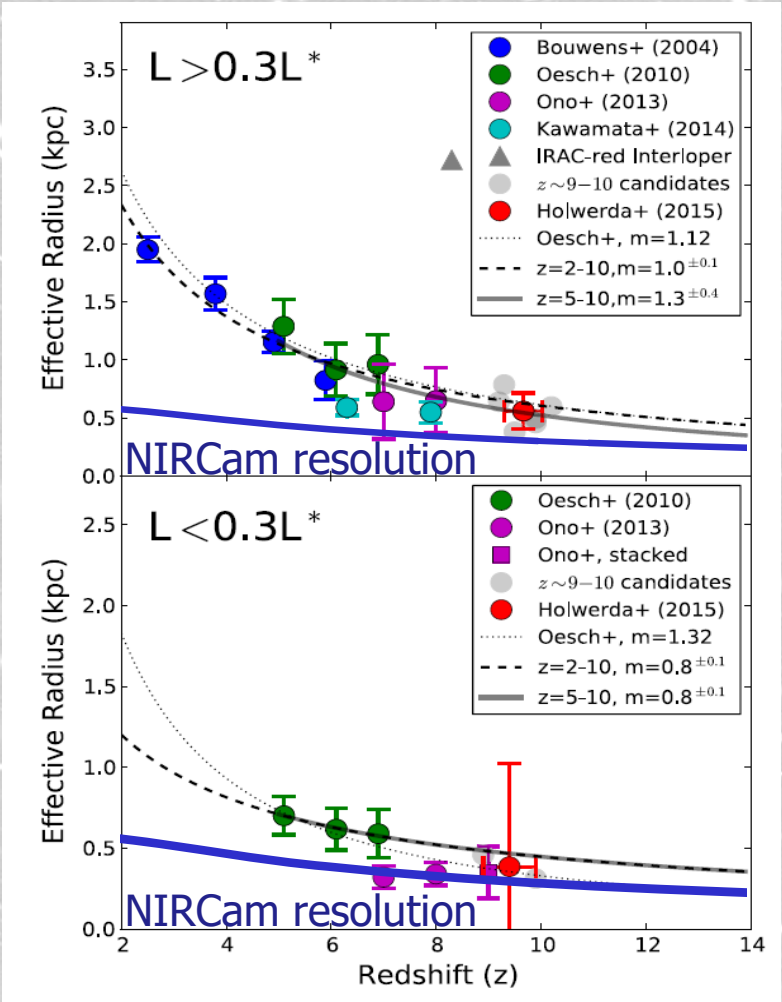
Spectrum of a z~8 Galaxy



Spectra from Ryan Endsley

Angular Resolution





JWST + NIRCam have enough resolution to study the structure of distant galaxies. The plots at right show the two-pixel resolution at 2 microns. NIRSpec MSA slit at 0.2"x0.4" is well-matched to galaxy sizes.

Holwerda et al. 2015
ApJ, 808,6

NIRSpec ⇔ NIRCam Synergy

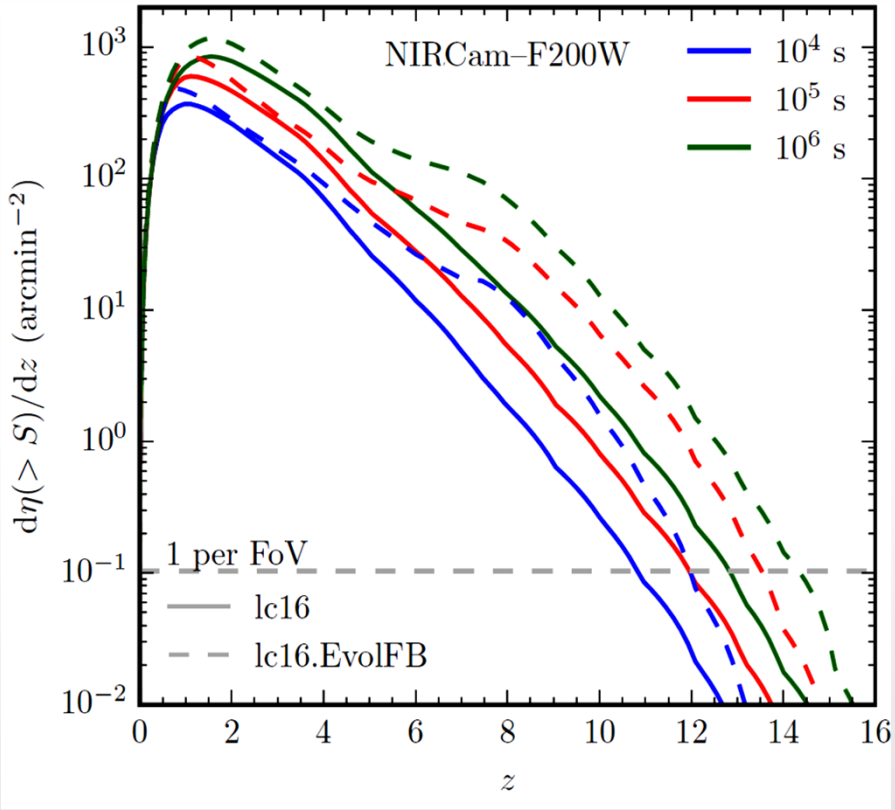
Synergy at "functional" level:

- NIRCam goals based on luminosity and mass functions need reliable photometric redshifts.
  - because spectra can be acquired only for a limited number of sources, a priority will be vetting and improving photometric redshifts.
- NIRSpec observations needs imaging.
  - needs some pre-imaging to find and locate sources.
  - needs imaging to enable accurate slit corrections for good spectrophotometry because of the inevitable mis-centering in a slit and diffraction effects.

➔Combining imaging and spectroscopy data yields a significant improvement in the quality and robustness of the results.

How Much Area is Needed?

Many of our science goals depends on having adequate numbers of galaxies at the highest redshifts.



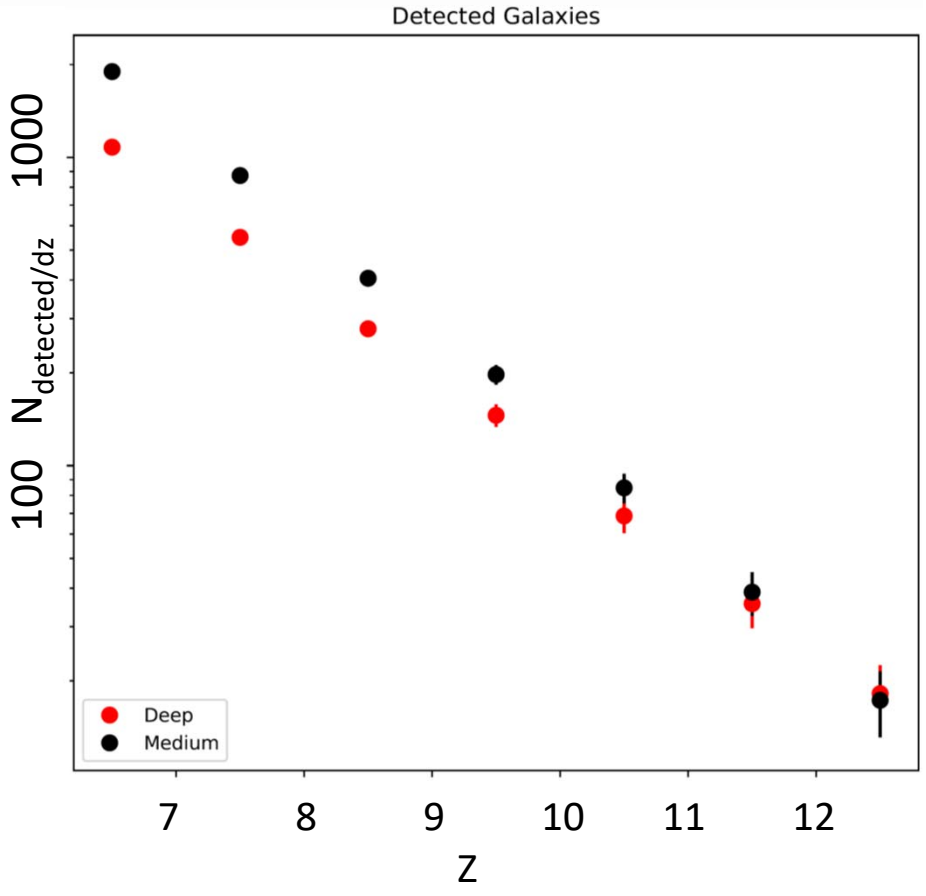
From Cowley et al. MNRAS in press
FoV here equals 2x 2.2'x2.2' = 9.7 sq arc min

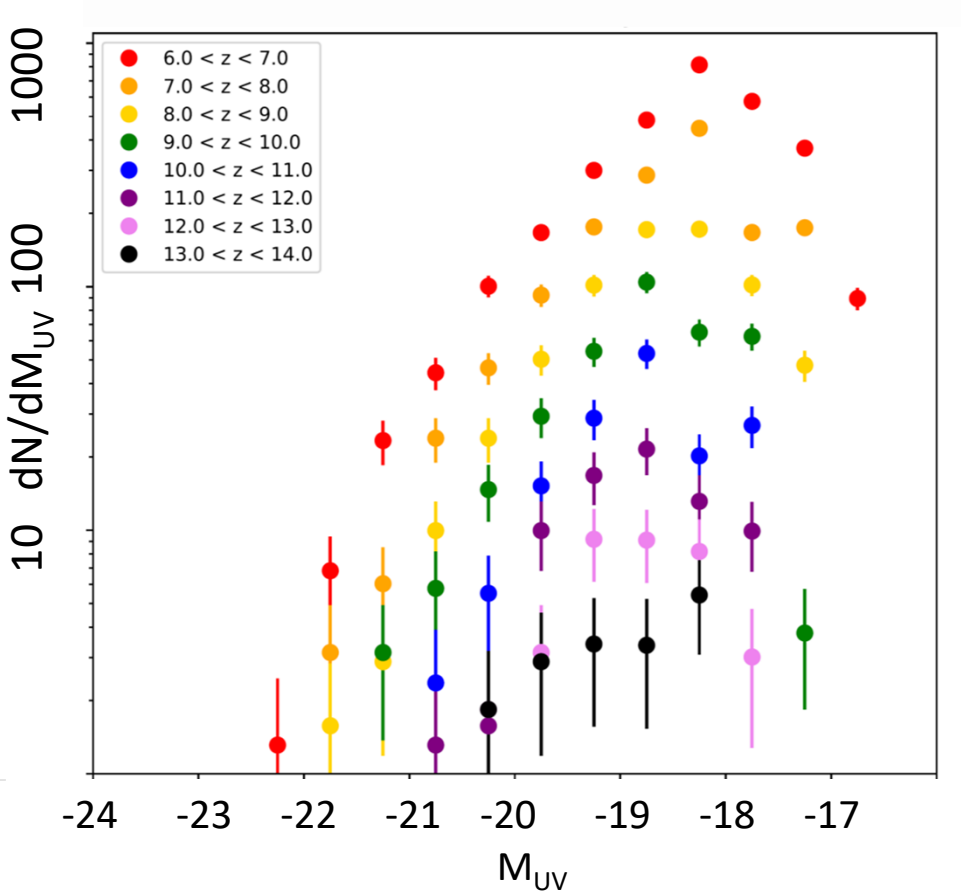
If a sample of 10 galaxies at z~12 is desired, then 10 galaxies/(0.1 gal/sq arc min) = 100 sq arc min using almost 100,000 secs of exposure time per location is needed (if the alternate SF history is correct, only 14 sq arc min are needed).

If a sample of 100 galaxies at z~7 is desired , then 100/(4 gal/sq arc min) = 25 sq arc min using 10,000 secs of exposure time per location is needed.

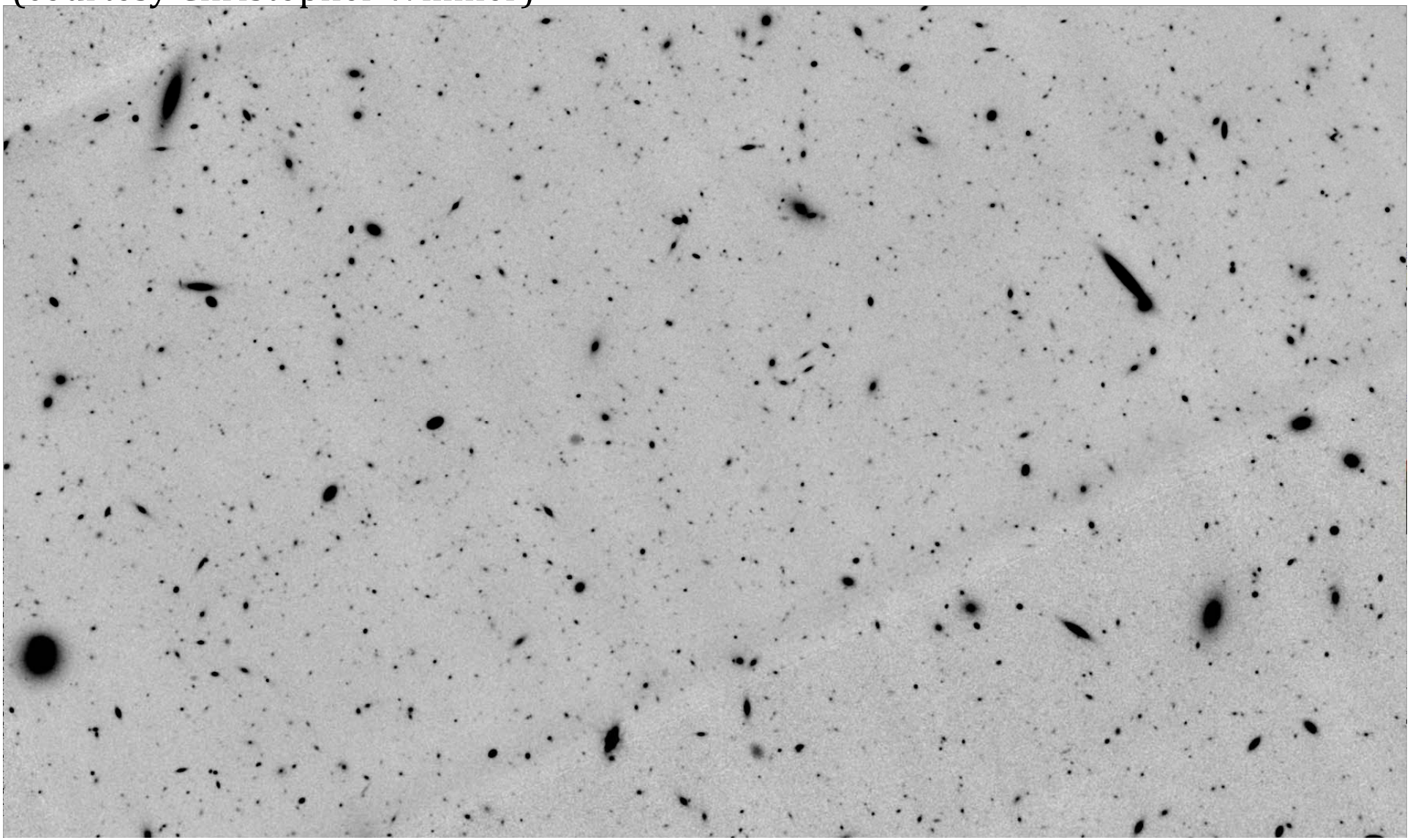
Mock Catalog to Help

Christina Williams, Emma Curtis Lake, Kevin Hainline, Jacopo Chevallard, and Brant Robertson have created Mock Galaxy Catalog to help with planning (to be released soon)



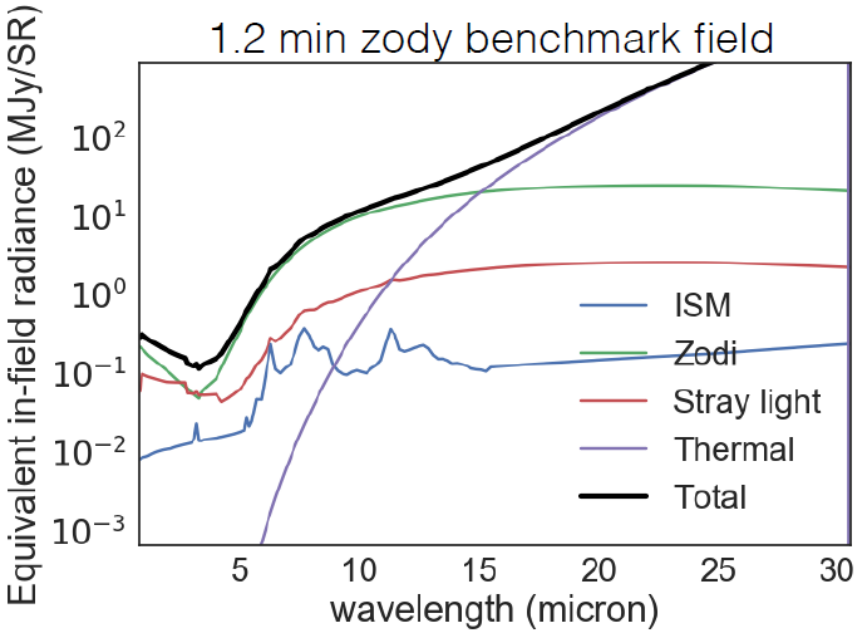


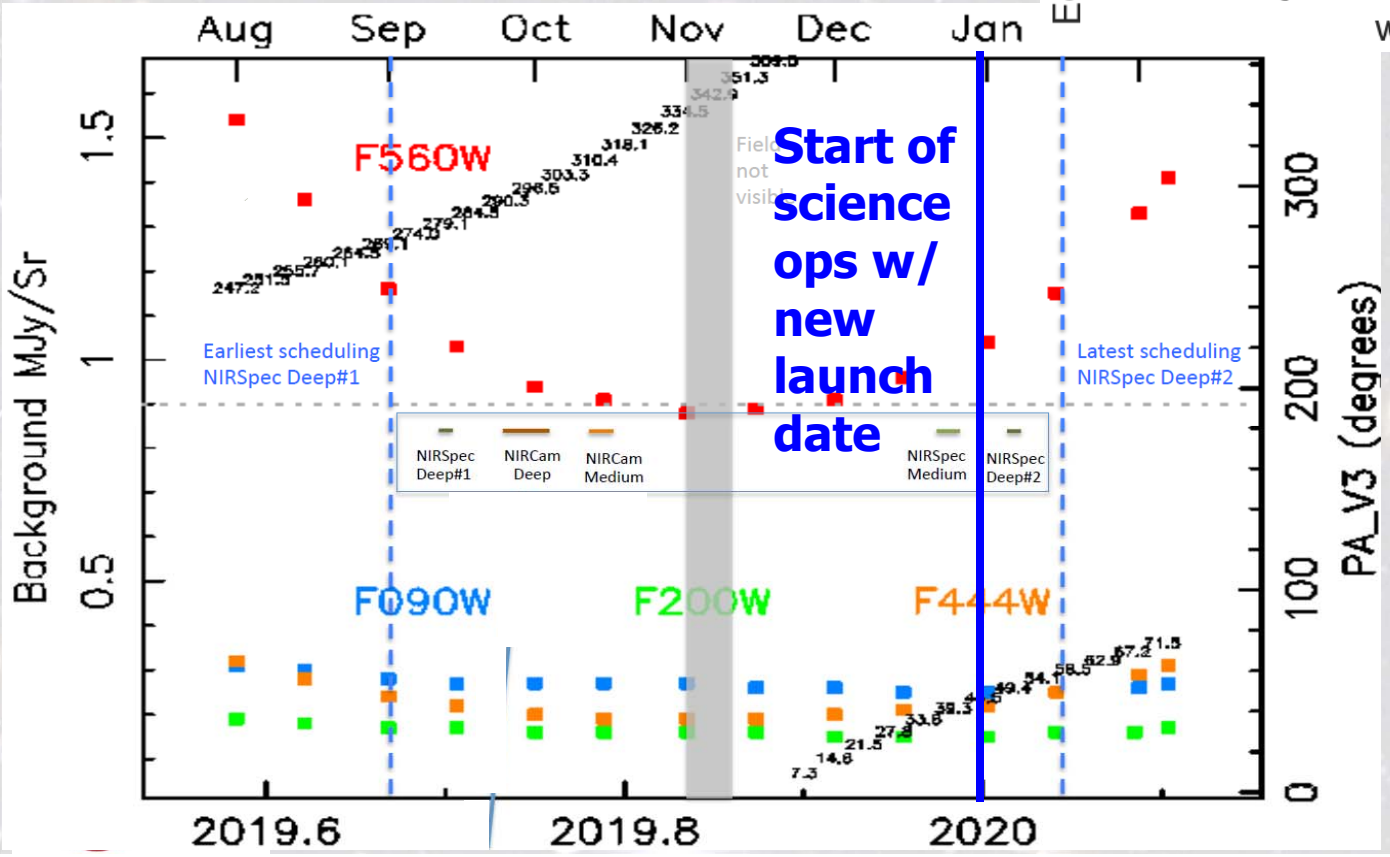
Guitarra NIRCam image simulation using F356W
(courtesy Christopher Willmer)



Sky Backgrounds Important!

Rapid increase at longer wavelengths is due to thermal emission from zodiacal dust – best to use shorter wavelengths in MIRI. ETC models the background in detail.





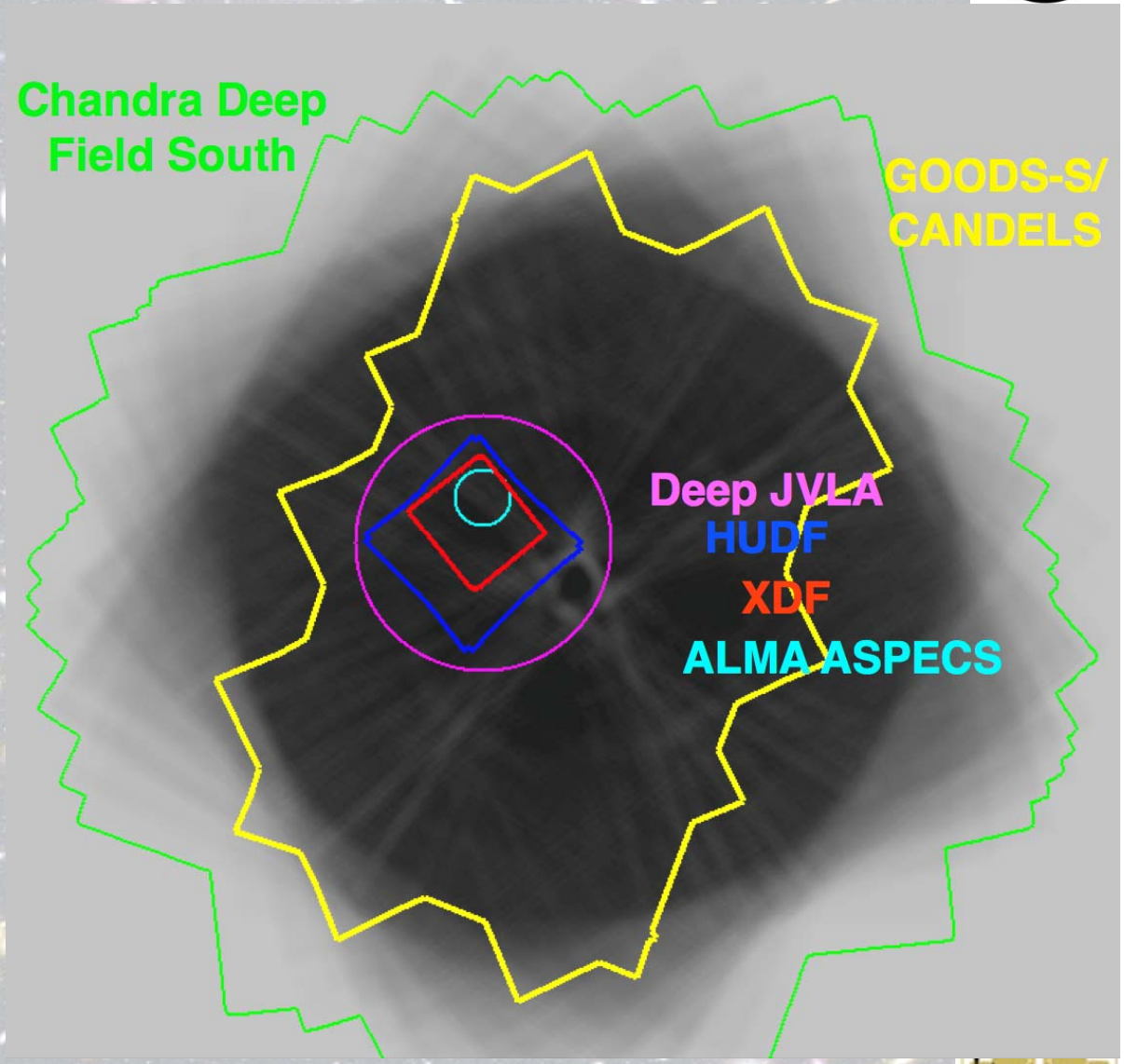
From J. Rigby

Even at F444W there is a 30% increase in the background near the edges of the visibility window.

From C. Willott

Where on the Sky?

Medium survey done on GOODS-N with the deepest exposures done on GOODS-S because of the wealth of ancillary data



Deep Surveys: Design Driver for NIRCam

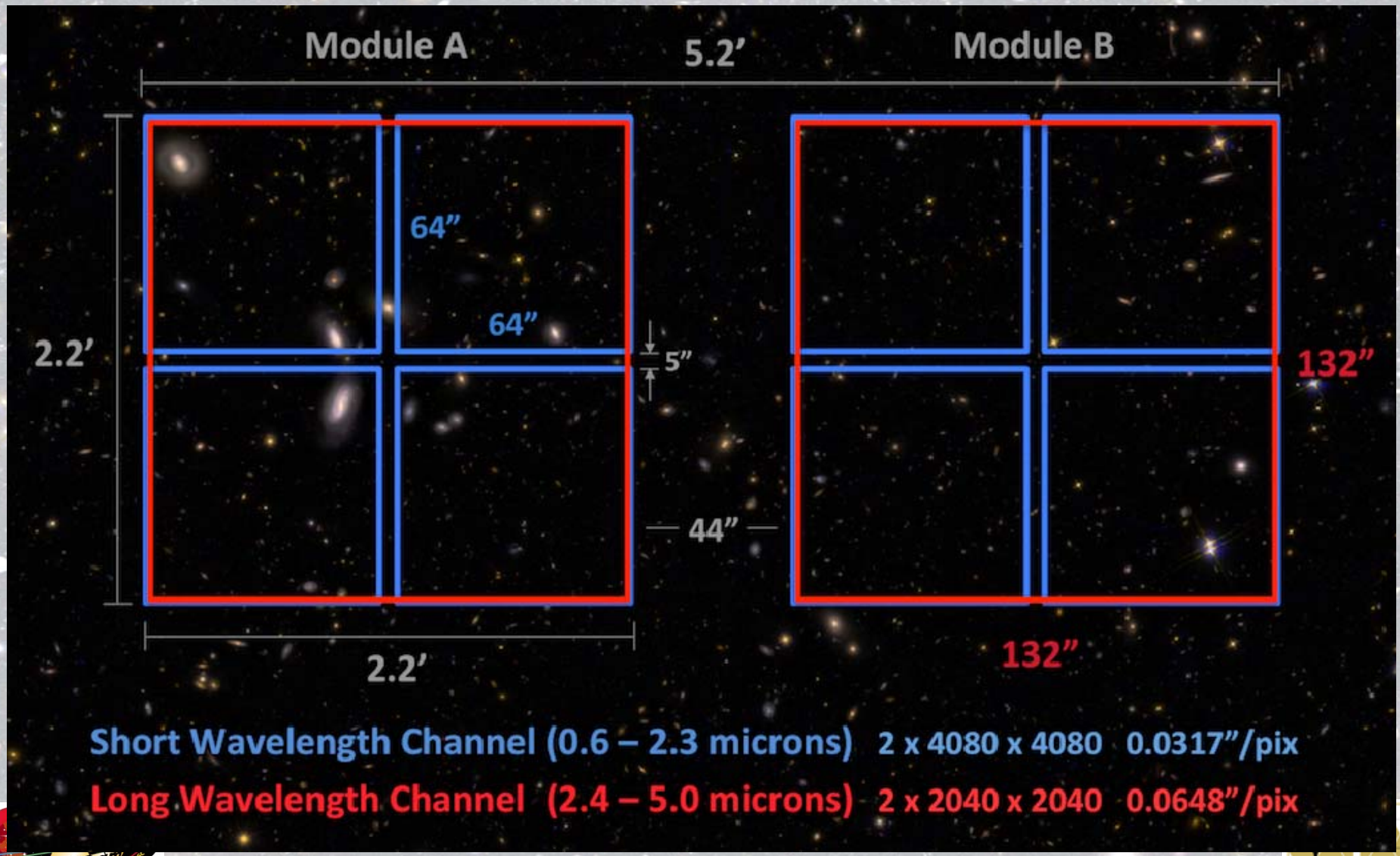
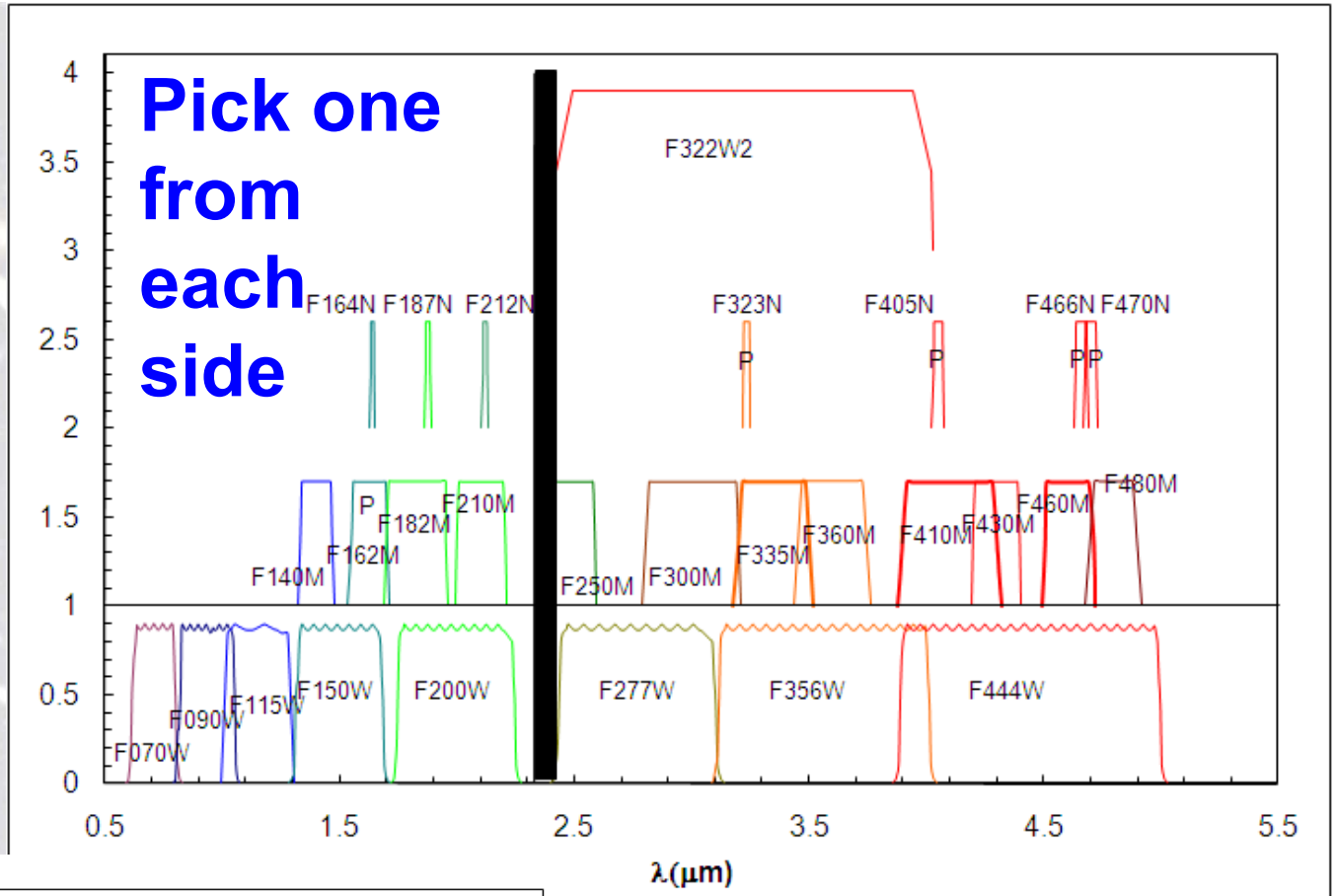
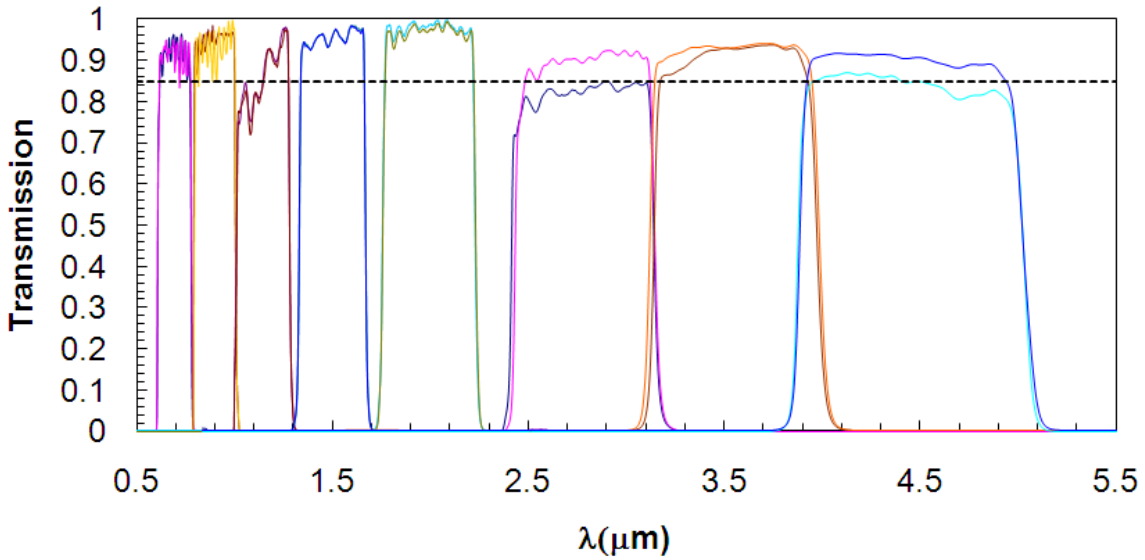


Figure courtesy of Dan Coe.

Filters

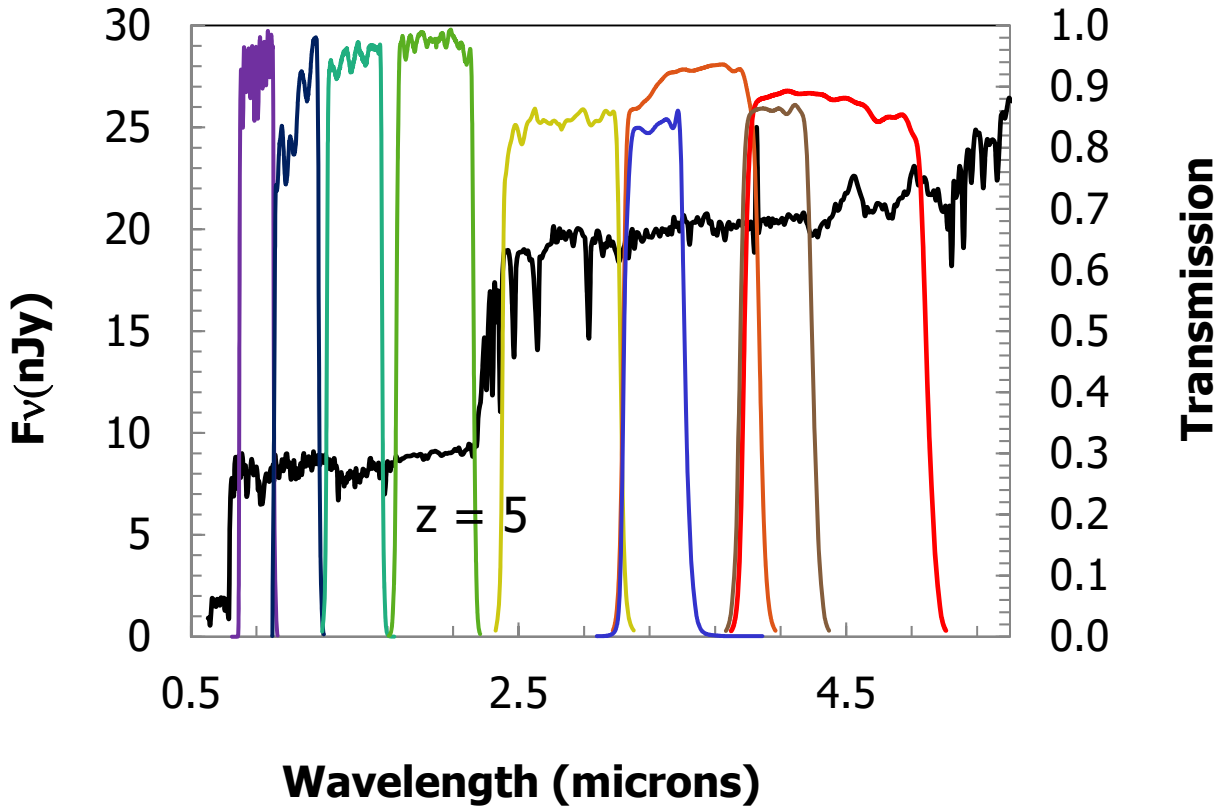
Filters have names indicating wavelength (100x microns) and width (Wide, Medium, or Narrow)





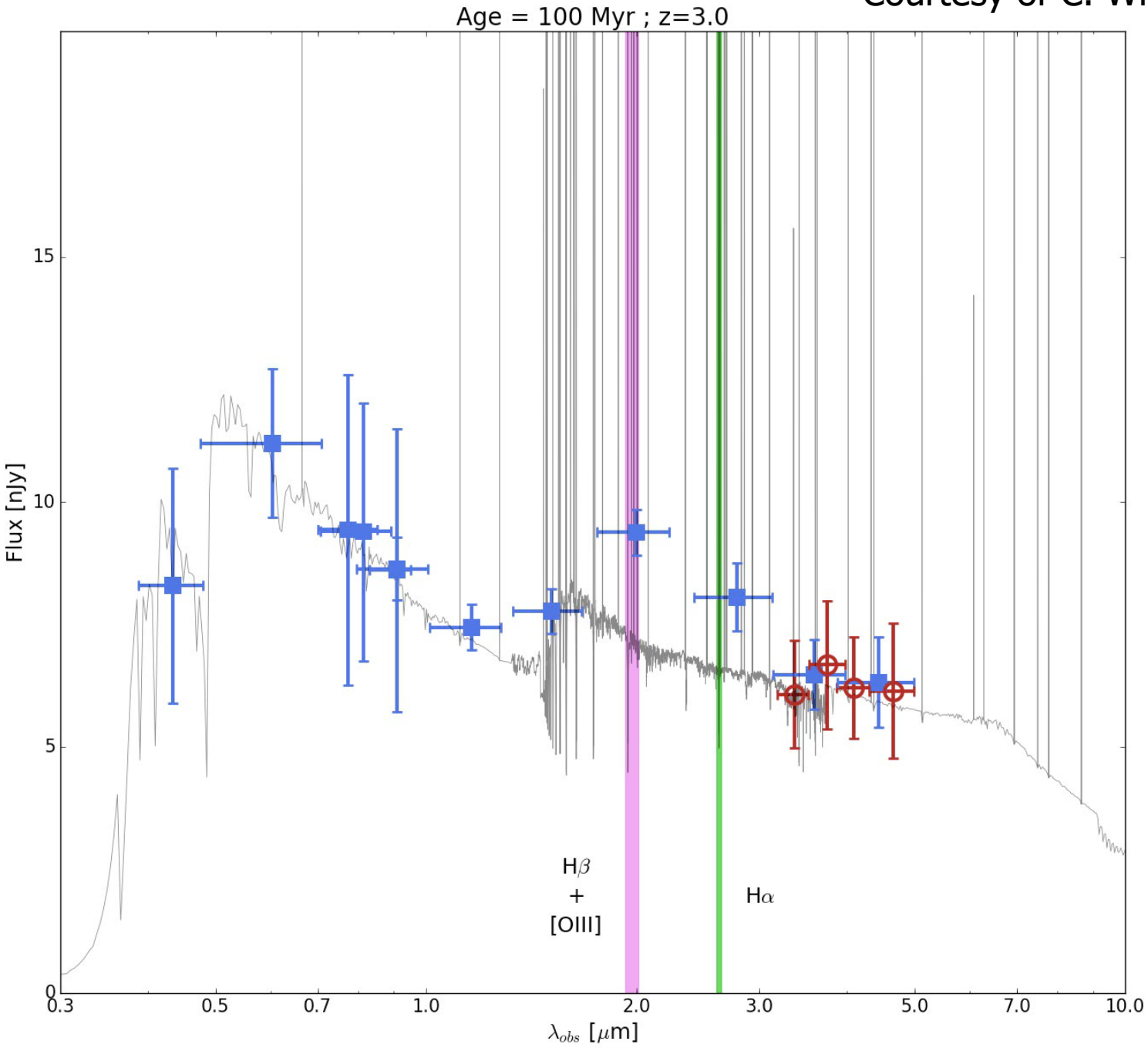
Transmission of flight W filters.

Filter Selection

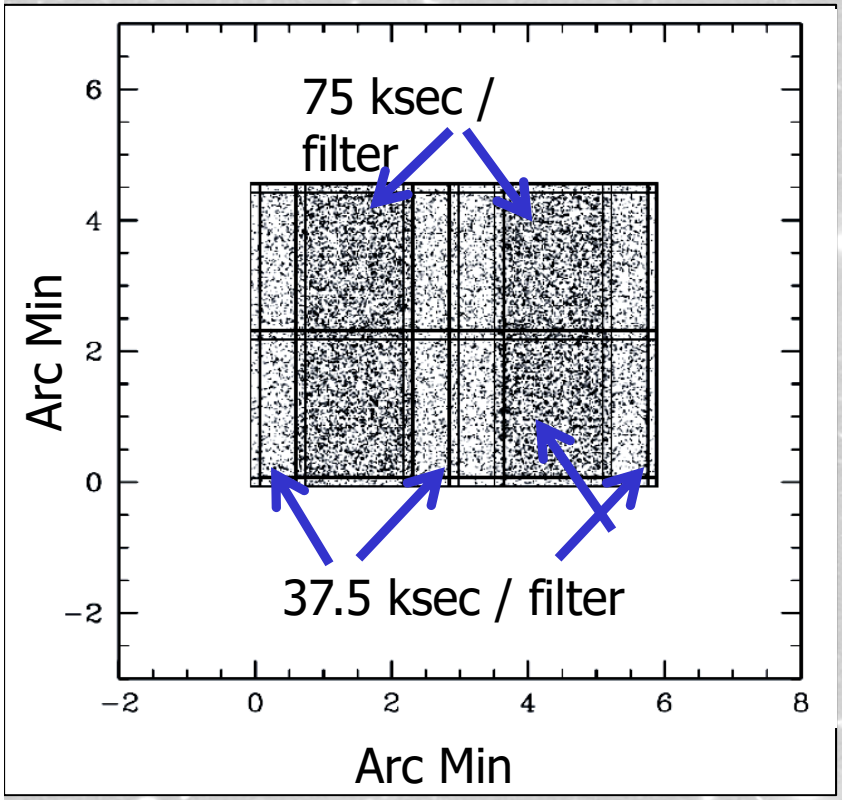


- Decided to use F090W rather than including F070W as deep red data are available from HST
- Use 4 filter pairs to cover 0.9 to 5 microns
- F410M has essentially the same sensitivity as F444W but adds some z discrimination as does F335M

Courtesy of C. Williams

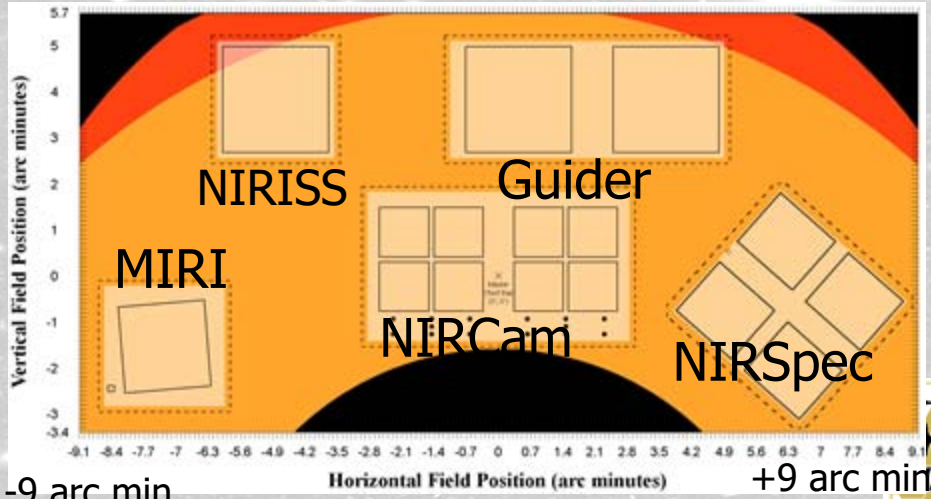


NIRCam Deep Program

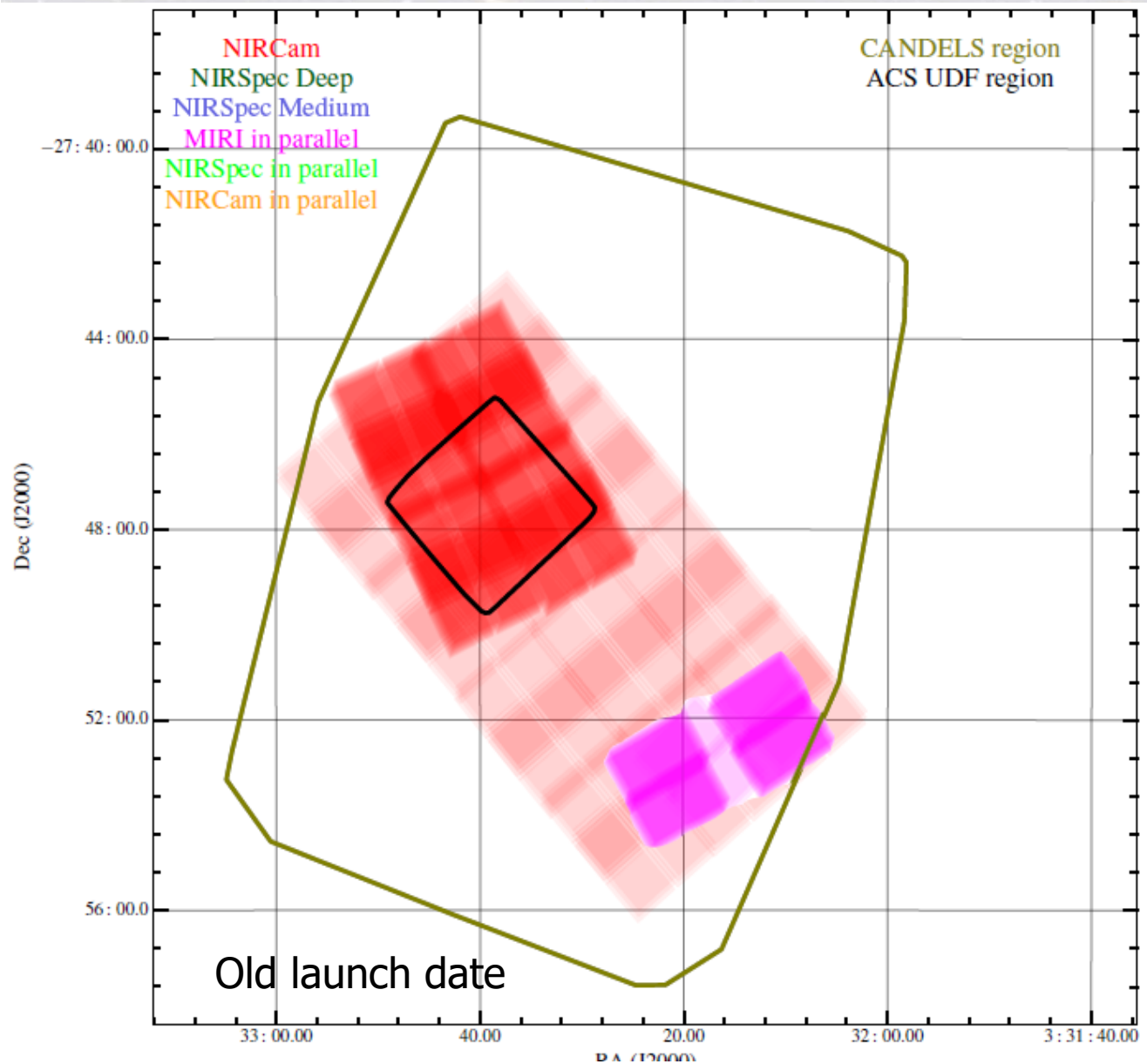


- Use two base positions + dithers to cover an area that can then be efficiently studied with the 4 NIRSpec MSA quadrants
- Use the mosaic mode in APT to replicate in "tiles"
- Dither size chosen to ensure good NIRCam coverage and adequate sampling for MIRI

Relative orientation of NIRCam FOV wrt to NIRSpec is an issue!

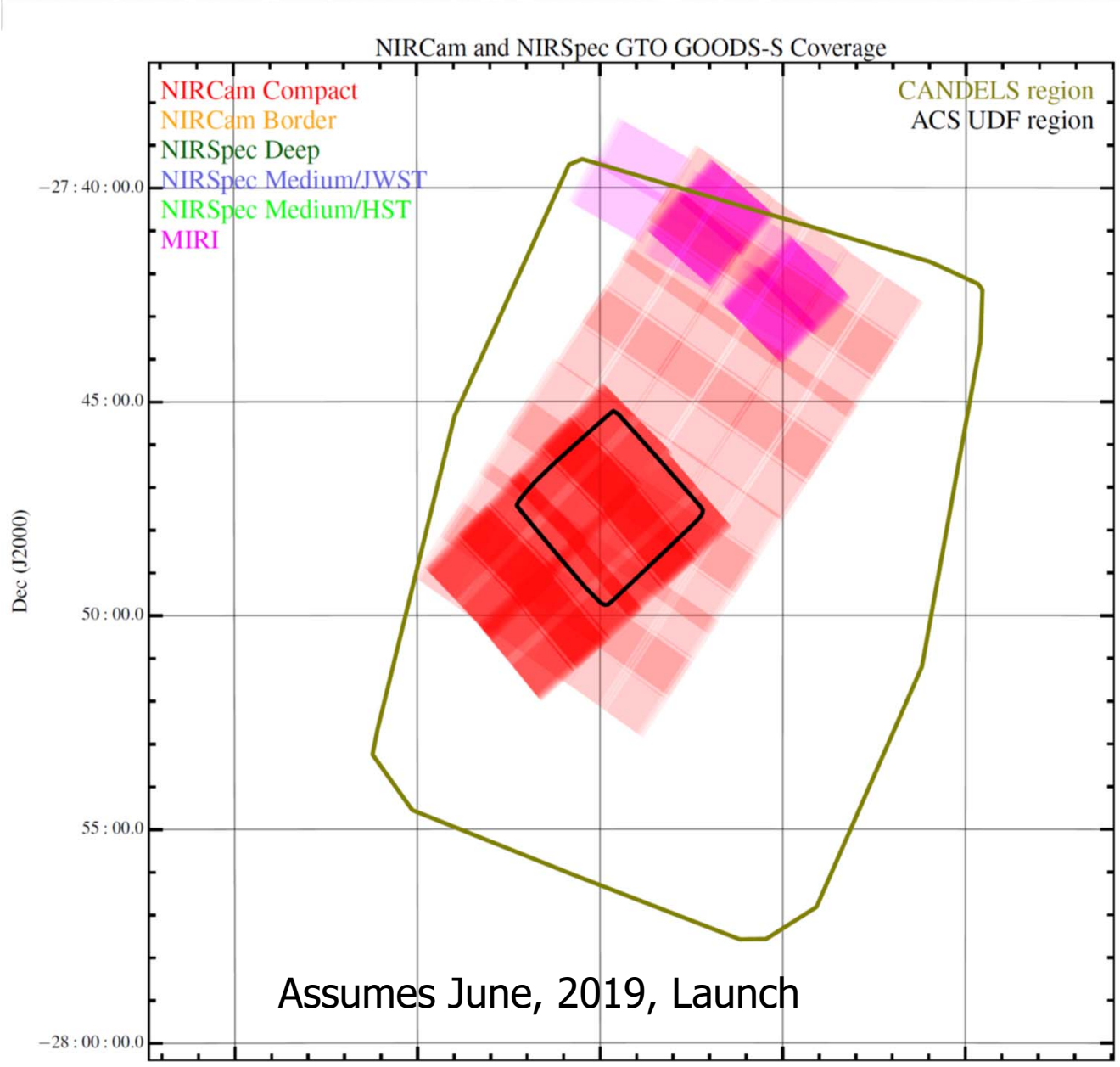


Pattern on GOODS-S



Red shows the NIRCam deep survey with exposure times ~60 ksec.
Pink is a medium NIRCam survey with exposure times ~10 ksec.
Magenta is MIRI done in parallel to the deep imaging.

Pattern on GOODS-S



Red shows the NIRCam deep survey with exposure times ~60 ksec.
Pink is a medium NIRCam survey with exposure times ~10 ksec.
Magenta is MIRI done in parallel to the deep imaging.

Predicted Sensitivities

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

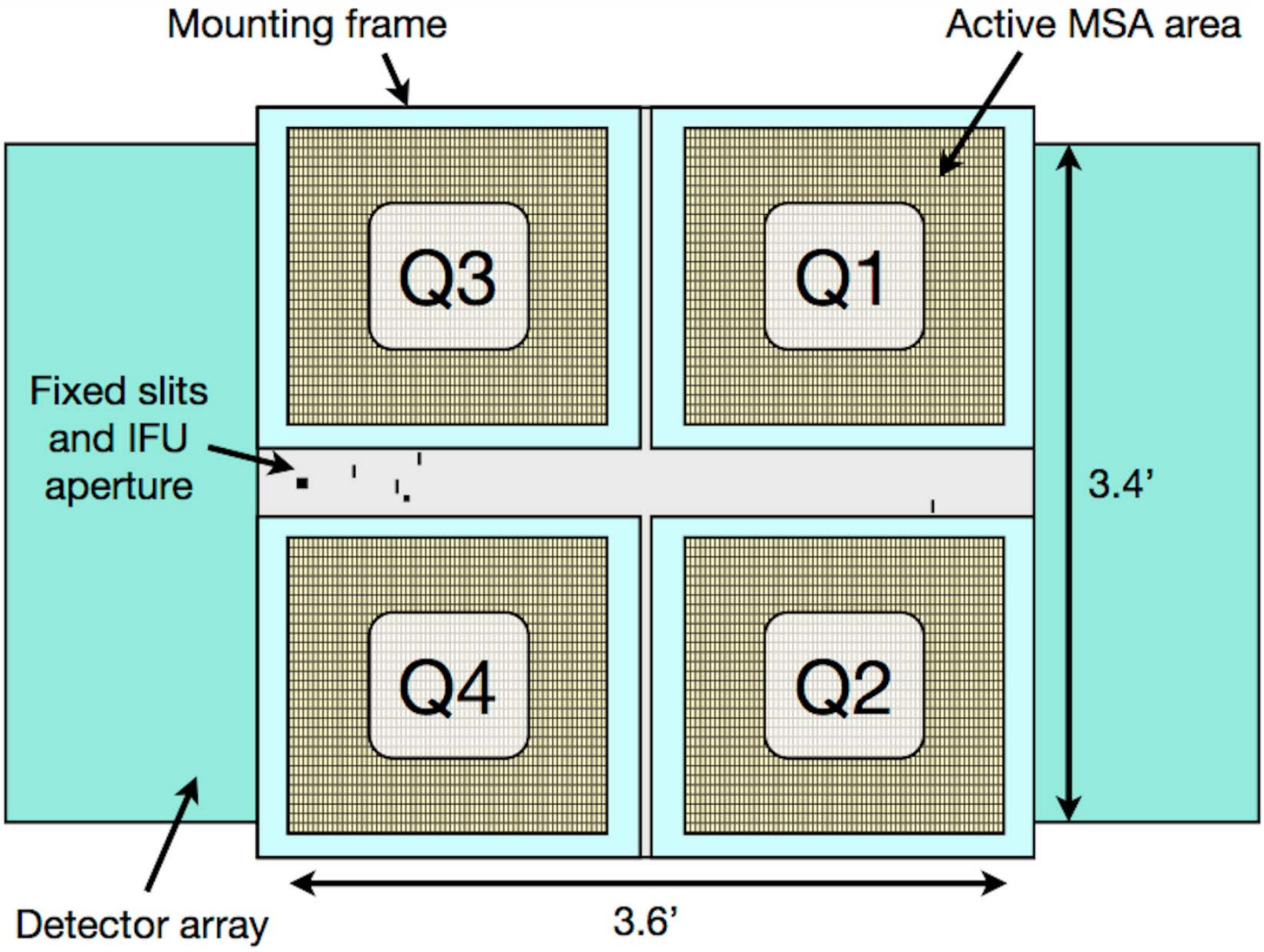
10 nJy = 28.9 AB

Subsurvey	Number Pointings	Area □′	Exposure Times (Ksec)		10σ AB Mag Limit	
			F770W	F1280W	F770W	F1280W
Deep/MIRI	4	8	167	—	26.7	—
Medium/MIRI	7	14	5.6	19.4	24.9	24.3

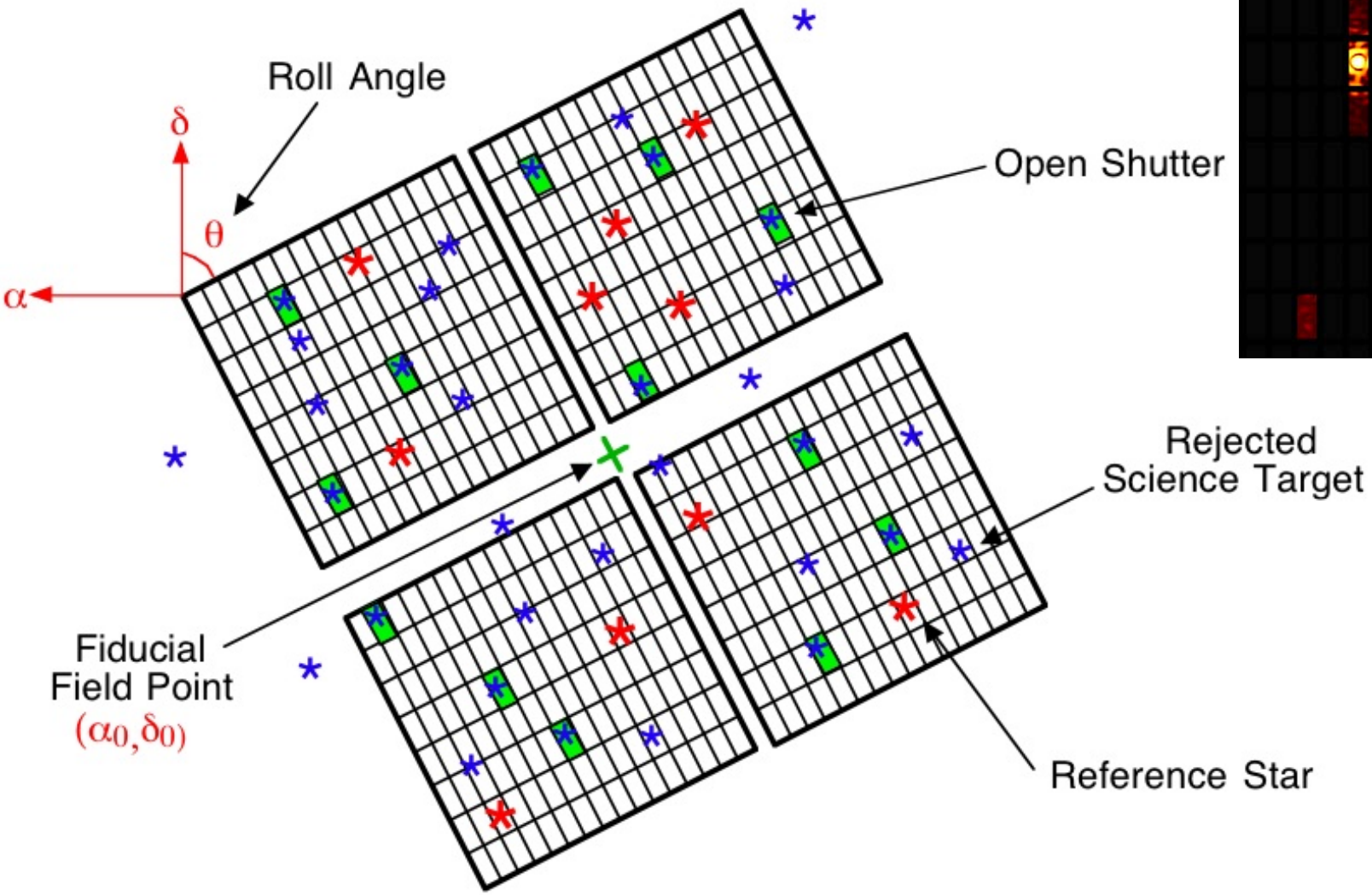
NIRCam limits are deeper than HST, have superior spatial resolution at wavelengths > 1 micron with superb imaging all the way to 5 microns.

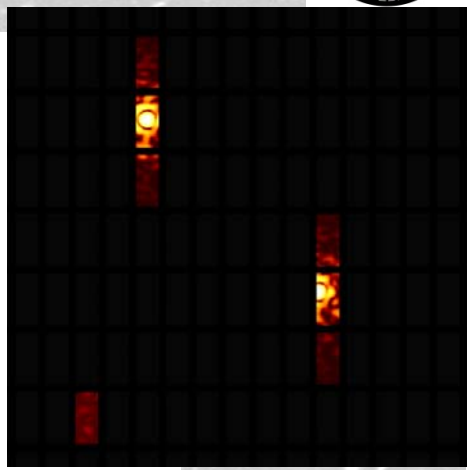
MIRI limits are 10x those achieved on Spitzer and will have much greater spatial resolution.

Microshutter Array

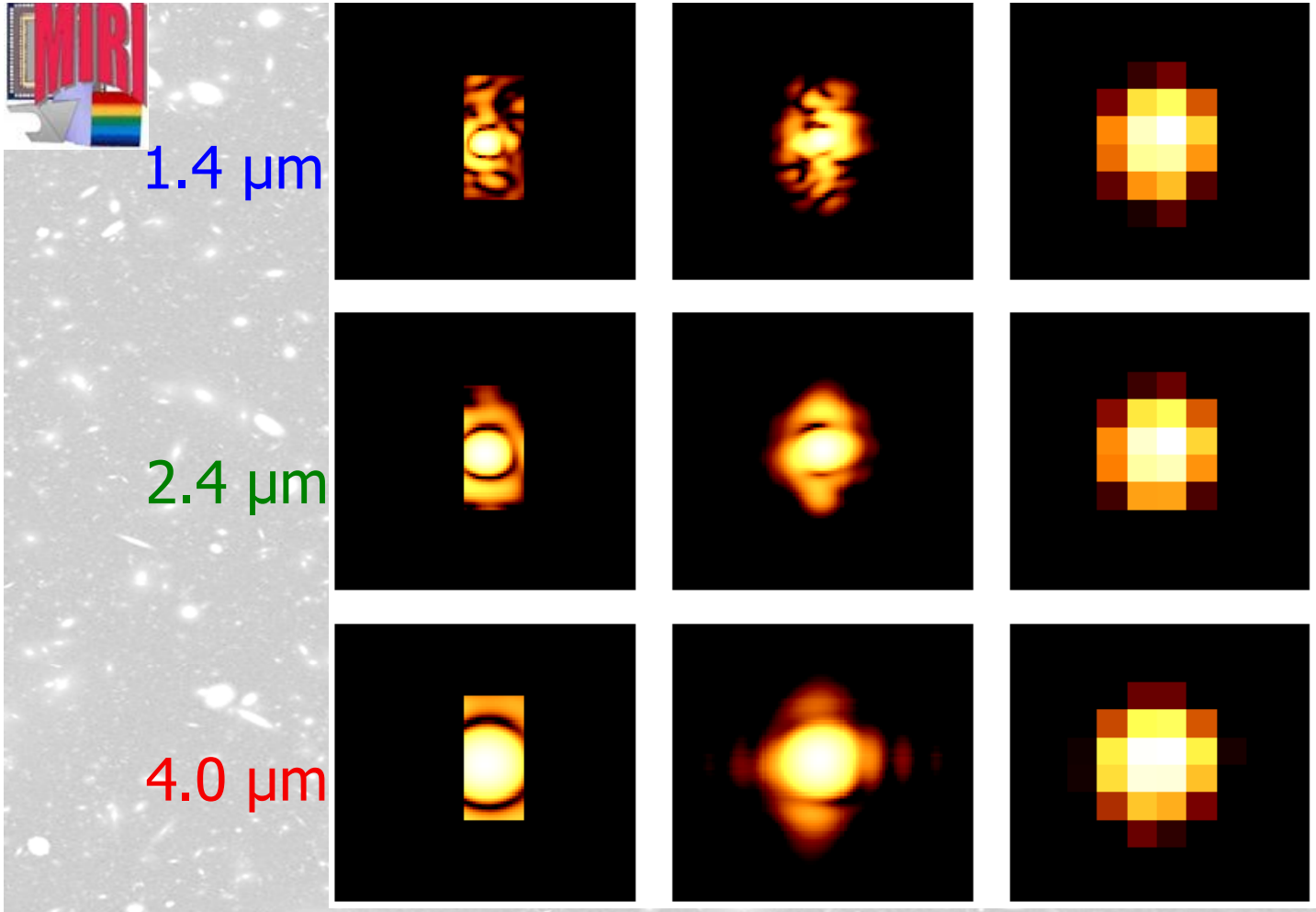


Schematic of Slit Layouts



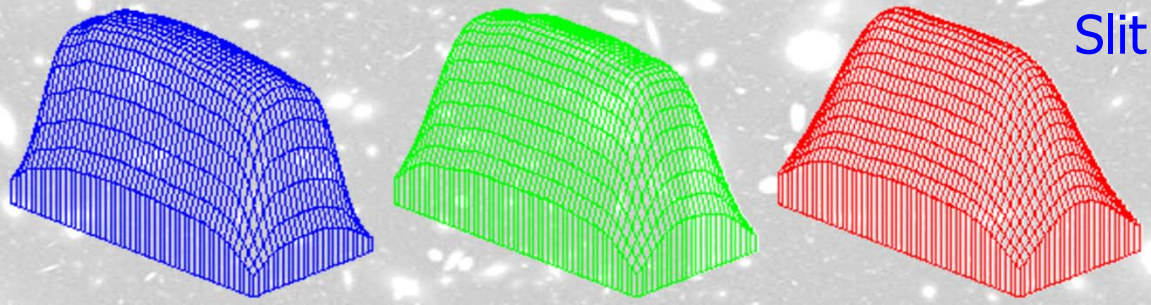


Observing lots of sources means compromises for centering.

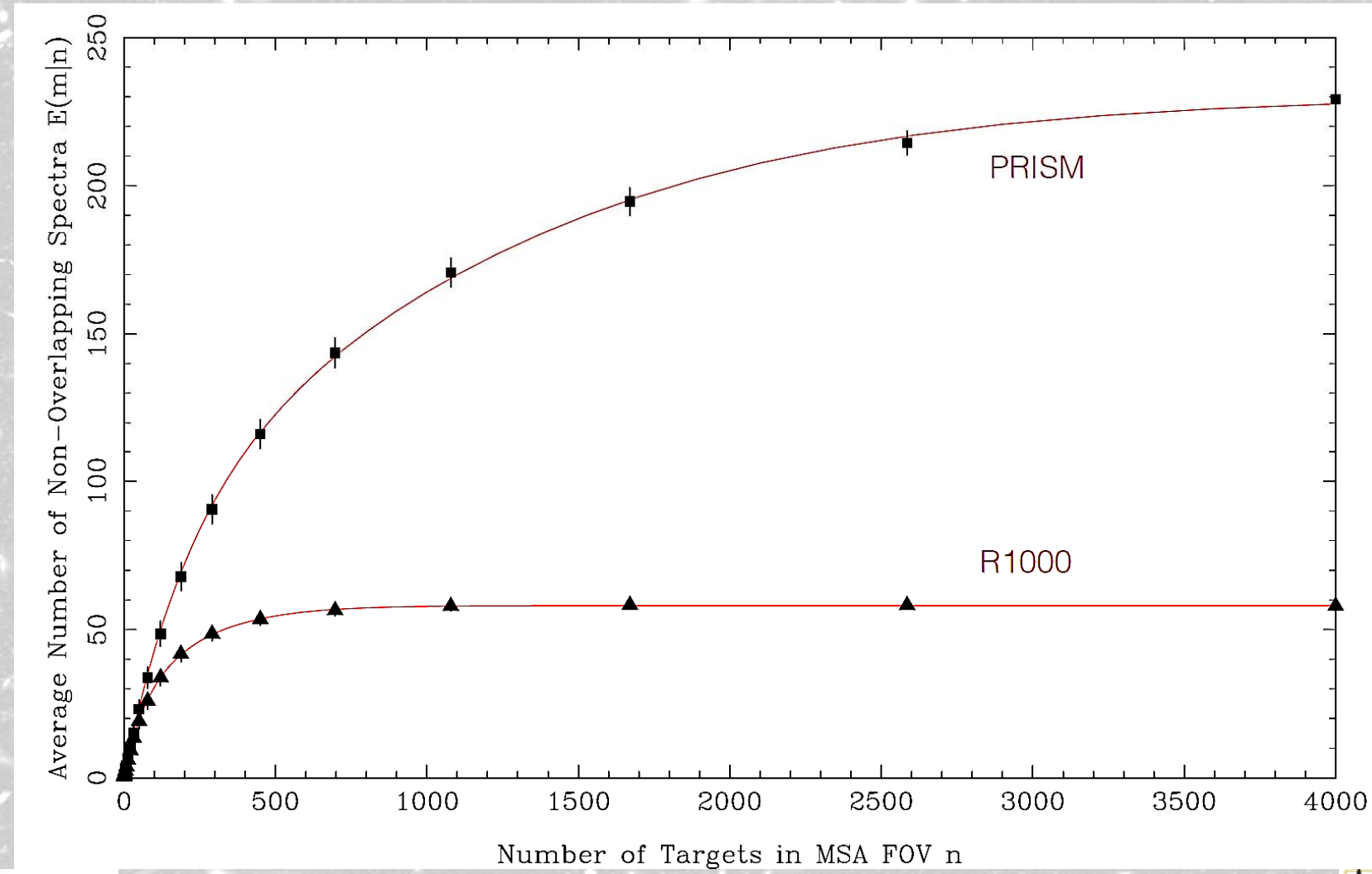


NIRCam useful for coordinates but needed for accurate spectrophotometry even for sources with HST positions.

Slit Throughput



Filling Slits Optimally



Spectroscopic Sensitivities

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}	—

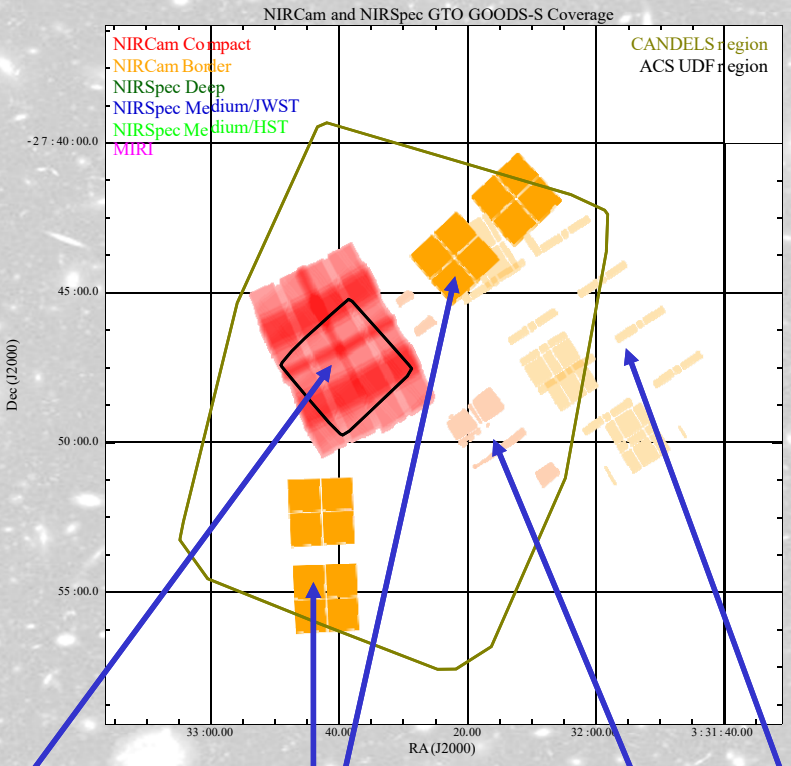
These values assume use of IRS^2 readout and ~1375 second exposures.

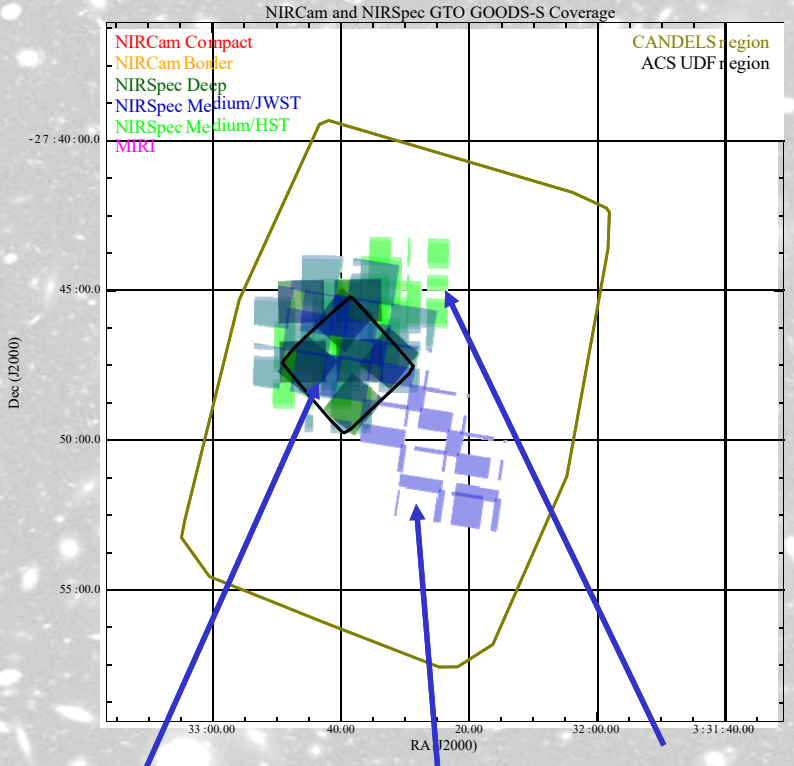
Putting it All Together

All proposed NIRCam imaging.

All proposed NIRSpec MOS spectroscopy

Old launch date





NIRCam deep compact

NIRCam deep border

NIRCam Medium compact

NIRCam medium border

NIRSpec deep JWST & HST

NIRSpec medium JWST

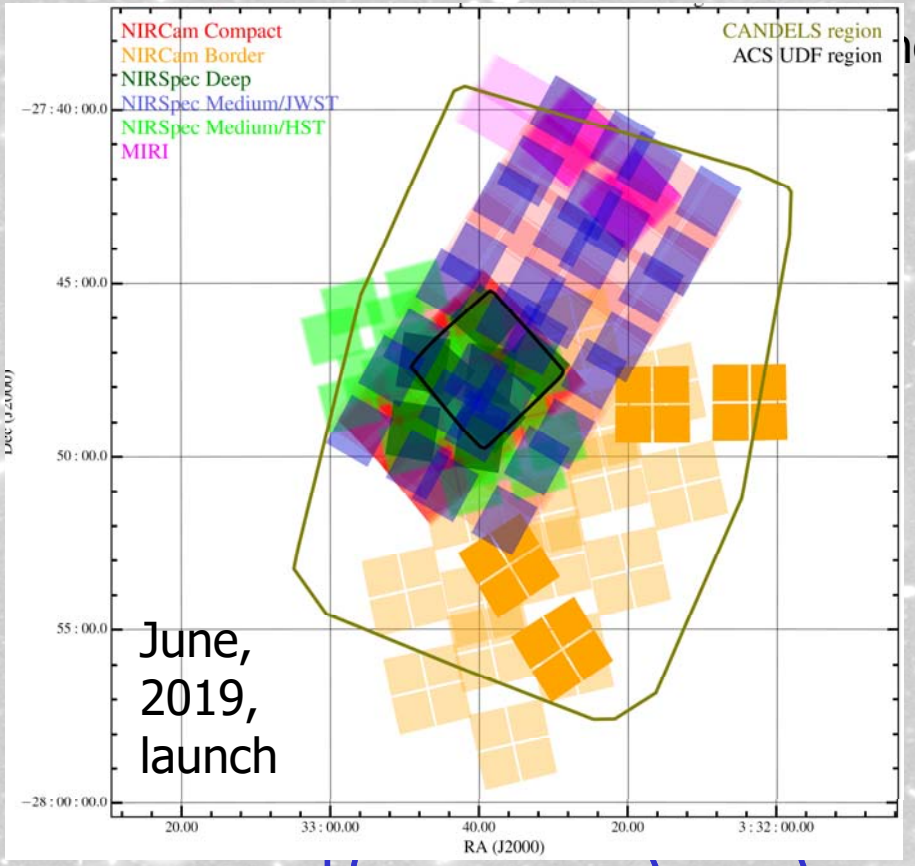
NIRSpec medium HST

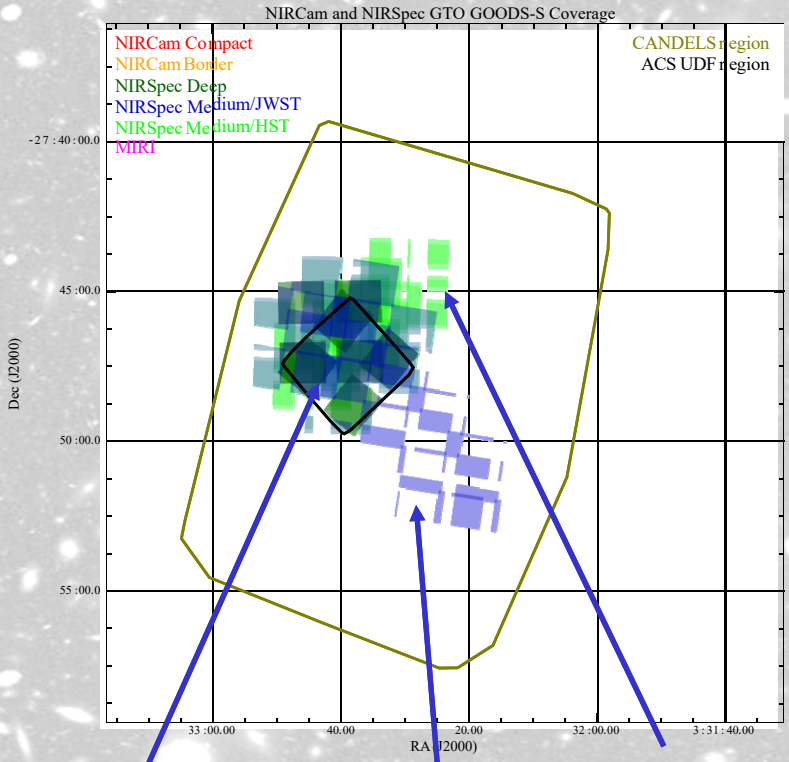
Putting it All Together

All proposed NIRCam imaging.

All proposed NIRSpec MOS spectroscopy

ch date





NIRCam deep compact

NIRCam deep border

NIRCam Medium compact

NIRCam medium border

NIRSpec deep JWST & HST

NIRSpec medium JWST

NIRSpec medium HST

Related Programs from the Early Release Science Program

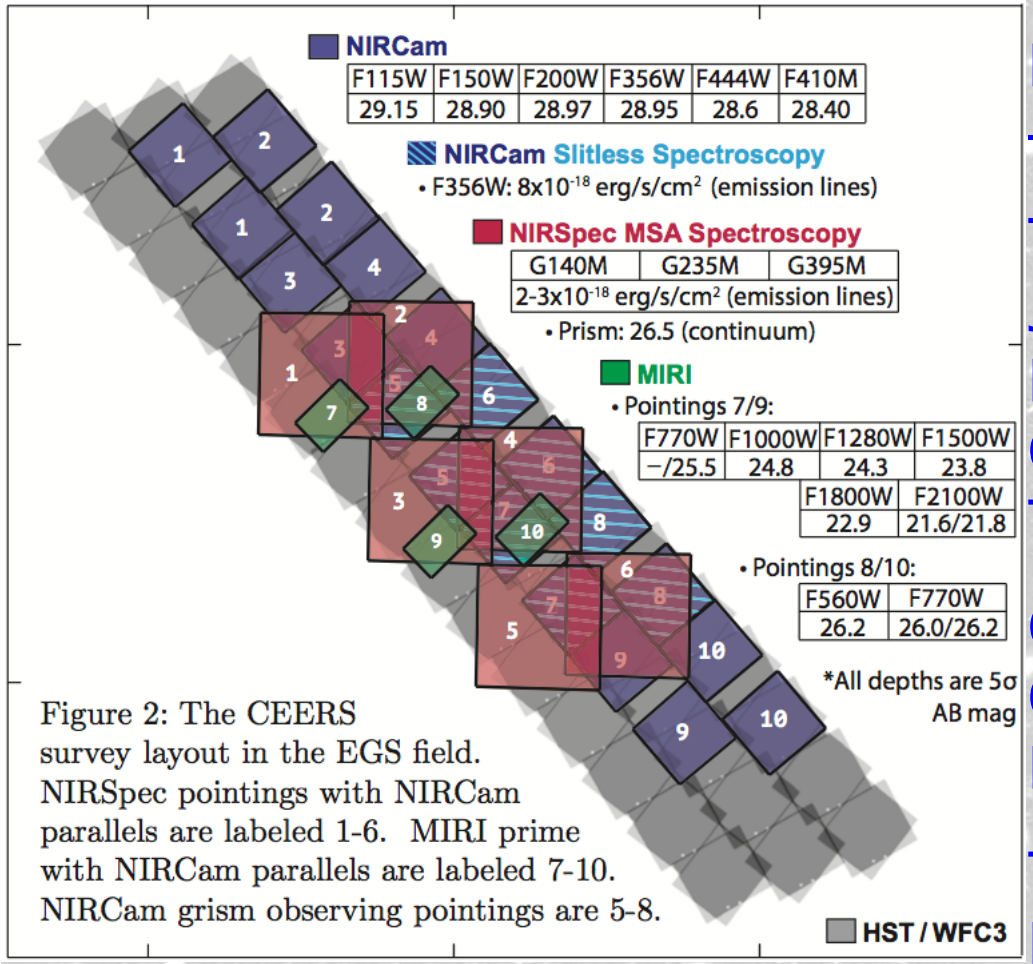


Figure 2: The CEERS survey layout in the EGS field. NIRSpec pointings with NIRCam parallels are labeled 1-6. MIRI prime with NIRCam parallels are labeled 7-10. NIRCam grism observing pointings are 5-8.

The Cosmic Evolution Early Release Science (CEERS) Survey – PI, Steve Finkelstein

Through the Looking GLASS: A JWST Exploration of Galaxy Formation and Evolution from Cosmic Dawn to Present Day – PI, Tommaso Treu

Q-3D: Imaging Spectroscopy of Quasar Hosts with JWST – PI, Dominika Wylezalek

TEMPLATES: Targeting Extremely Magnified Panchromatic Lensed Arcs and Their Extended Star Formation – PI, Jane Rigby

NIRSpec – NIRCam Deep Survey Summary

By taking advantage of parallel instrument operation, the NIRCam and NIRSpec GTO teams will create a legacy data set to guide future JWST high redshift work.

We also promise to release some datasets and "lessons learned" to guide GO observing with exact datasets dependent on launch date – the current launch window extends to a date for which GOODS-South data likely would not be taken until well after the Cycle 2 GO proposals are due.