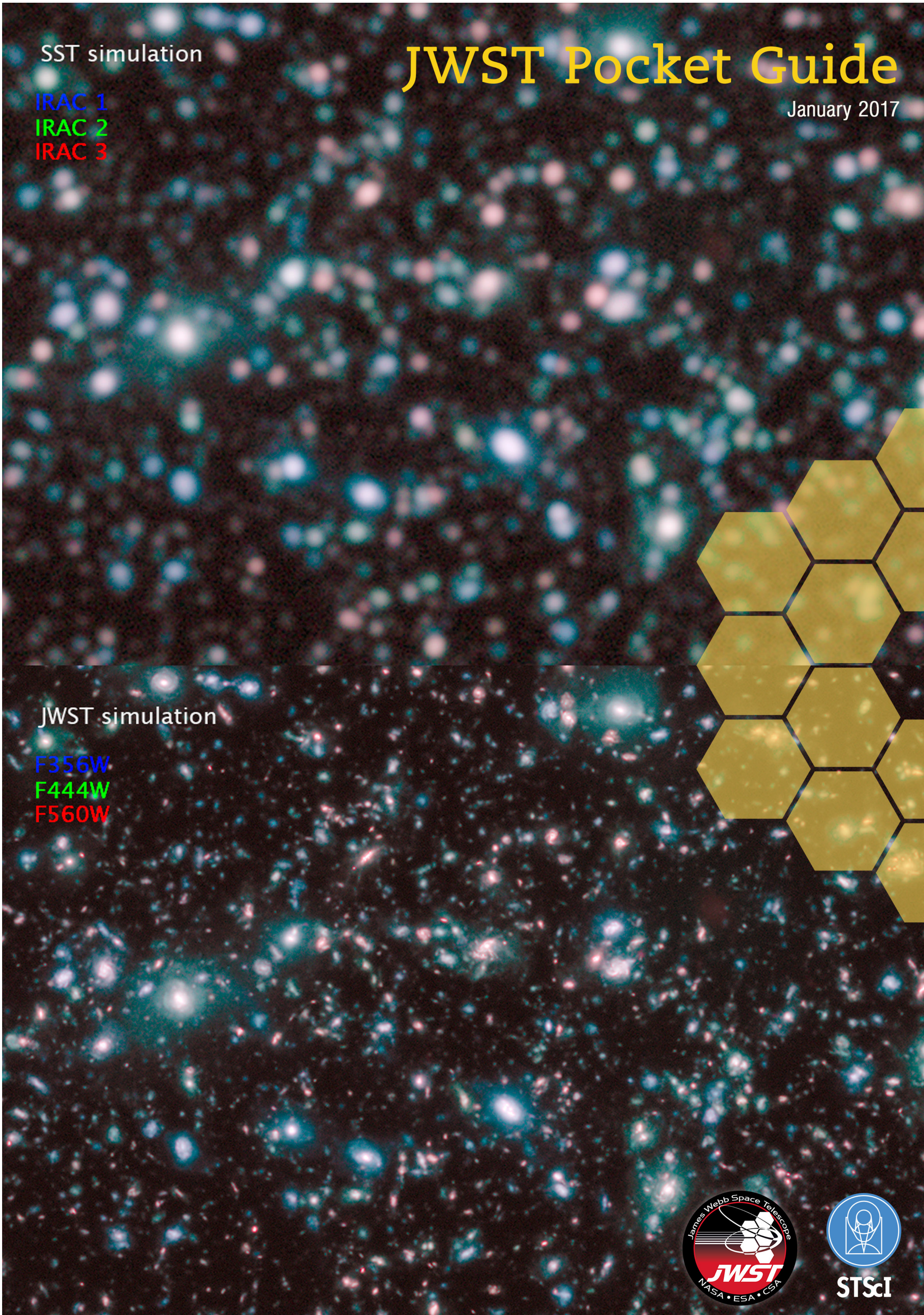
JWST Pocket Guide

January 2017



Cover: Simulated images of the Illustris universe with Spitzer and JWST

The front page illustration compares what JWST and Spitzer would measure from the cosmological hydrodynamical simulation Illustris in 2.8-arcminute-wide ultra-deep images in the near-infrared (3-6 microns). Illustris produced more faint galaxies than we observe in the real universe, but this highlights qualitatively the expected improvement in spatial detail with deep JWST observations.

Sources:

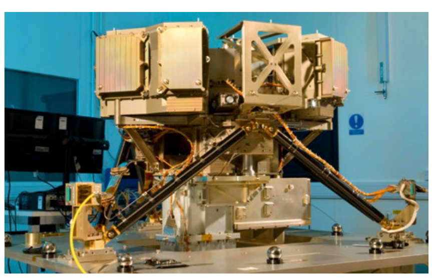
Vogelsberger et al. (2013): **http://adsabs.harvard.edu/abs/2014Natur.509..177V**
Snyder et al. (2016): **http://adsabs.harvard.edu/abs/2016arXiv161001156S**

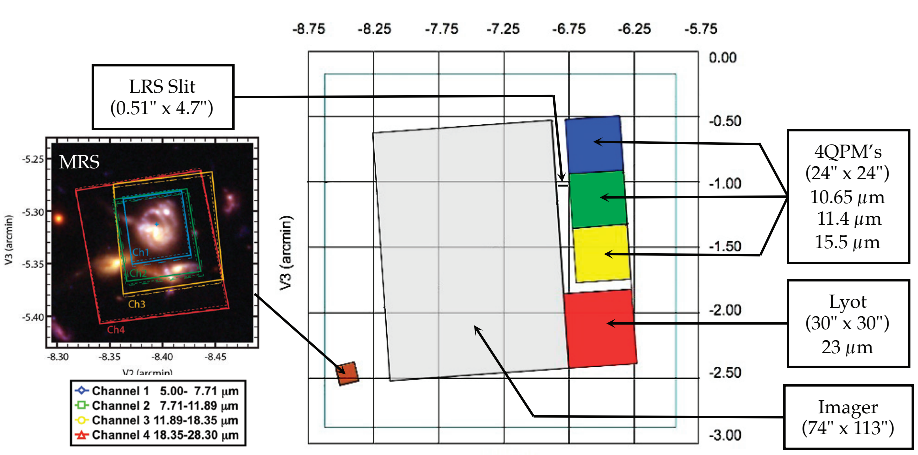
Photo credit: G. Snyder and Z. Levay

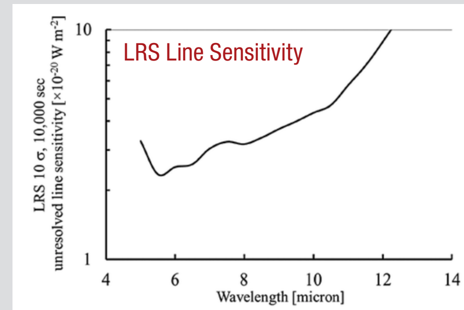
The Mid-Infrared Instrument (MIRI)

The Mid-Infrared Instrument (MIRI) provides:

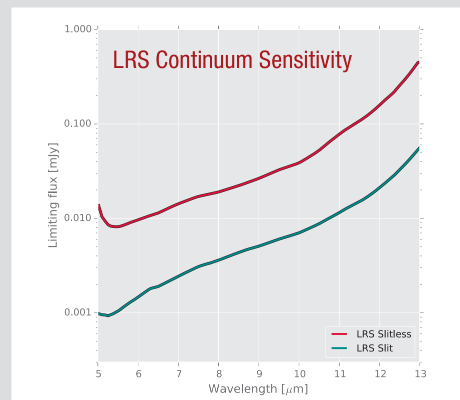
- Imaging in nine (9) photometric bands from 5 to 28 μm, $\lambda/\Delta\lambda \sim 5$, with a field of view (FOV) 74'' x 113''
- Sub-array imaging (with shorter exposure times) for bright targets and high sky backgrounds!
  - SUB64 – 7.0'' x 7.0''
  - SUB128 – 14.1'' x 14.1''
  - SUB256 – 28.2'' x 28.2''
  - BRIGHTSKY – 56.3'' x 56.3''
- Coronagraphic imaging facilitated by three (3) four-quadrant phase masks (4QPMs) at 10.65, 11.4, & 15.5 μm (24'' x 24''), and a Lyot coronagraph at 23 μm (30'' x 30'')!
- Low Resolution Spectrometer (LRS: $\lambda/\Delta\lambda \sim 100$ at 7.5 μm), which covers wavelengths from 5 to ~ 12 μm using a 0.51'' x 4.7'' slit, or in SLITLESS configuration!
- Medium Resolution Spectrometer (MRS: $\lambda/\Delta\lambda \sim 1550$–3250), which covers wavelengths from 4.9 to 28.8 μm, enabled by four Integral Field Units (IFUs) with FOVs of 3.9'' to 7.7''



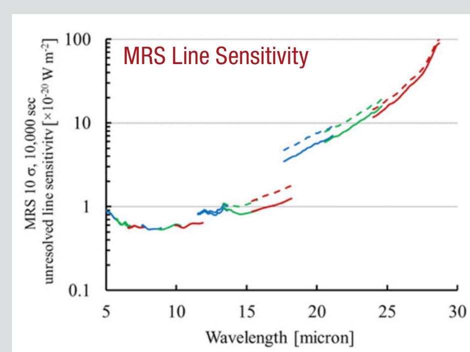




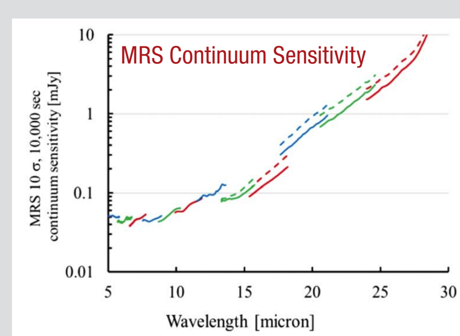
LRS limiting sensitivity for the detection of a spectrally and spatially unresolved target (units of 10^{-20} Watt m^{-2}).



LRS limiting sensitivity for the detection of the continuum spectrum for a spatially unresolved target (units of microJansky).

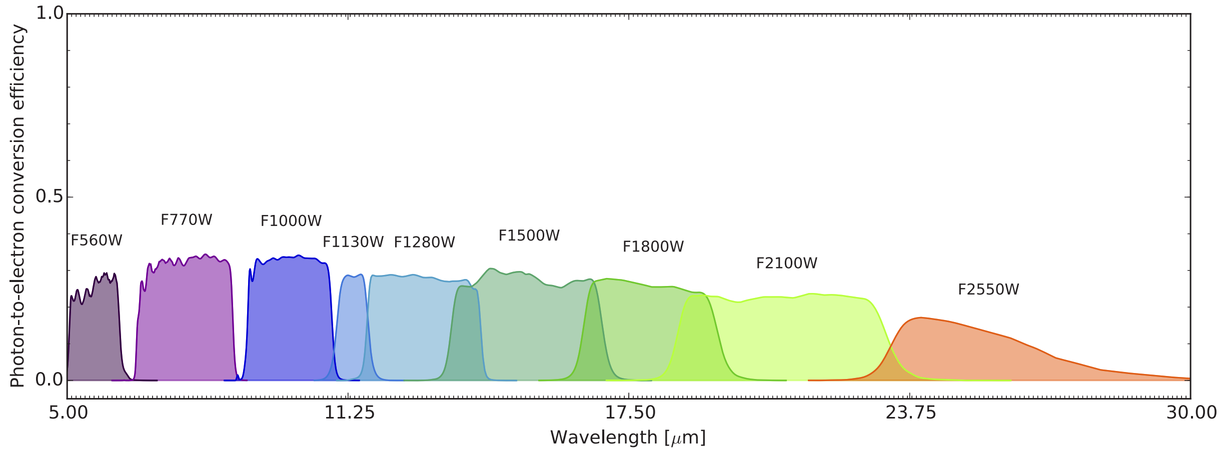


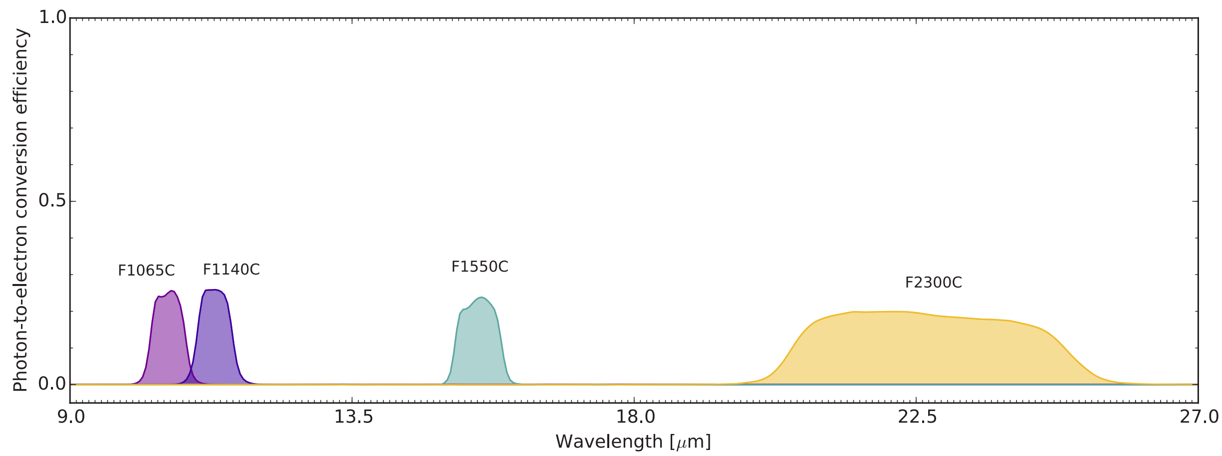
MRS limiting sensitivity for the detection of an unresolved spectral line in a spatially unresolved target (units of 10^{-20} Watt m^{-2}). The dashed lines are for the high-background case.



MRS limiting sensitivity for the detection of the continuum spectrum for a spatially unresolved target (units of milli-Jansky). The dashed lines are for the high-background case.

MIRI Imager





Name	λ (μm)	$\lambda/\Delta\lambda$	Point-Source Detection Limit[1]	Extended Source Detection Limit[1]	Point-Source Saturation Limit[2]
F560W	5.6	5.0	0.2 μJy	0.22 μJy arcsec^{-2}	7 mJy
F770W	7.7	3.5	0.28 μJy	0.26 μJy arcsec^{-2}	3 mJy
F1000W	10.0	5.0	0.7 μJy	0.53 μJy arcsec^{-2}	8 mJy
F1130W	11.3	16.0	1.7 μJy	1.2 μJy arcsec^{-2}	35 mJy
F1280W	12.8	5.0	1.4 μJy	0.83 μJy arcsec^{-2}	15 mJy
F1500W	15.0	5.0	1.8 μJy	0.93 μJy arcsec^{-2}	18 mJy
F1800W	18.0	6.0	4.3 μJy	1.9 μJy arcsec^{-2}	34 mJy
F2100W	21.0	4.0	8.6 μJy	3.3 μJy arcsec^{-2}	50 mJy
F2550W	25.5	6.0	28 μJy	9.1 μJy arcsec^{-2}	105 mJy
MRS1	6.4	3250	1.2×10^{-20} W m^{-2}	1.9×10^{-22} W m^{-2}/pix (0.2" pix)	2.5 Jy
MRS2	9.2	2650	0.9×10^{-20} W m^{-2}	2.2×10^{-22} W m^{-2}/pix (0.2"pix)	1.5 Jy
MRS3	14.5	2000	1.1×10^{-20} W m^{-2}	1.5×10^{-22} W m^{-2}/pix (0.24" pix)	2.5 Jy
MRS4	22.5	1550	10.4×10^{-20} W m^{-2}	8.7×10^{-22} W m^{-2}/pix (0.27" pix)	6 Jy
LRS	7.5	100	8 μJy	...	70 mJy

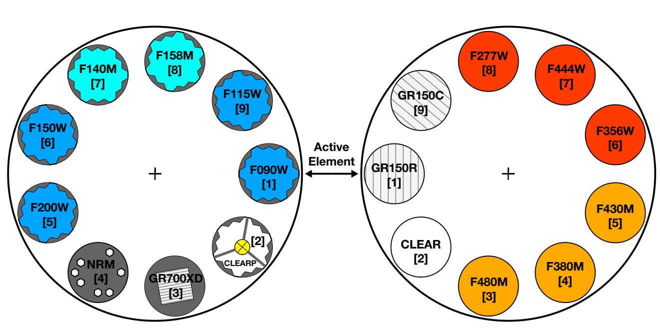
[1] 10σ in for a 10,000 second on-source integration time.
[2] Saturation based on 13% of flux falling within the brightest pixel for $\lambda \leq 8$ μm and 13 % x $(8\ \mu m/\lambda)^2$ for $\lambda > 8$ μm.

http://jwst.stsci.edu/instrumentation/miri
http://ircamera.as.arizona.edu/MIRI/
http://www.jstor.org/stable/10.1086/682264

Revised Dec. 2016

The Near-Infrared Imager and Slitless Spectrograph (NIRISS)

Pupil Wheel   Filter Wheel



At a glance:	
Detector	Teledyne HAWAII-2RG; HgCdTe with 5.2µm cutoff; 2048 × 2048 pixels
Field of View	2.2′ × 2.2′
Plate scale	0.065 arcsec / pixel
Pupil Wheel	"Blue" filters; Grism GR700XD; Aperture Mask NRM
Filter Wheel	"Red" filters; Grisms GR150C,R

Observing Modes

Imaging

Point-Source Sensitivity: S/N=10 in 10 ks

Filter	nJy
F090W	14.3
F115W	12.6
F150W	11.1
F200W	9.7
F277W	10.7
F356W	10.0
F444W	15.0
Estimated Cycle 1 Performance	

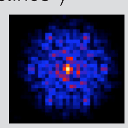
Aperture Masking Interferometry

Non-Redundant Mask (NRM)
+ Medium-Band "Red" Filters.

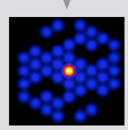
7-hole aperture mask with 21 distinct ("non-redundant") separations ("baselines")

Mask

Michelson:
$\delta\theta = 0.5\ \lambda / D$



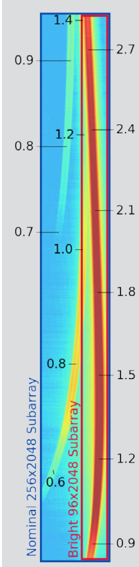
NRM PSF (Interferogram)



Fourier Transform

NIRISS AMI enables exoplanet detection at 3.8, 4.3, and 4.8 µm around stars as bright as M'~4, reaching 10^{-4} contrast at separations of 70–400 milli-arcseconds. It provides lower contrast at 2.8 µm with the F277W filter.

Image reconstruction is also enabled.



Single-Object Slitless Spectroscopy

GR700XD grism + CLEAR

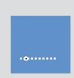
- Two cross-dispersed orders
- Spectral coverage 0.6 – 2.8 µm
- Resolving Power 1st order: 700 @ 1.25 µm
  2nd order: 700 @ 0.63 µm

The orders are broadened in the cross-dispersion direction by 20–25 pixels.
Subarray readout formats optimize SOSS for time-resolved spectroscopy of transiting exoplanets.

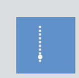
Estimated bright limits (G2 V star):

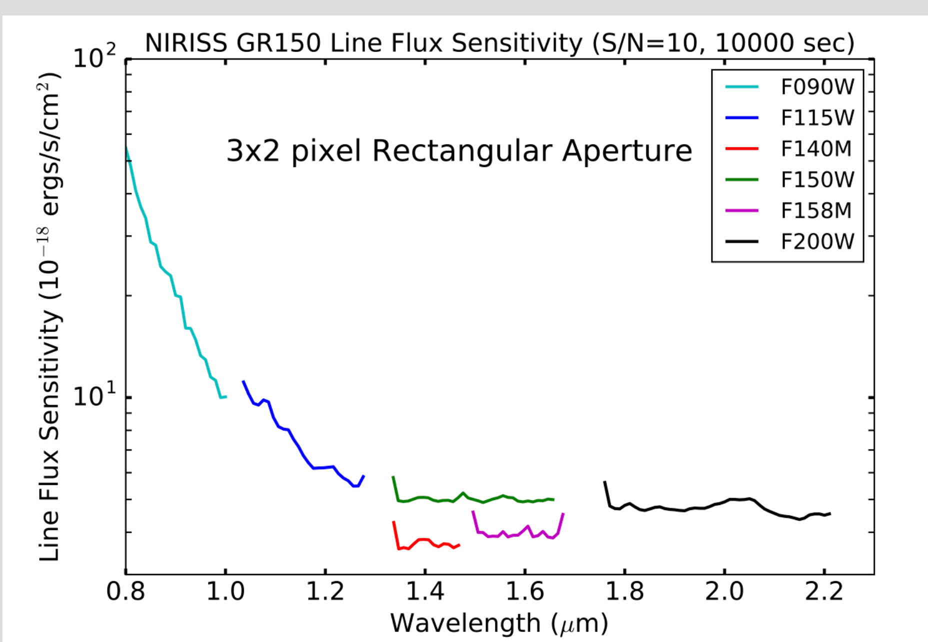
Subarray	Order	NGROUPS	J mag
256 x 2048	1	2	8.05
256 x 2048	2	2	6.75
96 x 2048	1	2	7.05
96 x 2048	1	1	6.35

NGROUPS = 2 corresponds to a correlated double sample

"C" 

Wide-Field Slitless Spectroscopy

 "R"

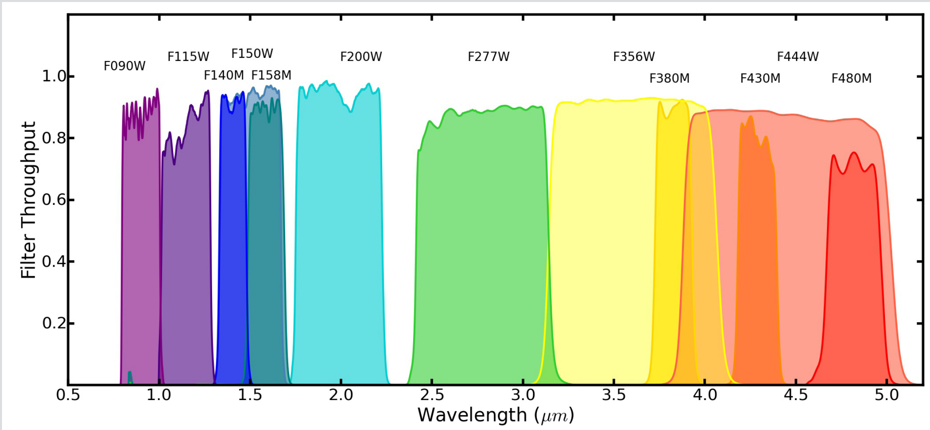


GR150{C, R} grisms + "Blue" Filters

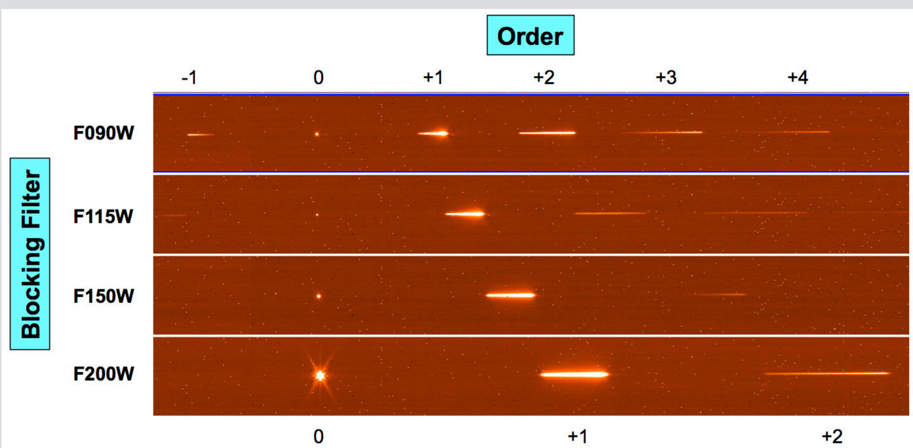
- Resolving Power (1st order): ~150
- Spectral coverage (1st order): 0.8 – 2.2 µm
- Blocking filters isolate wavelengths of interest.
- {C, R} orientations provide orthogonal dispersion directions on the detector to mitigate blending.

Fiducial sensitivity (unresolved line):
5 x 10^{-18} erg/s/cm^2 with S/N = 10 in 10 ks

Filter Transmission Profiles

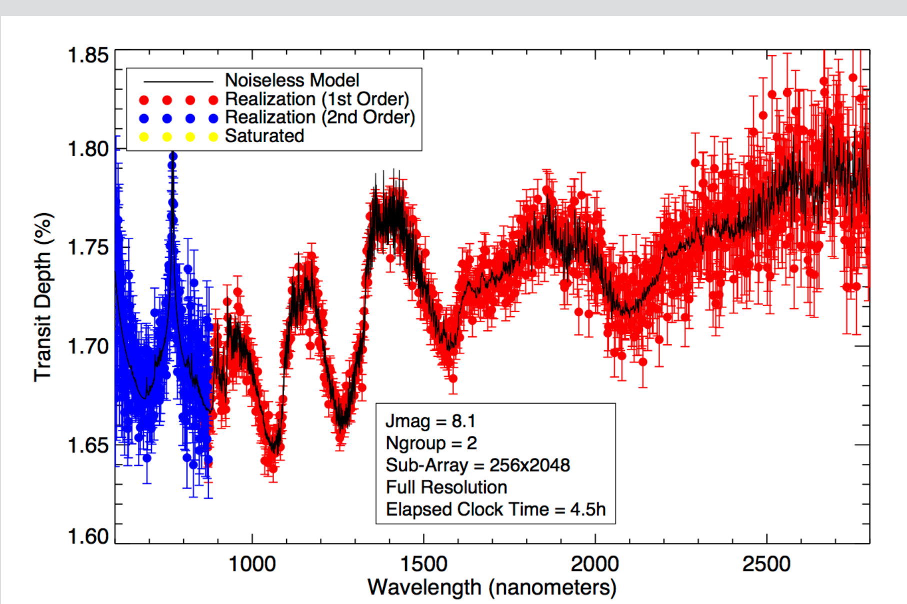


Layout of Spectral Orders (Wide-Field Slitless Spectroscopy)



Single-Object Slitless Spectroscopy with NIRISS

Simulated NIRISS/SOSS spectrum of the atmosphere of WASP 69b
Model courtesy of Björn Benneke



Wide-Field Slitless Spectroscopy with NIRISS: Simulations of MACS J0416.1-2403

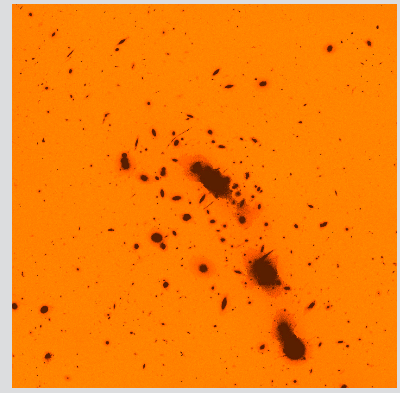
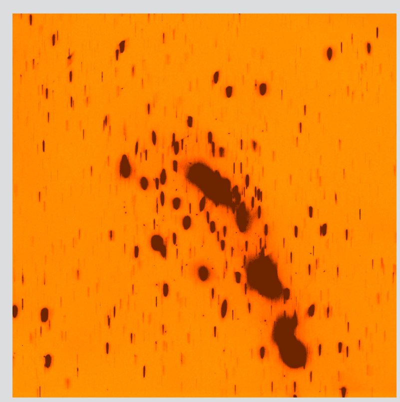


Image: F115W

Spectra: GR150C, F115W



Spectra: GR150R, F115W

http://jwst.stsci.edu/instrumentation/niriss

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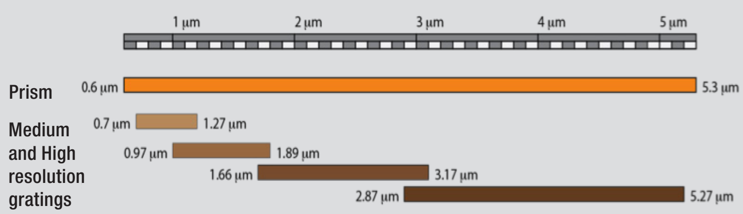
Near Infrared Spectrograph (NIRSpec)

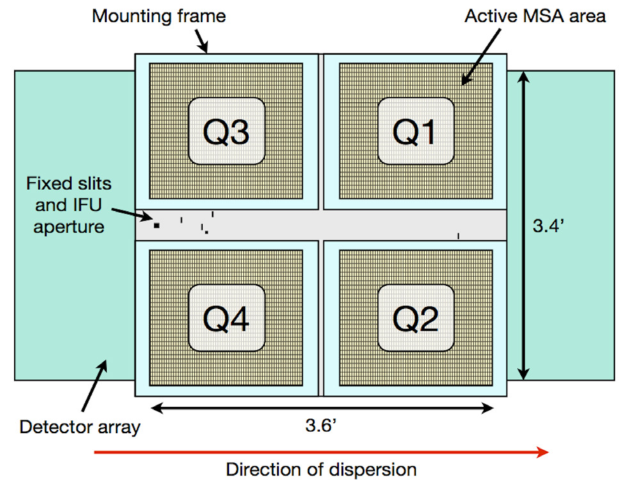
At a glance:

NIRSpec Modes: multi-object, integral-field and slit single object and time series spectroscopy

- Detectors: Two HAWAII 2RG infrared detectors with 0.1 arcsec/pixel
- Three Spectral resolutions: ~100, ~1000, ~2700
- Wavelength coverage: 0.6 to 5.3 micron



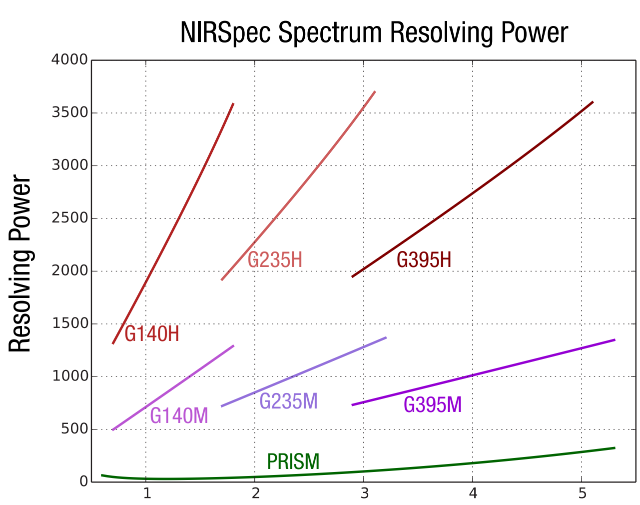
Field of View



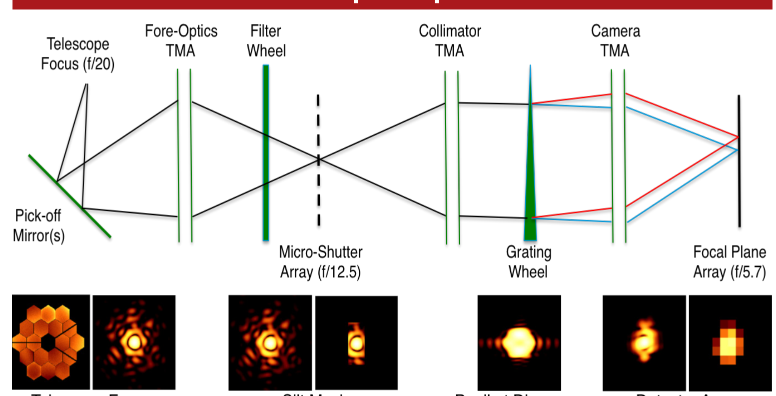
The NIRSpec focal plane and apertures. The Micro-shutter Assembly (MSA) has four quadrants of micro-shutters to create the slits for NIRSpec MOS.

NIRSpec Modes	Targets	Wavelengths	Aperture/FOV	Resolving Powers
Multi-object spectroscopy (MOS)	Rich fields; extended targets	Prism: 0.7–5.3µm 0.7–1.27µm 0.97–1.89µm 1.66-3.17µm 2.87–5.27µm	0.20 × 0.46 arcsec MSA Shutters	~ 100 (Prism only) ~ 1000 ~ 2700
Fixed slits (FSs)	Single sources; bright stars		0.2 × 3.3 arcsec 0.4 × 3.65 arcsec 1.6 × 1.6 arcsec	
Integral Field Unit (IFU)	Sources with ~few arcsec extent		3.0 × 3.0 arcsec	
Bright Object Time Series (BOTS)	Optimized for Exoplanet Transits		1.6 x 1.6 arcsec fixed slit	

Spectral Properties



NIRSpec Optics

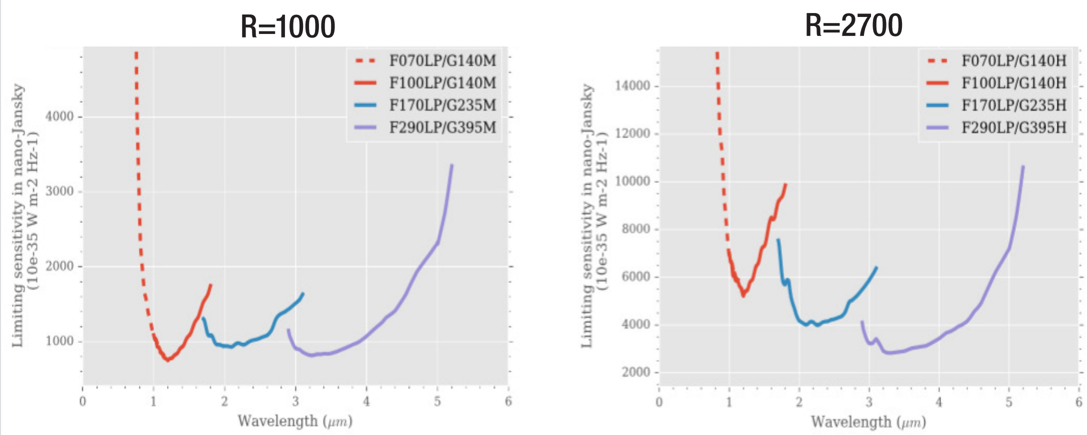


The NIRSpec optical light path, with the major optical elements labeled (TMA = three mirror anastigmat). NIRSpec has filters + dispersers to provide the wavelength coverage. The image of a star is shown in the lower panel, showing a NIRSpec model point spread function (PSF) at different points through the light path.

Highlights of the NIRSpec Observing Modes

- MOS Mode: The NIRSpec multi-object spectroscopy mode uses configurable shutters in the MSA to obtain simultaneous spectra of many science targets within the 3.6′ × 3.4′ (non-contiguous) field of view.
- IFU Mode: The NIRSpec Integral Field Unit provides spatially resolved imaging spectroscopy over a 3″ × 3″ square region. Each spatial element in the resulting IFU data cube is 0.1″ × 0.1″.
- FS Mode: NIRSpec has several Fixed Slits (FSs) for high sensitivity single object spectroscopy. The FS mode can acquire the most accurate single object spectroscopy of both the brightest and faintest targets that NIRSpec will observe.
- BOTS Mode: The NIRSpec Bright Object Time Series mode uses the 1.6″ x 1.6″ fixed slit aperture and is optimized for exoplanet transit observations requiring stable, long duration, high photometric precision timeseries spectroscopy.

NIRSpec Point Source Sensitivities

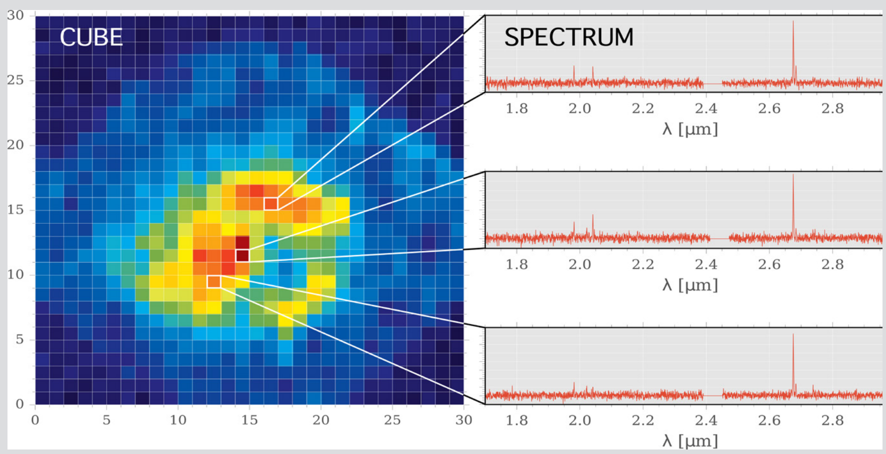


The most recent NIRSpec sensitivity information is availabe through the JWST NIRSpec Exposure Time Calculator (ETC) accessed at:

jwst.etc.stsci.edu

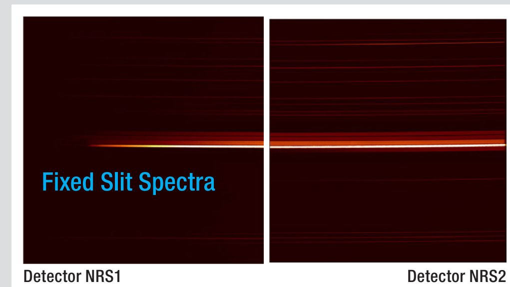
Curves of limiting NIRSpec point source sensitivity defined as S/N of 10 on a source of the presented brightness achieved in ten 966s exposures with a 0.2" MSA slit width.

NIRSpec IFU Spectroscopy Mode



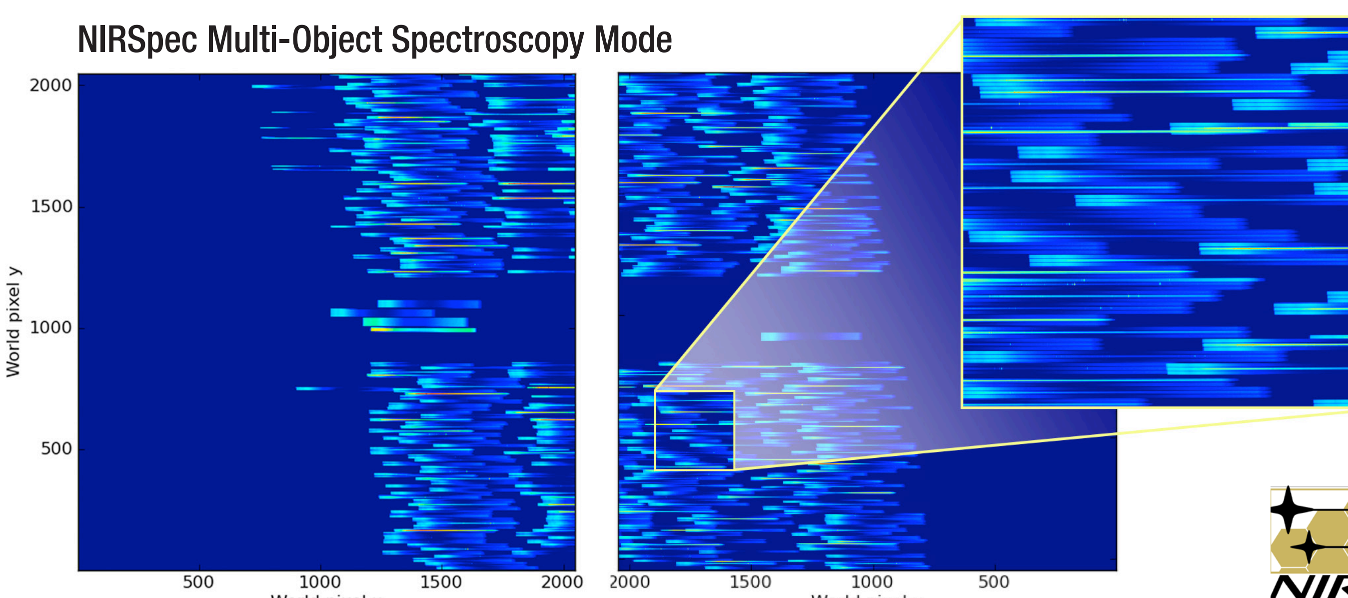
A simulated NIRSpec IFU spectroscopy data cube of an emission line galaxy (C. Pacifici, private communication). Each spatial element in the IFU data is 0.1" by 0.1", and every position has a spectrum at resolving power 2700.

Fixed Slit Mode



The short wavelength (0.97 - 1.89 micron) spectral resolution = 2700 flat field calibration lamp spectrum showing data for the NIRSpec FSs spectroscopy mode.

NIRSpec Multi-Object Spectroscopy Mode



A simulated NIRSpec MOS observation of ~300 objects observed in a very dense field, using the R~100 (PRISM) with NIRSpec and the configurable Micro-Shutters. The MOS mode spectra are dispersed across the two NIRSpec detectors, shown in blue. A portion of the field is enlarged on the right to reveal individual spectra with emission lines.

NIRSPEC

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EADS ASTRIUM

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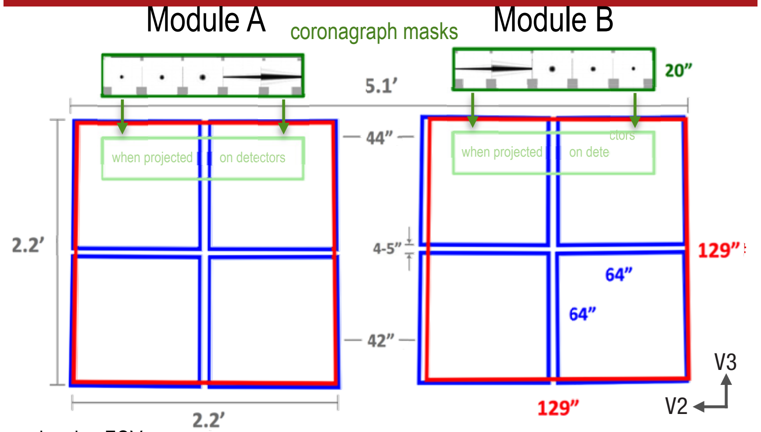
The Near Infrared Camera (NIRCam)

Field of View



overlapping FOVs imaged simultaneously using a dichroic

short wavelength detectors
long wavelength detectors

Teledyne HgCdTe H2RG detectors
2048 × 2048 pixels including reference rows and columns insensitive to light

At a Glance:

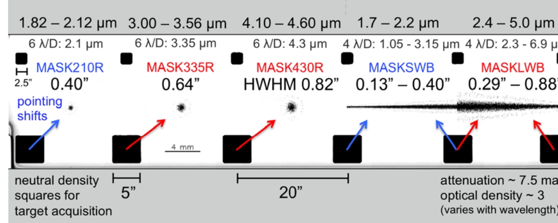
	Short Wavelength Channel	Long Wavelength Channel
Wavelength Range	0.6 – 2.3 μm	2.4 – 5.0 μm
Nyquist Wavelength *	2.0 μm	4.0 μm
Fields of View **	2 × 2.2' × 2.2' (with 4-5" gaps)	2 × 2.2' × 2.2'
Imaging Pixels	8 × 2040 × 2040 pixels	2 × 2040 × 2040 pixels
Pixel Scale	0.032" / pixel	0.065" / pixel
Grism Slitless Spectroscopy	(wavefront sensing across mirror edges)	R = 1200 – 1550
Coronagraphy occulters + Lyot stops	round: 2.1 μm bar: 1.7 – 2.2 μm	round: 3.35, 4.3 μm bar: 2.4 – 5.0 μm

* PSF FWHM ~ 2 pixels; undersampled at lower wavelengths.
** Two modules image adjacent fields in both channels simultaneously.

Coronagraphy

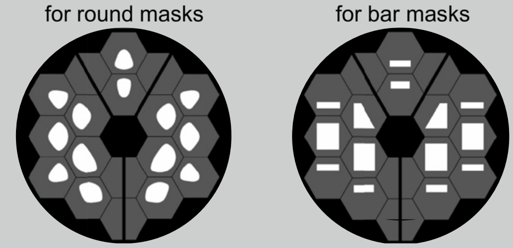
Occulting Masks

arget Acquisition squares



Lyot Stops

18.9% throughput



yot stops are affixed to optical wedges in the pupil plane that project the occulting masks onto the detectors

Imaging

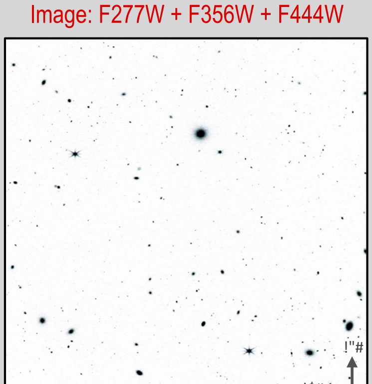
Filter	Sensitivity Point source S/N=10 in 10 ks	Saturation G2V star 80% full well 2 reads of 64x64 subarray
F090W	13.1 nJy	K ~ 9.5 Vega
F115W	11.8 nJy	K ~ 9.6 Vega
F150W	9.6 nJy	K ~ 9.8 Vega
F200W	7.9 nJy	K ~ 9.3 Vega
F277W	11.5 nJy	K ~ 9.6 Vega
F356W	11.0 nJy	K ~ 8.9 Vega
F410M	20.6 nJy	K ~ 7.4 Vega
F444W	17.6 nJy	K ~ 8.0 Vega

Preliminary ETC sensitivity estimates assume:
low zodiacal background (UDF in November)
0.08" radius aperture for short wavelength filters
0.16" radius aperture for long wavelength filters
large annuli for background subtraction

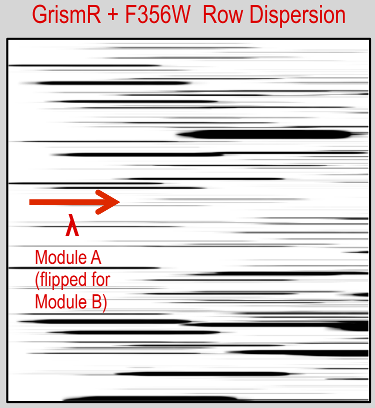
Observing Mode	Subarray Pixels	Frame Time	Detector Outputs
Imaging	2040 × 2040	10.737 s	4
	640 × 640	4.179 s	1
	320 × 320	1.066 s	1
	160 × 160	0.277 s	1
Time Series Imaging	2040 × 2040	10.737 s	4
	400 × 400	1.652 s	1
	160 × 160	0.277 s	1
	64 × 64	0.049 s	1
Grism Time Series	2040 × 2040	42.209 s 10.737 s	1 4
	2040 × 256	5.294 s 1.347 s	1 4
	2040 × 128	2.657 s 0.676 s	1 4
	2040 × 64	1.339 s 0.341 s	1 4

Imaging + Grism Slitless Spectroscopy

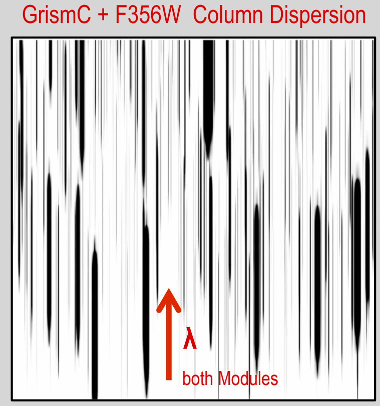
Image: F277W + F356W + F444W



GrismR + F356W Row Dispersion



GrismC + F356W Column Dispersion



Grism combined with a filter in long wavelength channel (2.4 – 5.0 μm)

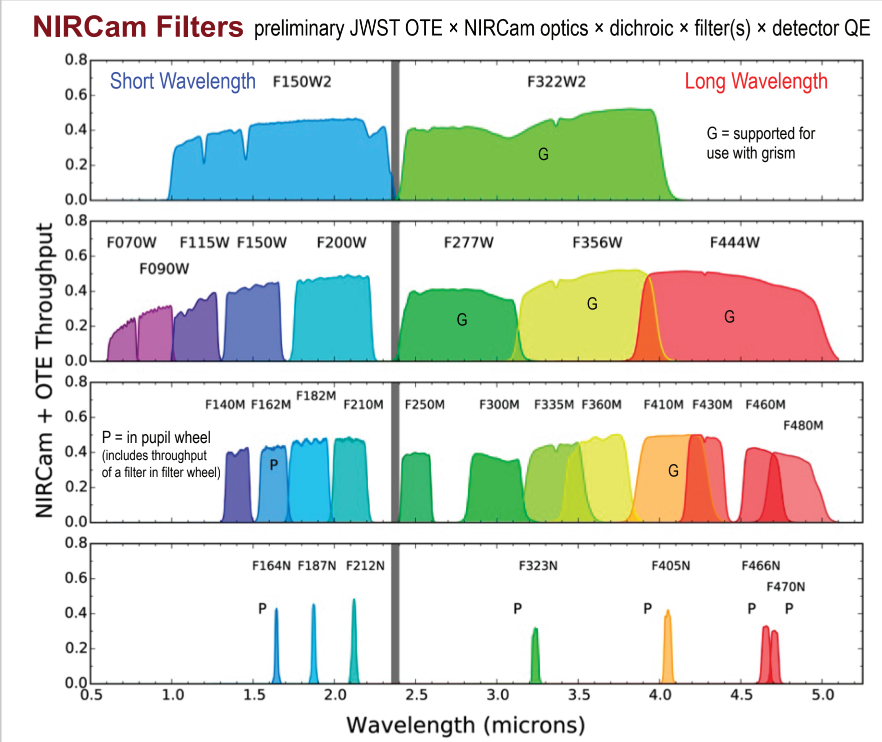
Resolving Power:
R ~ 1500 at 3.7 μm (blaze)

Fiducial sensitivity (unresolved line):
5×10^{-18} erg/s/cm^2
(S/N = 10 at 4 μm in 10 ks)

Saturation limit:
K ~ 4 (Vega mag) G2V star
(2048 x 64 subarray)

NIRCam Filters

preliminary JWST OTE × NIRCam optics × dichroic × filter(s) × detector QE



Short Wavelength		Long Wavelength	
Pupil Wheel	Filter Wheel	Pupil Wheel	Filter Wheel
CLEAR	F070W	CLEAR	F277W
Dark	F090W	Dark	F356W
PAPPA	F115W	IPR Wedge	F444W
WL +8	F150W	PAPPA	F300M
DHS 0°	F200W	F405N Br-α	F480M
WL -8	F212N H_2	F323N H_2	F410M
Corona round	WL+4 +F212N	Corona round	F360M
F162M CO	F187N Pα	Grism R V2	F430M
DHS 60°	F210M	F466N CO	F460M
Corona bar	F182M	Grism C V3	F250M
F164N [Fe II]	F140M	F470N H_2	F335M
IPR Wedge	F150W2	Corona bar	F322W2

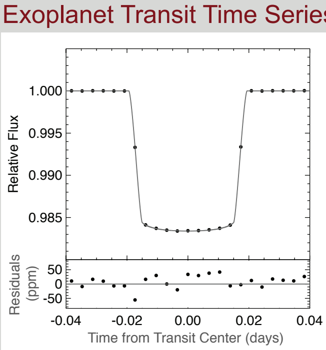
W, M, N filters have R ~ 4, 10, 100, respectively

WL: Weak Lens (defocus for alignment or bright star imaging)

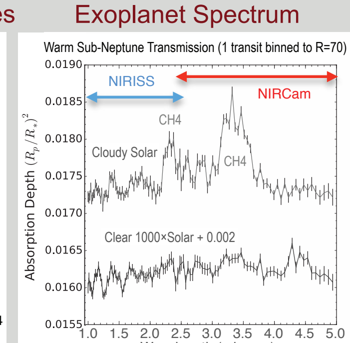
PAPPA: Pupil Alignment Pinhole Projector Assembly
DHS: Dispersed Hartman Sensing (subaperture grisms)
IPR (Internal Phase Retrieval) Wedge to measure NIRCam wavefront errors using LEDs mounted on coronagraphs

Grism Slitless Spectroscopy: Simulated Data

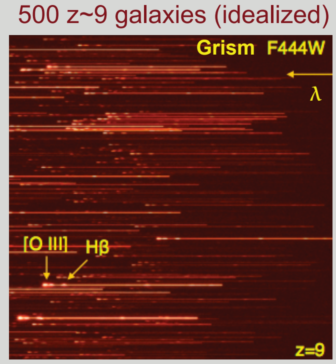
Exoplanet Transit Time Series

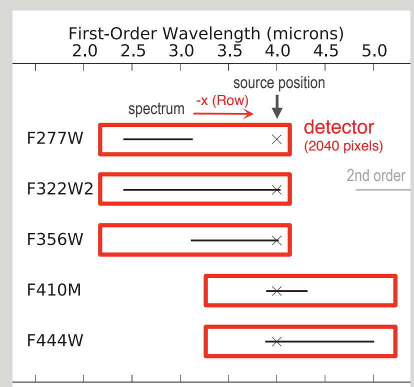


Exoplanet Spectrum

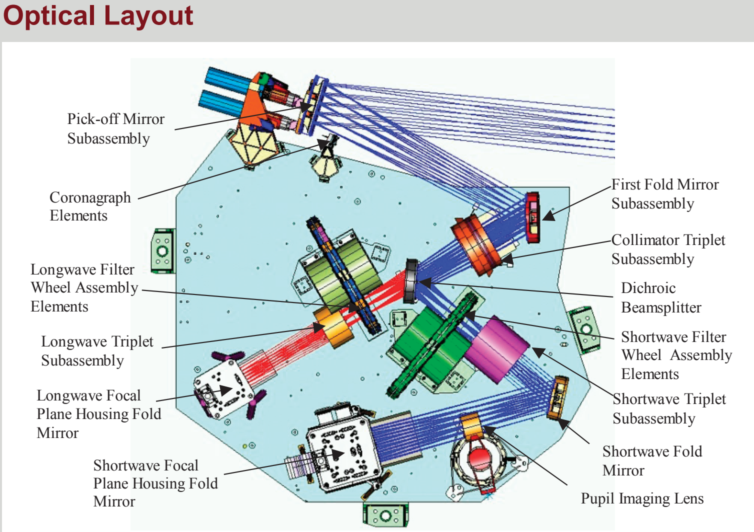


500 z~9 galaxies (idealized)





Optical Layout

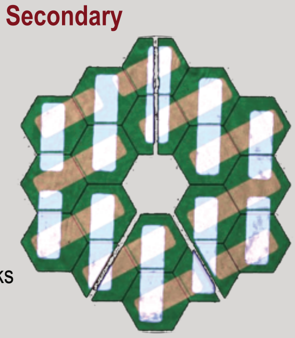


Telescope Wavefront Sensing

Primary Mirror Segments and Secondary

Coarse phasing:
Dispersed Hartman Sensing
- align mirror segments in pairwise fashion

Fine phasing:
weak lens defocused images
- sensing every two days
- adjustments planned every two weeks



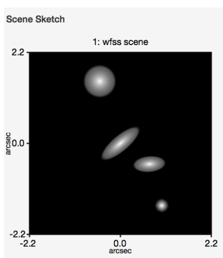
https://jwst.stsci.edu/instrumentation/nircam
https://jwst-docs.stsci.edu

Revised Dec. 2016

JWST Exposure Time Calculator

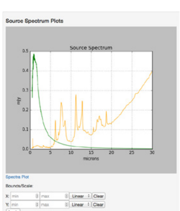
Pandeia is a simulation-hybrid, pixel-based ETC paired with a modern, graphical user interface, supporting all JWST science modes: imaging, spectroscopy (slitted, slitless, and IFU), coronagraphy, and aperture masking interferometry. The advanced user interface provides enhanced capabilities supporting multiple workflows. Users can create workbooks to save related sets of calculations, can create complex astronomical scenes with multiple sources, can compare the results of multiple calculations, and can copy and modify individual calculations or whole workbooks.

Under the Hood: the ETC Engine



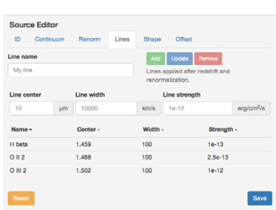
- A “simulation-hybrid” engine performs calculations on two-dimensional astronomical scenes created by the user
- Uses a pixel-based 3D approach: models both the spatial and wavelength dimensions using realistic PSFs for each instrument mode
- Handles saturation, correlated read noise, and inter-pixel capacitance

Workbooks: Organize and save your ETC calculations



- Create multiple, persistent workbooks, which can be accessed at any time via STScI’s Single-Sign On authentication— or work anonymously
- Start from scratch, copy your own existing workbooks, or retrieve copies of sample workbooks designed for tutorial use

Build Your Own Sources and Scenes Library



Sources and scenes are saved within a workbook and can be simultaneously used in multiple calculations and across instruments and modes. Every scene and calculation using a source will automatically be updated when that source is changed.

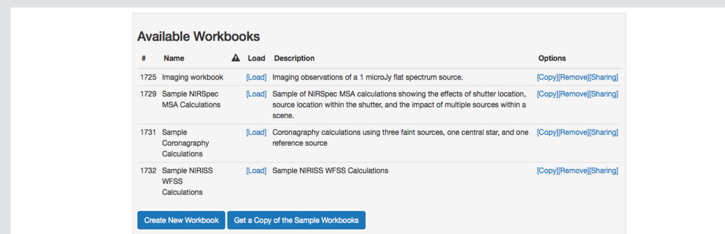
Sources

- Choose a spectrum from provided libraries (analytic, stellar, galactic) or upload your own
- Redshift the spectrum and/or add emission lines
- Renormalize at a specified wavelength or bandpass
- For extended sources, specify the shape and flux distribution (flat, Gaussian, or Sersic)
- View the input spectrum of selected sources

Scenes

- Place, move, and even overlap multiple sources within a small (typically a few arcseconds) scene
- Use the same source in multiple scenes
- View an interactive sketch of the scene: a source can be selected for editing by clicking in the sketch

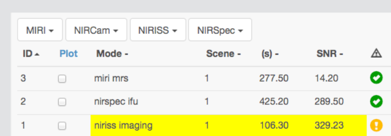
The background model includes celestial sources (zodiacal light, interstellar medium, and cosmic infrared background) for a given date and coordinates, as well as telescope thermal and scattered light. Alternatively, users can choose a pre-calculated low, medium, or high background to run non-dated calculations. Additional sources of astrophysical backgrounds can be modeled by including a large, spatially flat source covering the scene.



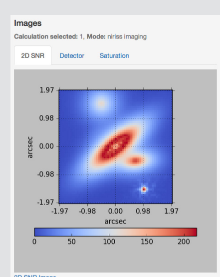
Build a Set of Calculations

Initialize a calculation by choosing the instrument and mode. Then specify the parameters for each calculation:

- Choose a scene from your scene library
- Choose a dated or dateless background estimate
- Specify the instrument and detector setup (e.g., filters, gratings, exposure specifications)
- Specify the extraction strategies for the source and background

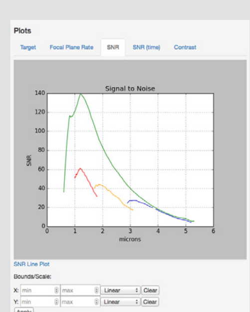


Copy and Modify Calculations



- Explore variations of observation setup or extraction strategies
- Select different sources or locations in the scene to calculate the SNR
- Use batch expansions to automate the process of copying calculations and varying the exposure specifications (groups, integrations, readout patterns) or filters (for imaging modes)

Analyze the Results



- View 2D images of per-pixel SNR, count rate at the detector, and saturation
- Plot and compare the SNR vs. wavelength, SNR vs. time, and contrast vs. separation (coronagraphy) for multiple selected calculations
- Download all 2D and 1D products, and the 3D data cube for IFU calculations
- A report tab presents scalar results, warnings, errors, and the download link

jwst.etc.stsci.edu

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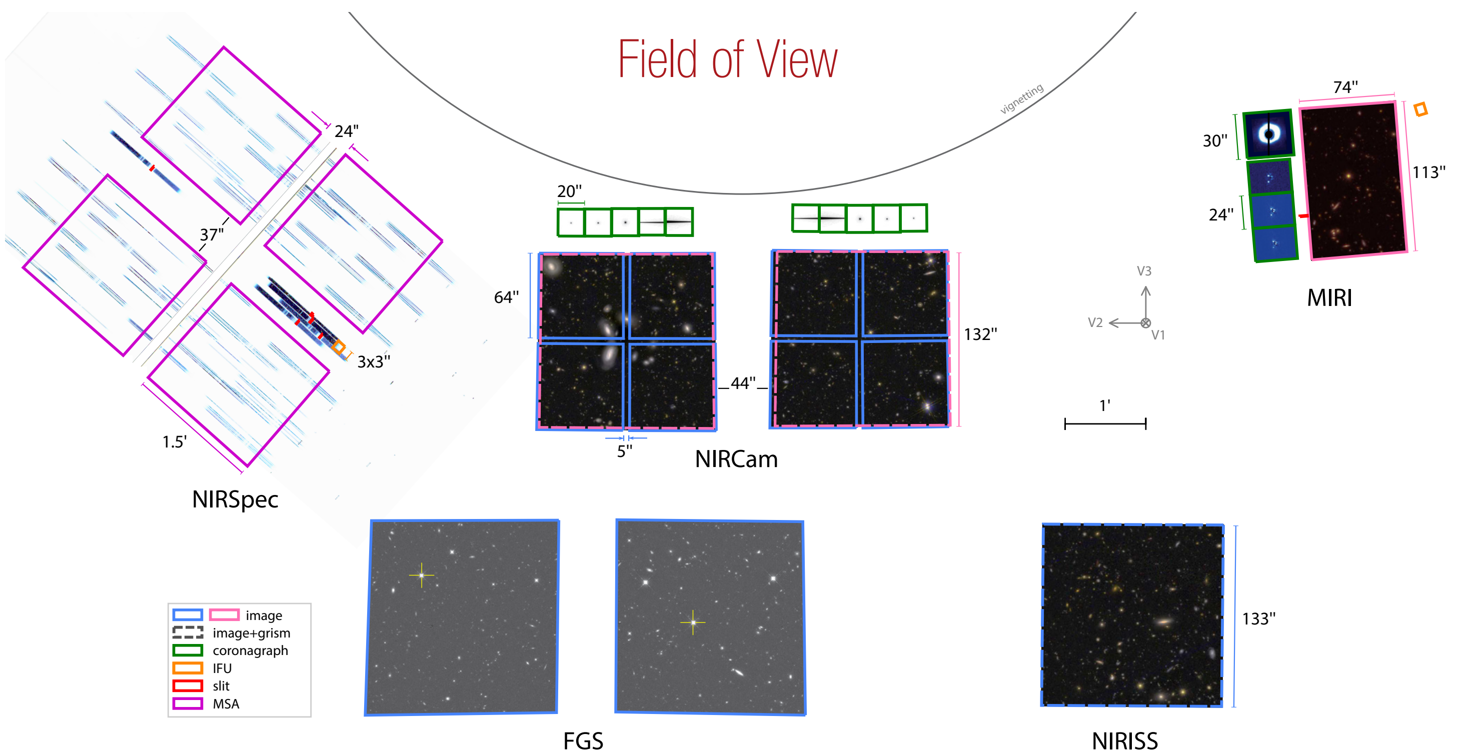
Major Milestones

May 2019	JWST Cycle 1 start
Oct 2018	JWST Launch!
Mar 2 2018	Deadline for GO Cycle 1
Nov 30 2017	General Observer (GO) Cycle 1 Call for Proposals
Aug 18 2017	Deadline for DD-ERS proposals
May 19 2017	DD-ERS Call for Proposals
Mar 3 2017	Deadline for DD-ERS Notices of Intent
Jan 6 2017	Early Release Science (DD-ERS) Call for Notices of Intent

Field of View



More information at:

- JWST science website — jwst.stsci.edu
- JWST public website — webbtelescope.org
- JWST documentation — jwst-docs.stsci.edu
- JWST Exposure Time Calculator — jwst.etc.stsci.edu
- JWST milestone status and recent accomplishments — jwst.nasa.gov/recentaccomplish.html
- For updates and announcements on JWST science, follow @JWSTObserver on twitter and facebook

Revised Dec. 2016

Images courtesy of NASA