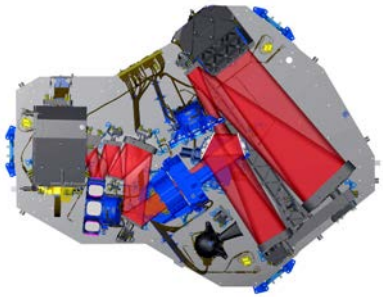
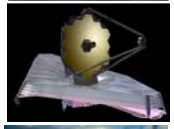
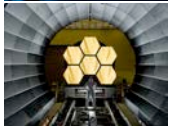
JWST/NIRSpec

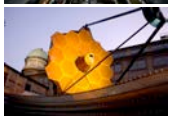
P. Ferruit

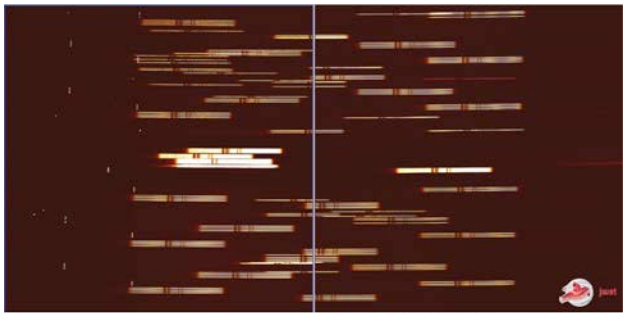
(ESA JWST project scientist)



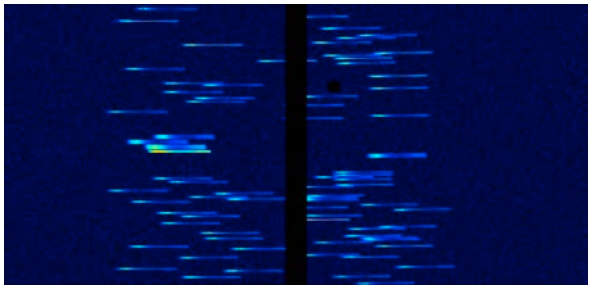








JWST/NIRSpec - FM2 cyrogenic test campaign 01/2013



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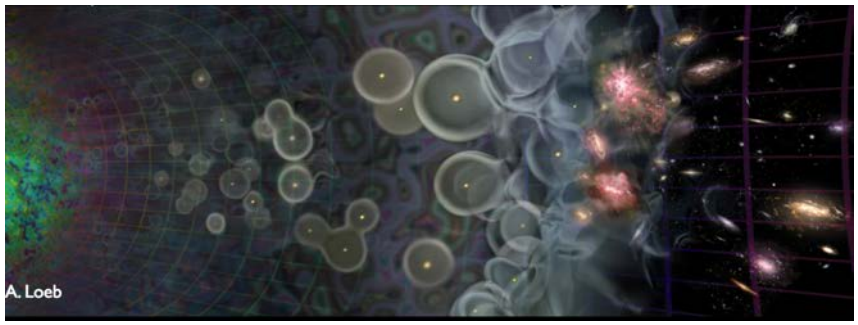
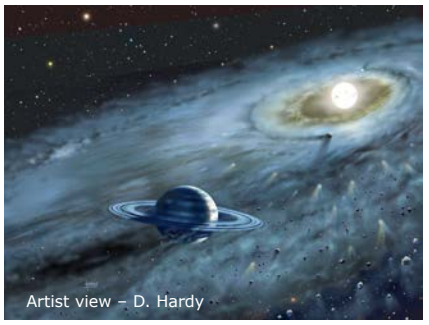
Acknowledgements

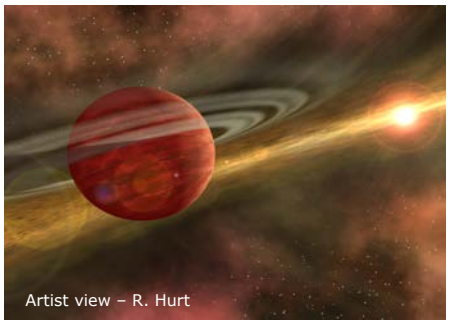
- **Thanks for giving me the opportunity to present the NIRSpec instrument.**

- **All along this presentation you will see the results of work conducted by a large number of teams in Europe and USA.**

JWST/NIRSpec – The origin…

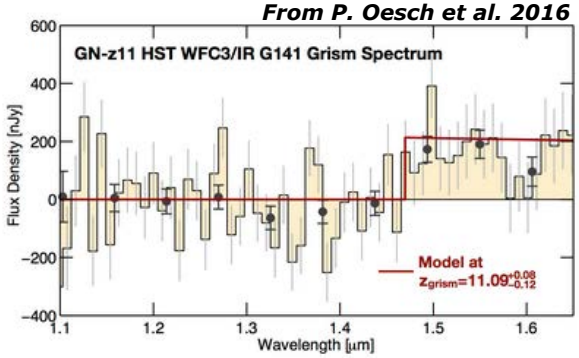




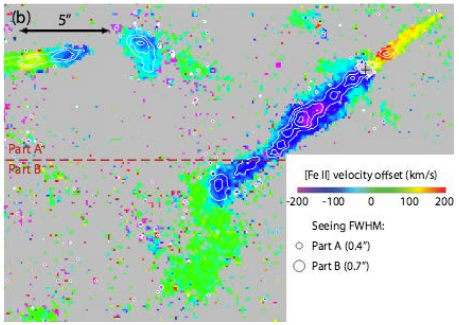


JWST will be one of the major space-based observatories of the next decade and its science goals encompass a very broad set of topics.

From P. Oesch et al. 2016

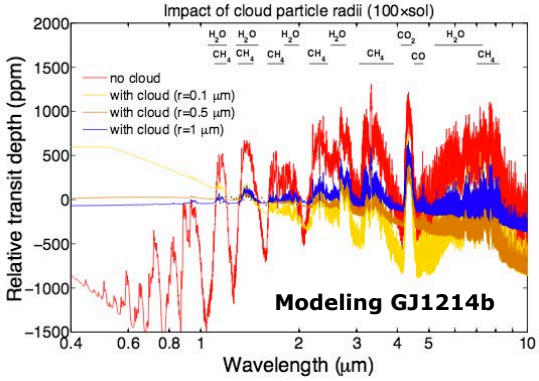


From Ellerbroek et al. 201



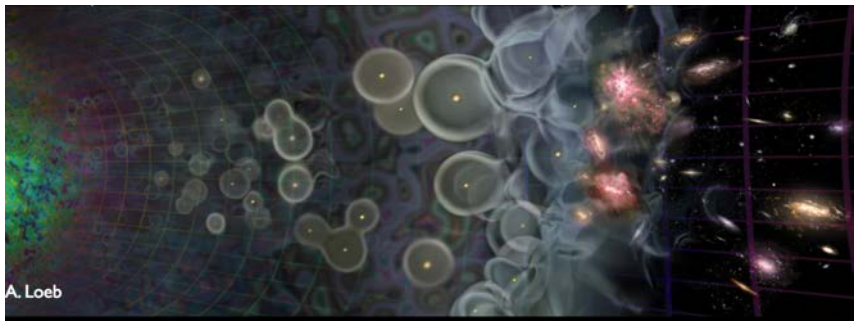
3D spectroscopy – YSO disk-jet system

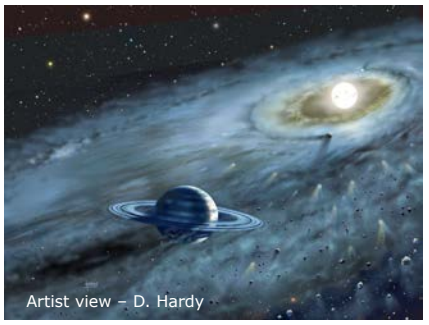
Charnay et al. **arXiv:1510.01706**

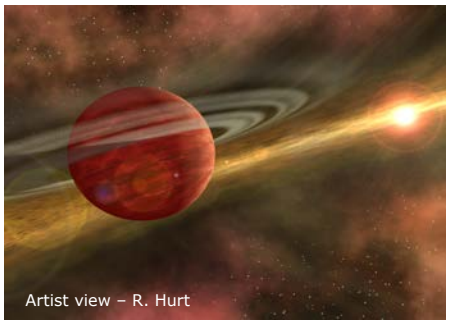


Spectroscopy will be a key tool to achieve JWST science goals.

JWST/NIRSpec – The origin…



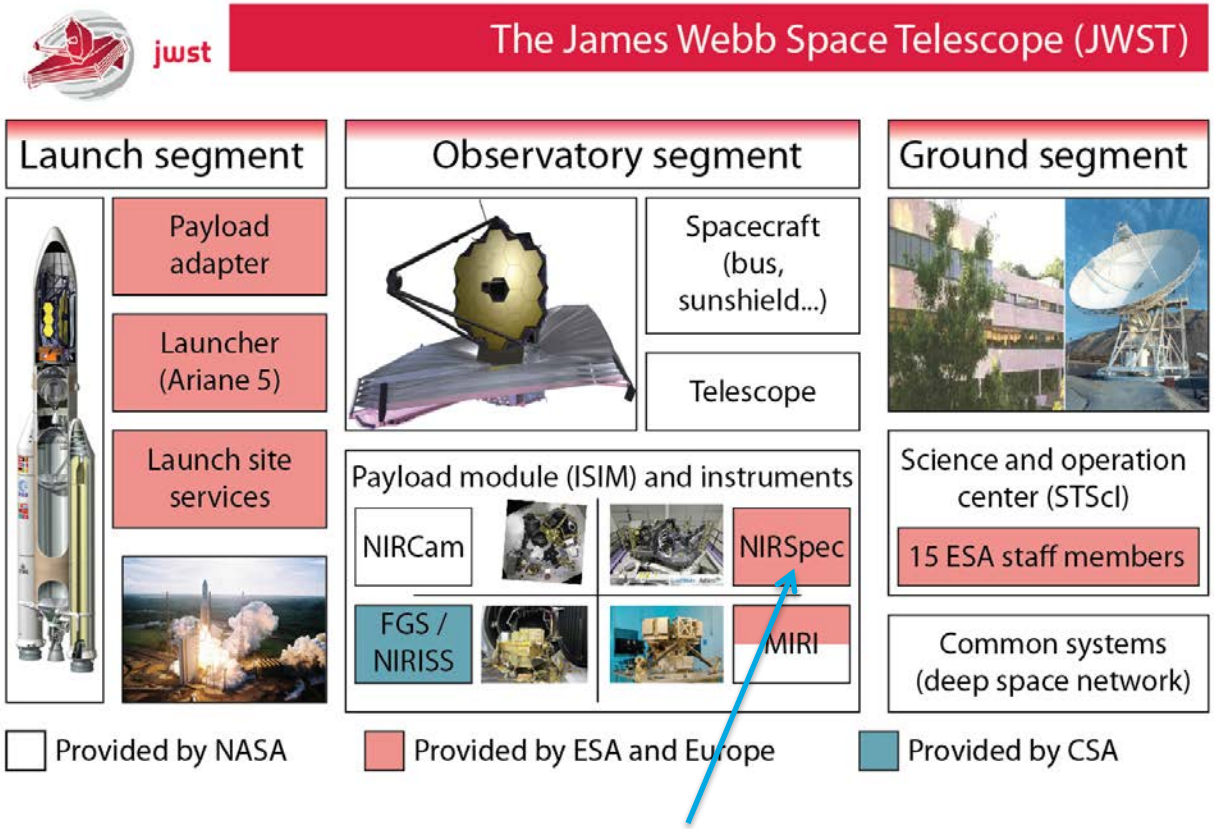




To achieve JWST science goals a near-infrared spectrograph was needed in the instrument suite. It should be capable of:

- **Deep multi-object spectroscopy at low, medium (around 1000) resolution over a "wide" field of view.**
- **Spatially-resolved, single-object spectroscopy at "high" (a few thousands) spectral resolution over a "small" (a few arc seconds) field of view.**
- **High-contrast slit spectroscopy at various spectral resolutions, including an aperture for extra-solar planet transit observations.**

JWST/NIRSpec – The origin...



NIRSpec is part of the European contribution to the JWST mission.

ASWG recommendation in January 2000.

Becomes part of ESA contribution in the following year.

NIRSpec = Near-infrared Spectrograph

Provided by the European Space Agency. Built by an industrial consortium led by Airbus Defence and Space.

JWST/NIRSpec – The instrument

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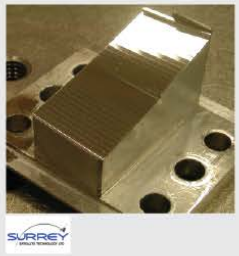
JWST/NIRSpec				
	MOS		**Multi-object spectroscopy with 0.2″-wide mini-slits.**	- 9 square arcmin. field of view - Low spectral resolution (30 to 300), prism-based mode covering the 0.6-5.0 micron range in one exposure. - Medium spectral resolution (500 to 1300), grating-based mode covering the 0.7-5.0 range
	IFU		**IFU spectroscopy with a 0.1″ sampling.** (IFU made of 30 slices for a total of 900 "spaxels")	- 3″x3″ field of view - Low spectral resolution (30 to 300), prism-based mode covering the 0.6-5.0 micron range in one exposure. - Medium (500 to 1300) and high (1400-3600) spectral resolution modes, covering the 0.7-5.0 range in 4 exposures. - IFU and MOS cannot be used at the same time.
	SLIT		**High-contrast slit spectroscopy.** (including with a 1.6″x1.6″ square aperture for extra-solar planet transit observation)	- 5 slits available All spectral resolution modes available. - SLIT can be used simultaneously to IFU or MOS.

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JWST NIRSpec – The instrument

- **Yes this is a NIRSpec presentation but do not forget that in JWST, spectroscopy comes in many flavors.**
  - Always take a careful look and pick the instrument and the mode most suited to your science objectives.

Instrument	Type	Wavelength (microns)	Spectral resolution	Field of view
NIRISS	slitless	1.0-2.5	~150	2.2′ x 2.2′
NIRCam	slitless	2.4-5.0	~2000	2.2′ x 2.2′
NIRSpec	MOS	0.6-5.3	100/1000/[2700]	9 square arcmin.
NIRSpec	IFU	0.6-5.3	100/1000/2700	3″ x 3″
MIRI	IFU	5.0-28.8	2000-3500	>3″ x >3.9″
NIRSpec	SLIT	0.6-5.3	100/1000/2700	Single object
MIRI	SLIT	5.0-10.0	60-140	Single object
NIRSpec	Aperture	0.6-5.3	100/1000/2700	Single object
NIRISS	Aperture	0.6-2.5	700	Single object

Note: MIRI also has slitless spectroscopy capabilities over its imager field of view and over the 5.0-10.0 micron range.

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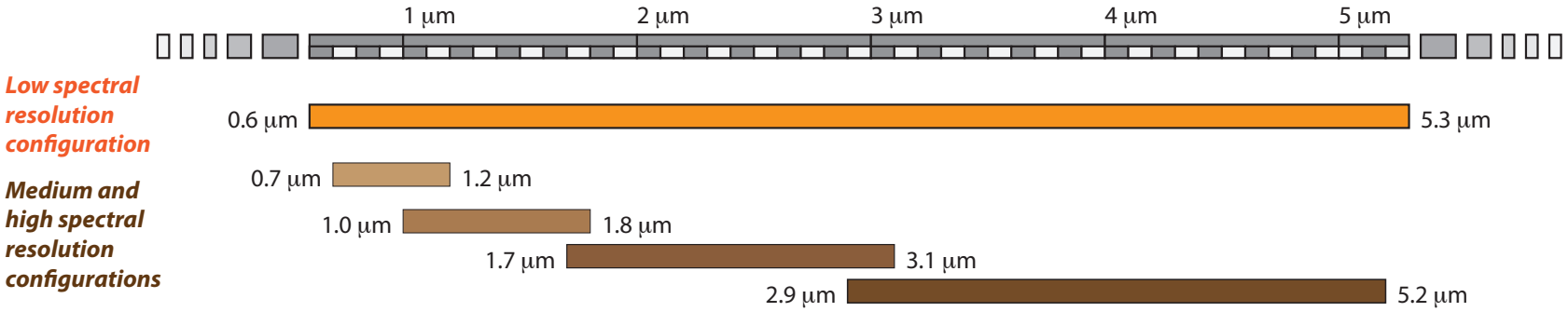
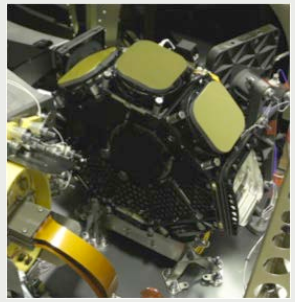
JWST/NIRSpec - spectral configurations



- **At low spectral resolution, full coverage of the 0.6-5.3 micron range in one shot.**
  - R ~30-300 (low).
- **At medium and high spectral resolution, several exposures are necessary to cover the full wavelength range of NIRSpec.**
  - R ~1000 and ~2700.

Configurations that can be obtained thanks to a combination of filters and dispersers installed on two wheels (FWA and GWA)



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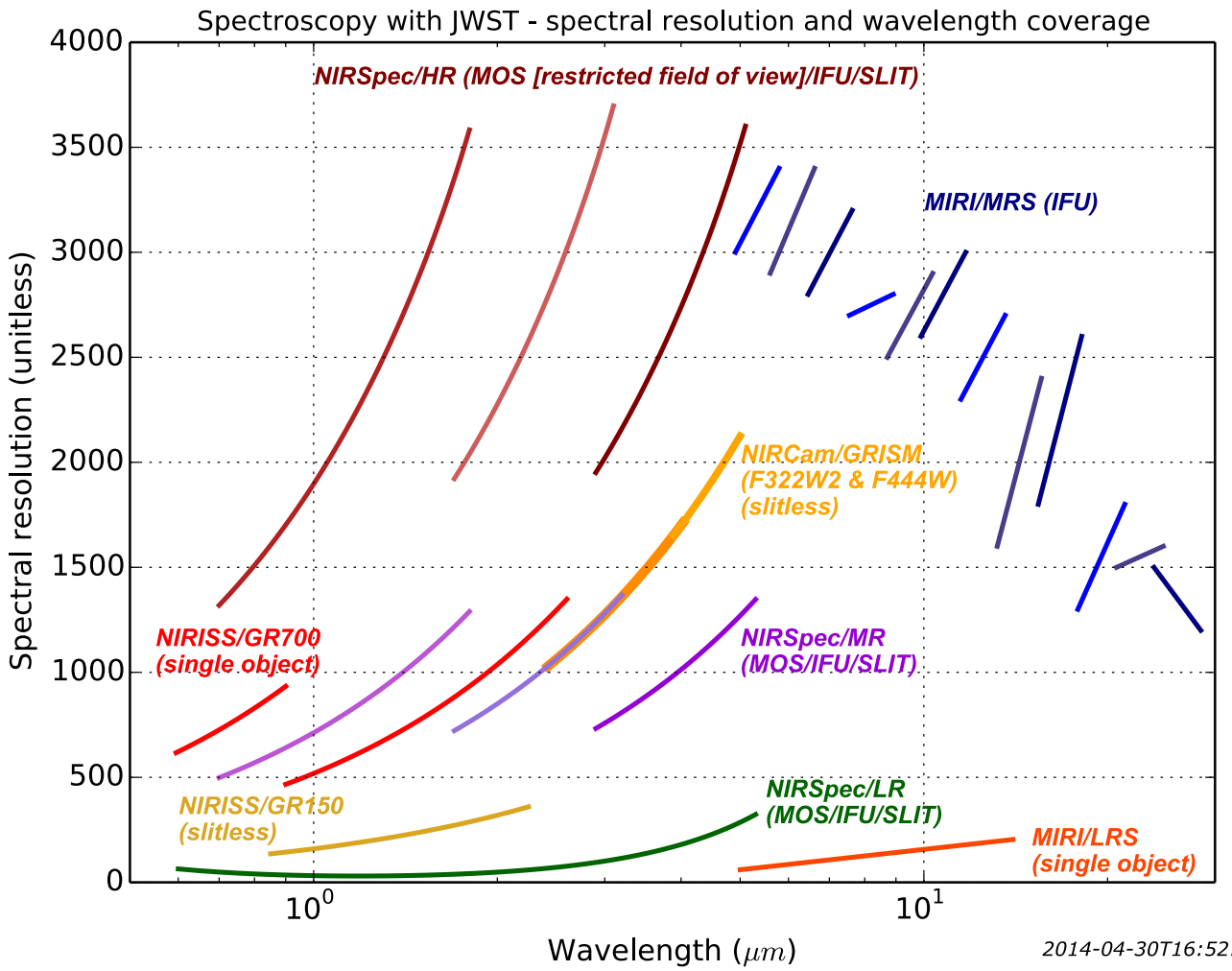
JWST/NIRSpec – The instrument

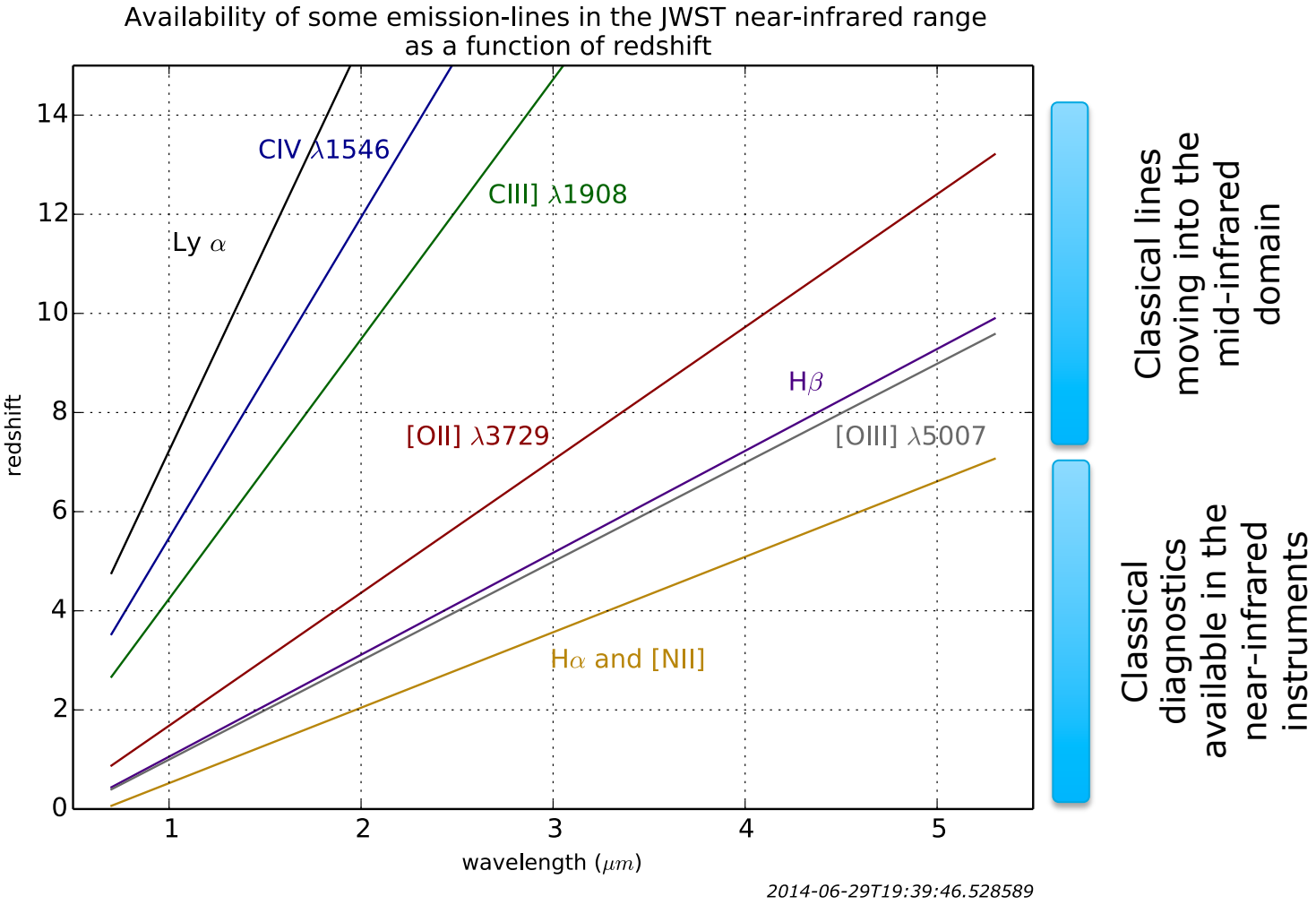
- **Again JWST offers a large variety of configurations.**

And NIRSpec proposes its share…



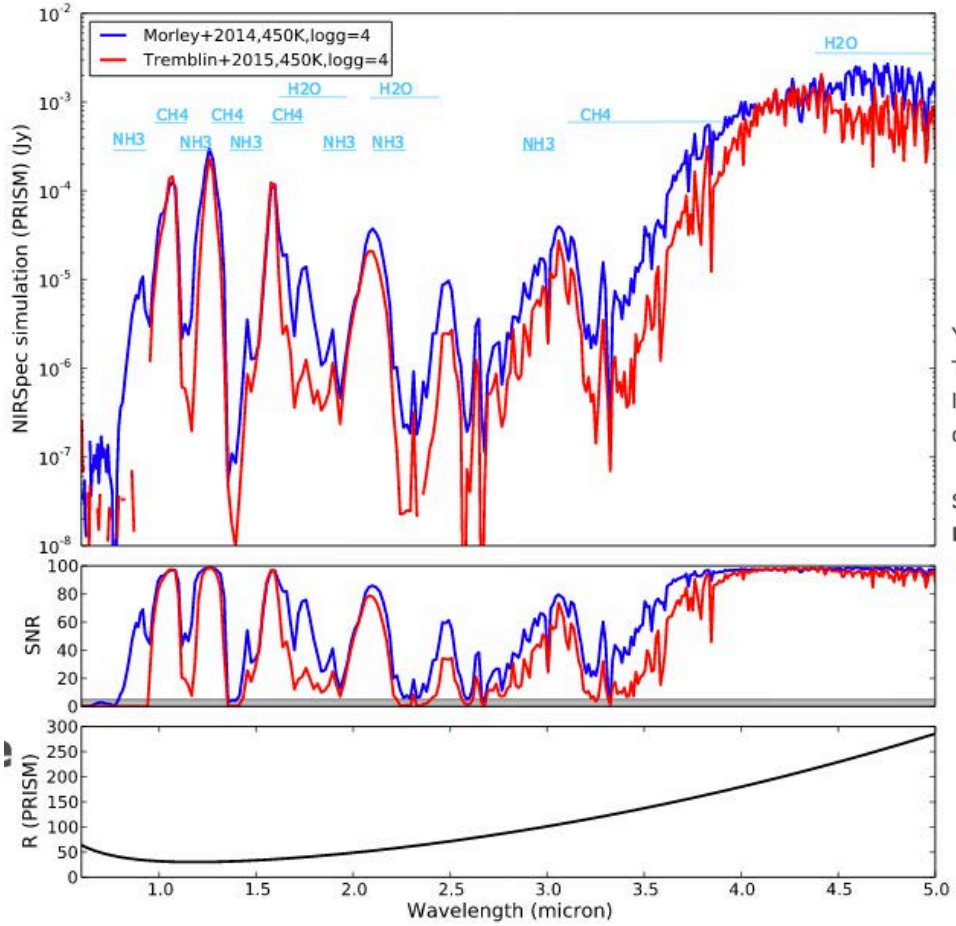
JWST/NIRSpec – The instrument

- **Nice emission-line diagnostics for galaxy assembly fans…**



JWST/NIRSpec – The instrument

- **Or nice molecular bands / signatures for Y-dwarfs aficionados…**



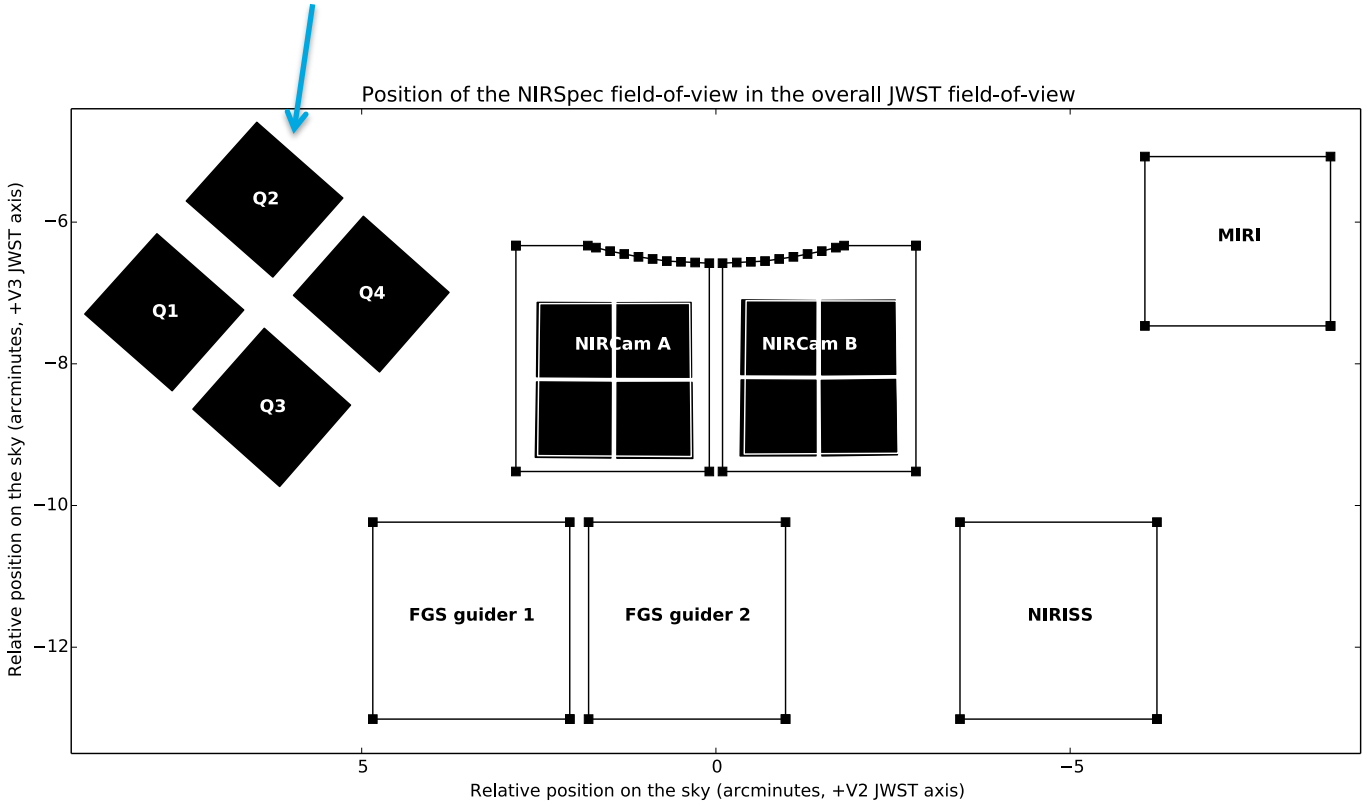
Y dwarf:
Teff: 450K
logg: 4
distance: 5 pc

Simulations:
NIRSpec, 15 minutes on-source

From C. Alves de Oliveira @JWST 2015

JWST/NIRSpec Multi-object spectroscopy (MOS)

NIRSpec MOS field of view of 9 square arc minutes divided in 4 distinct quadrants, each with its associated array of micro-shutters for target selection.



p_figure_FoVSKY.py - version 3.0.1 - 2015-12-31T16:56:40.938346

Model: NIRS_FM2_05_fitted_cal2a

JWST/NIRSpec
Multi-object spectroscopy (MOS)

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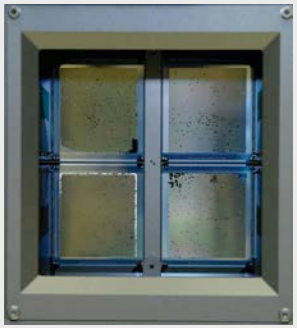
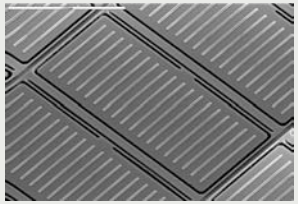
- **The challenge of multi-object spectroscopy**
  - Letting the light from selected objects go through while blocking the light from all the other objects.
  - A configurable mask was needed.

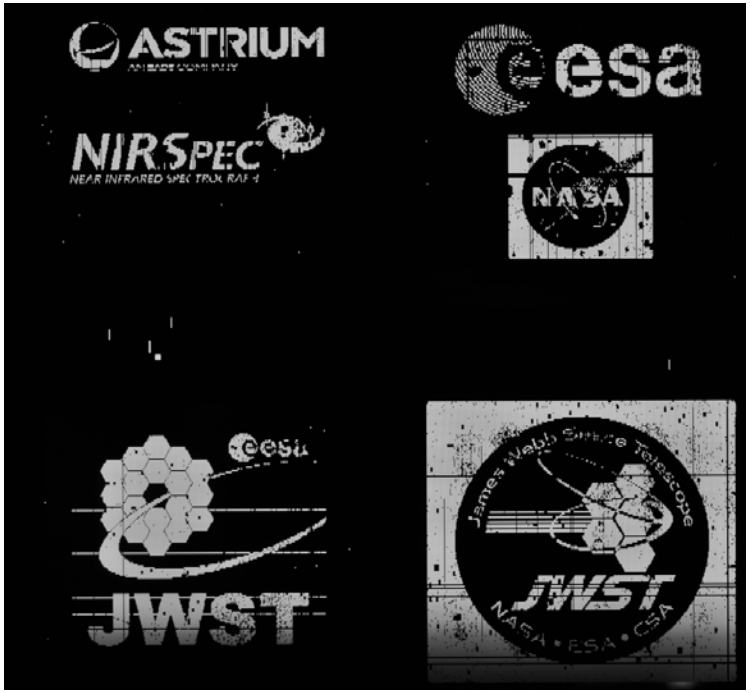
Using 4 arrays of 365x171 micro-shutters each, provided by NASA GSFC.

This gives us a total of almost **250 000** small apertures that can be individually opened/ closed



MEMS device – 105x204 micron shutters





We typically need > 85-90 % of the shutters operable.

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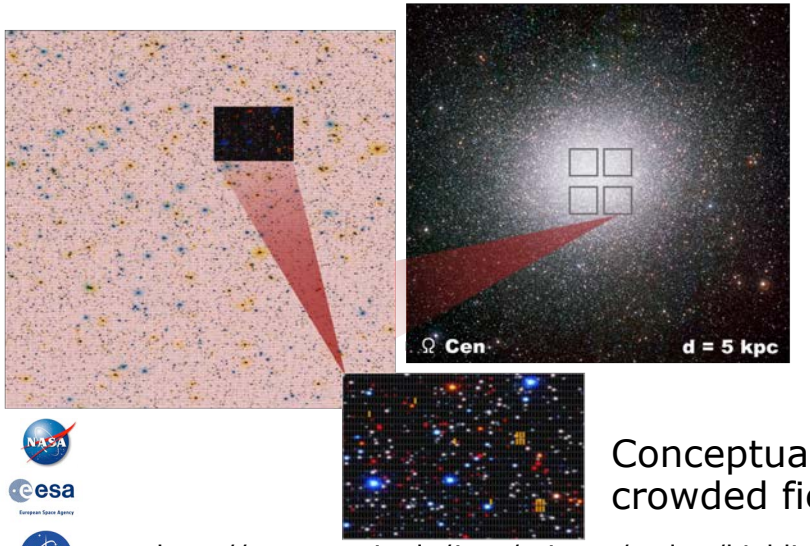
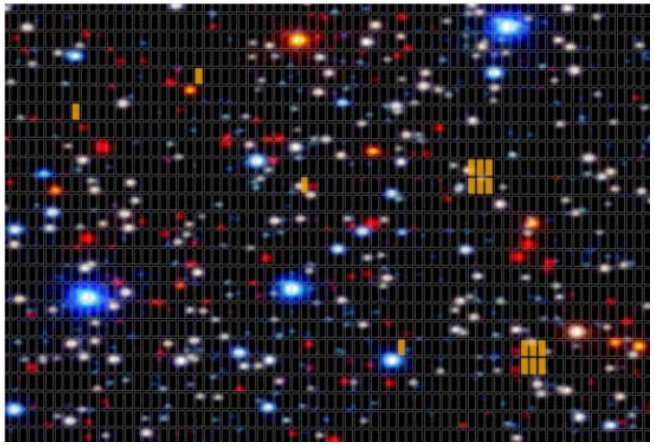
JWST/NIRSpec
Multi-object spectroscopy (MOS)

- **An unusual MOS: a regular grid of apertures.**
  - → Finding the best combination of pointing parameters (RA, DEC, PA) AND the best list of targets.
  - → A dedicated tool is being developed for the preparation of the observations (called MPT, Karakla et al. SPIE 2014).
  - → The way the spectra overlap on the detectors is complex.
    - → Working to incorporate the latest knowledge of the instrument in the MOS preparation tool.



Conceptual example on a very crowded field! Omega Centauri.

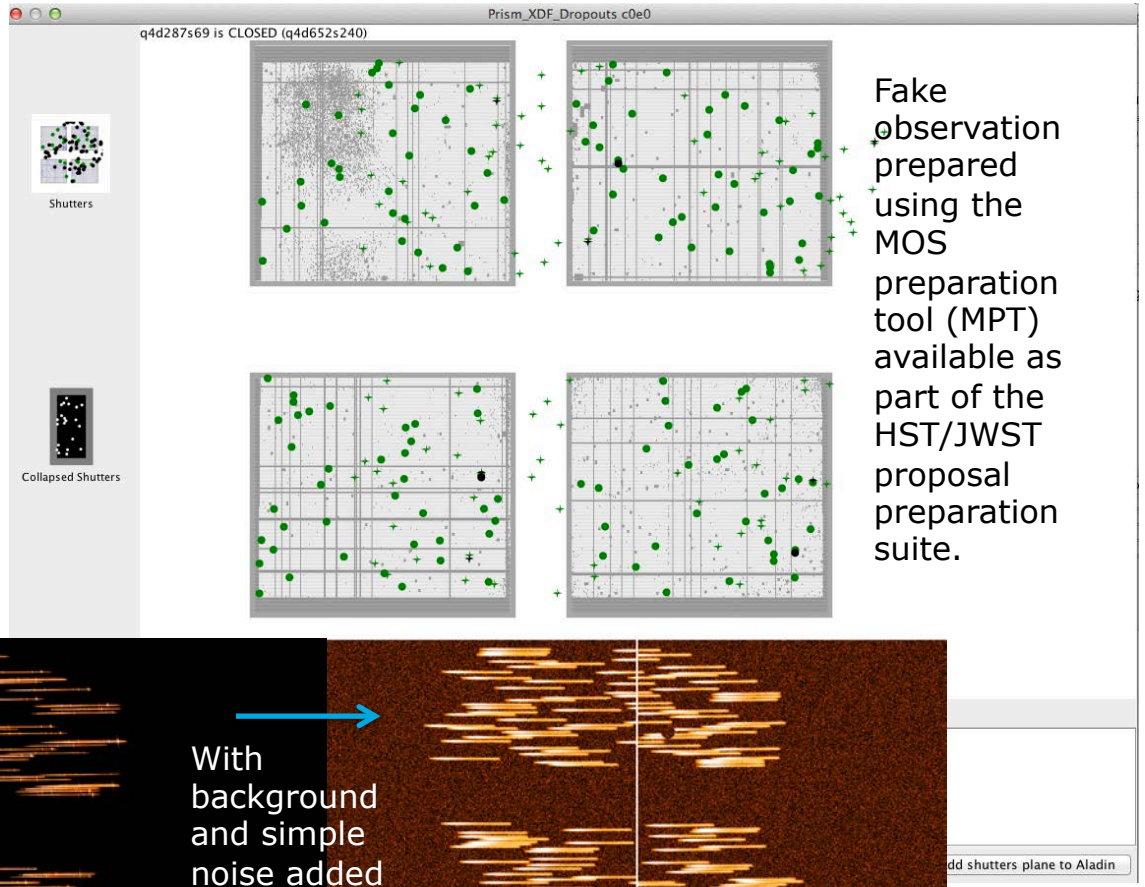


In yellow: non-operable shutters (cannot be opened)

http://www.stsci.edu/jwst/science/sodrm/highlightSpecDenseStellarFields.pdf

JWST/NIRSpec
Multi-object spectroscopy (MOS)

Conceptual example on deep-field type of observation (tiled-version of a XDF drop-out catalog)

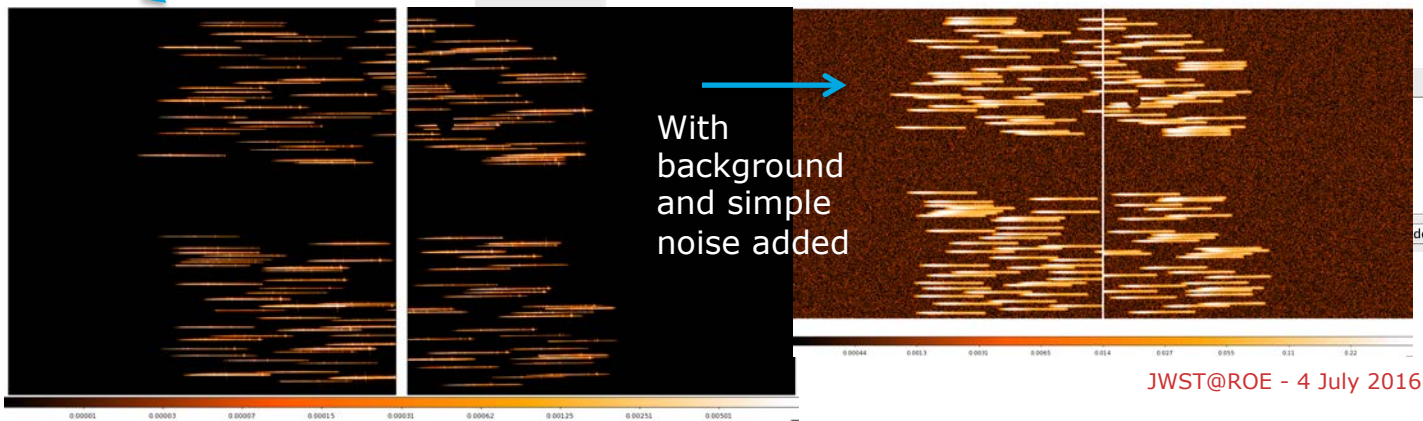


Fake observation prepared using the MOS preparation tool (MPT) available as part of the HST/JWST proposal preparation suite.

Spectra generated using BEAGLE (Chevallard & Charlot 2016)

Objects only, noiseless exposure.

CLEAR/PRISM (short spectra, high multiplex)



With background and simple noise added

JWST/NIRSpec
Multi-object spectroscopy (MOS)

- **An unusual MOS: a regular grid of apertures.**
  - → When observing a sample of objects, there will be a distribution of objects positions within the apertures.
    - → For compact objects, better centering = more photons make it through the aperture, more accurate radiometric calibration.
  - → Depending on the orientation of the telescope (known once the observation is scheduled), the list of observable objects may change.
    - → Proposed sample will have to be able to cover for this "feature".
  - → Same-cycle pre-imaging observations with NIRCam will be possible.
    - → Spectroscopic sample derived from this NIRCam imaging.

WORK IN PROGRESS, STAY TUNED.

Current version of the proposal preparation tools for JWST (same as HST):
http://www.stsci.edu/hst/proposing/apt

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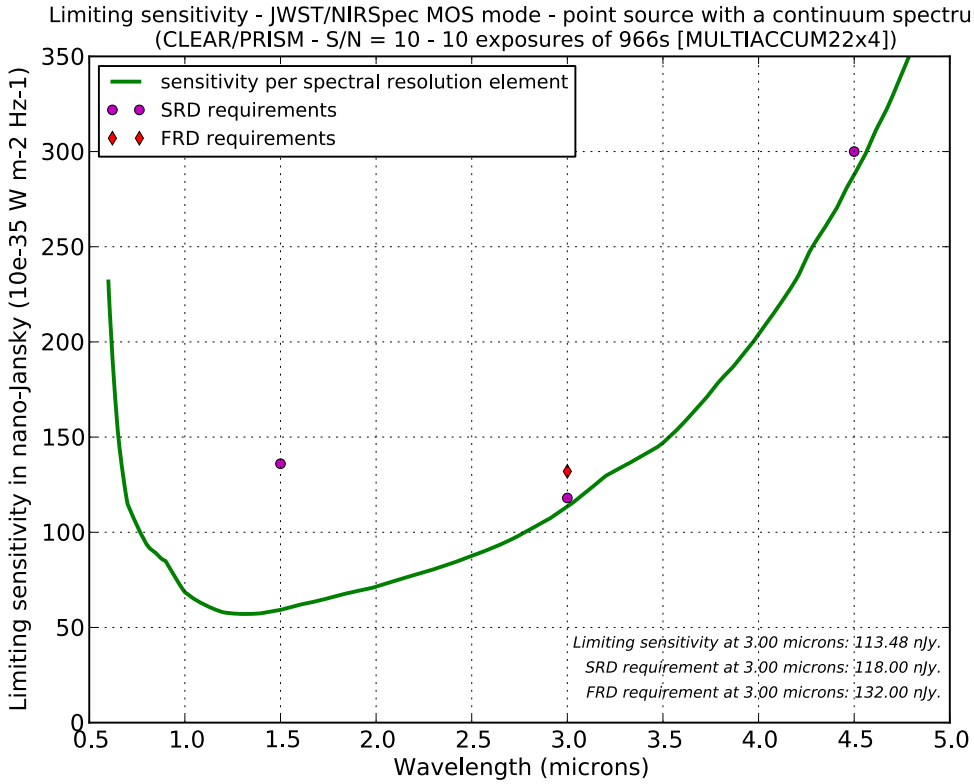
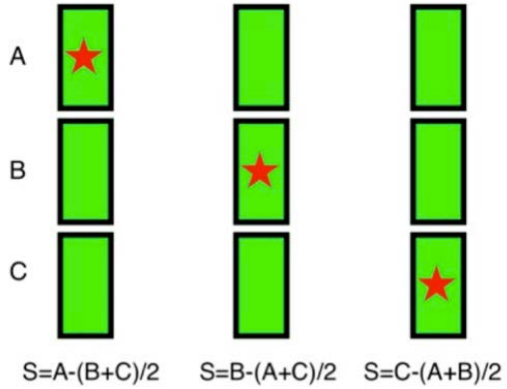
- **Limiting sensitivity**
  - Conservative estimates including a recipe to account for data loss due to detector cosmetics.

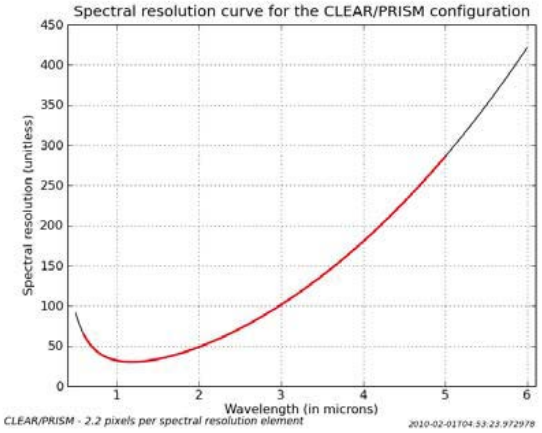


100 nJy = 1e-30 erg s-1 cm-2 Hz-1 = 1e-33 W m-2 Hz-1 = 26.4 AB mag = 24.3 K-band mag

Note the gaps between the shutters are real (pitch = 202 microns, aperture = 175 microns, 14% relative bar size)



- Low spectral resolution



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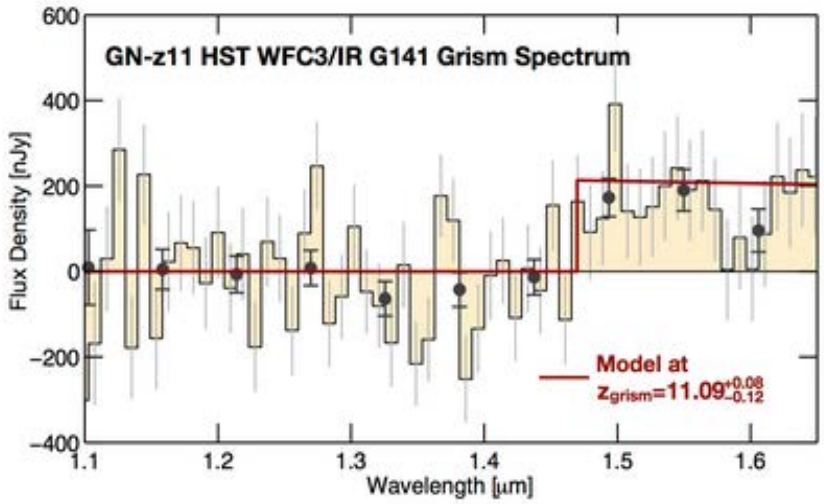
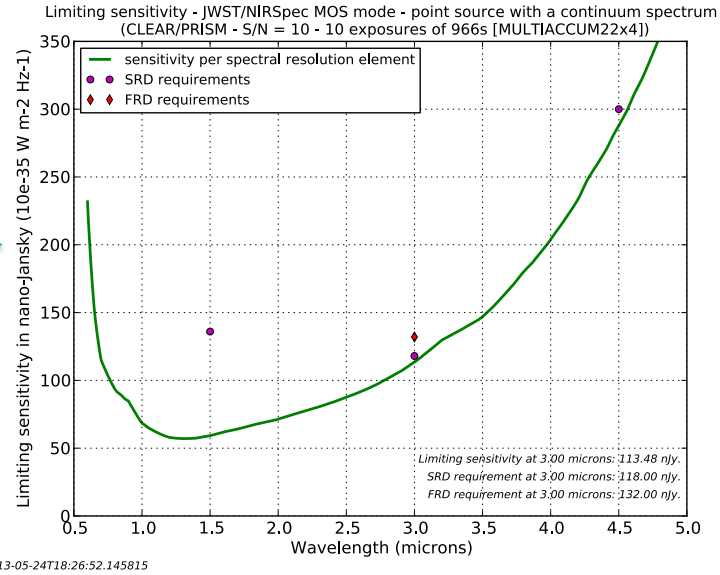
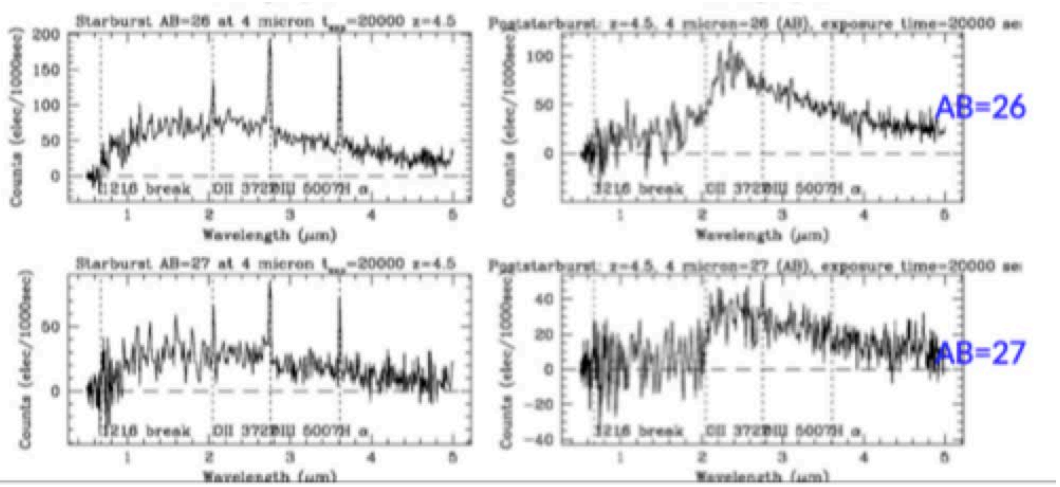
JWST/NIRSpec
Multi-object spectroscopy – Example

From P. Oesch et al. 2016







From Bunker 2015, presentation at the JWST2015 conference at ESA/ESTEC

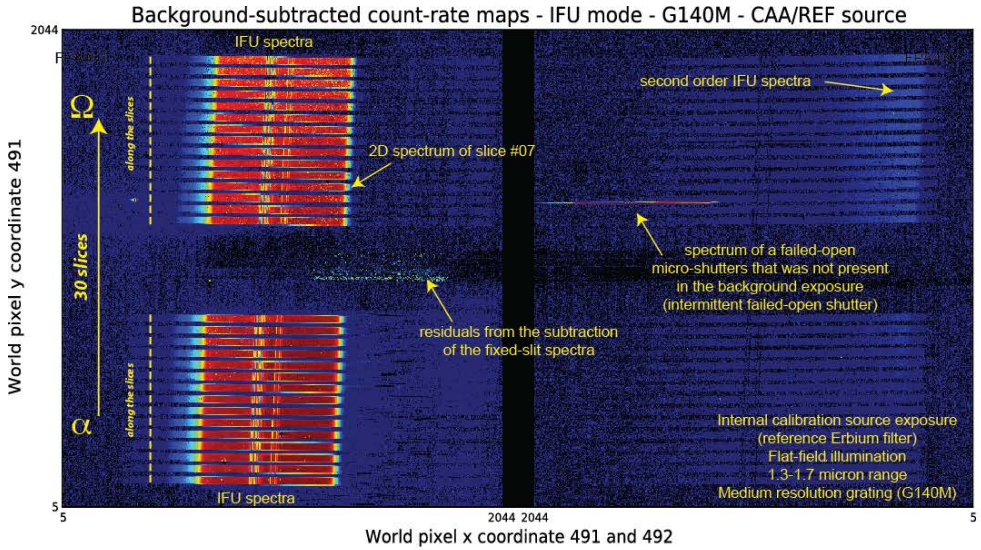
Simulated spectra of starbust & post-starbust galaxies at z=4.5.

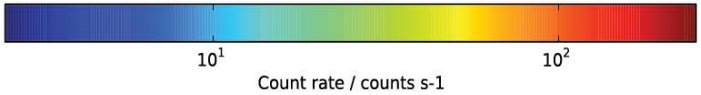
20ks at low spectral resolution.

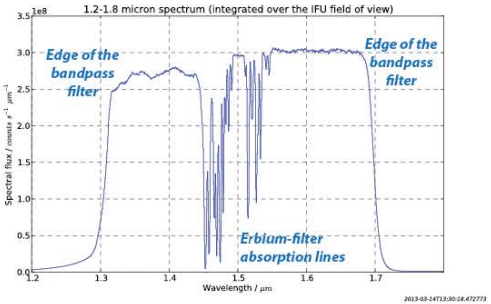
JWST/NIRSpec
Integral field spectroscopy

NIRSpec IFU properties	
Concept	Advanced image slicer module (Content 1997)
Manufacturer	Surrey Satellite Technology LTD (SSTL) University of Durham – CfAI as a sub-contractor
Size and weight	Size of a shoebox for a weight of less than 1kg
Number of slices	30
Field of view	3 arcsec × 3 arcsec
Spaxel size	0.1 arcsec × 0.1 arcsec
Throughput	> 50 % from 0.6 to 3.0 microns; > 80 % above 3 microns
Spectral Configurations (using NIRSpec spectrograph)	Coverage of the 0.6-5.0 µm spectral domain in one shot at $25 \leq R \leq 300$ (using a prism) Coverage of the 0.7-5.0 µm spectral domain in four configurations at $R \approx 1000$ and $R \approx 2700$ (using gratings)

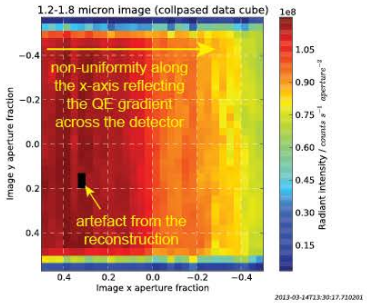
JWST/NIRSpec
Integral field spectroscopy



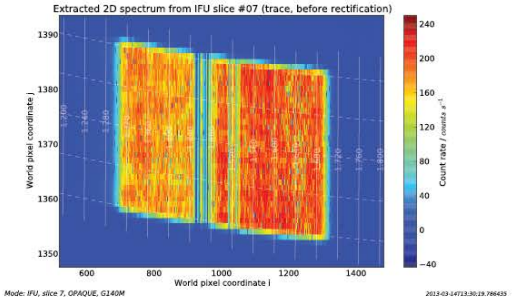


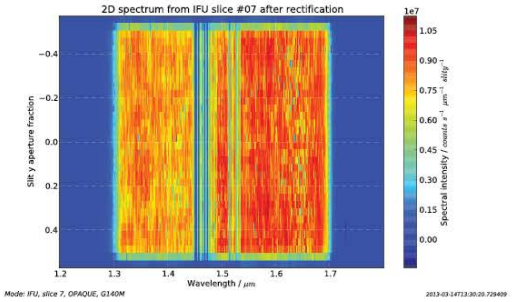


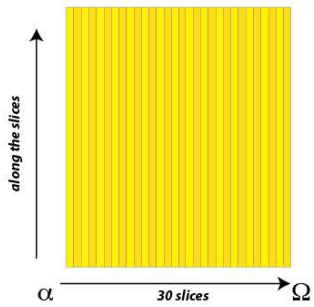
integrated spectrum
(summation over the IFU field of view)



integrated image
(summation over the IFU wavelength range)







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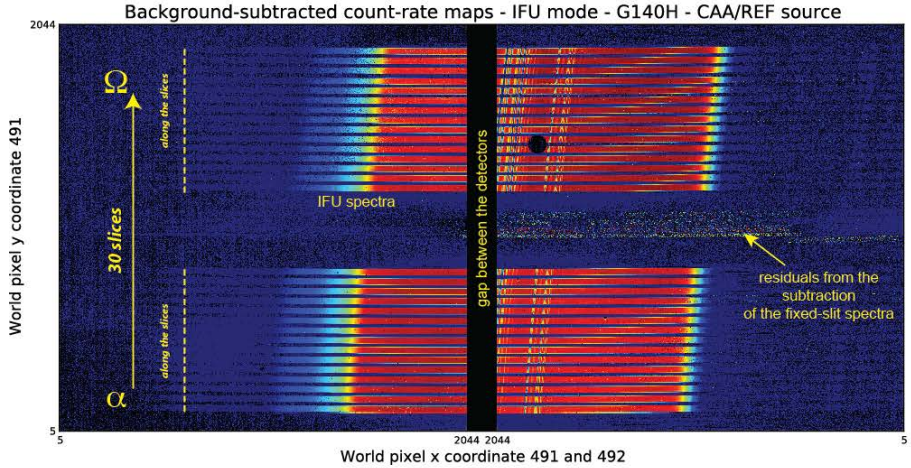
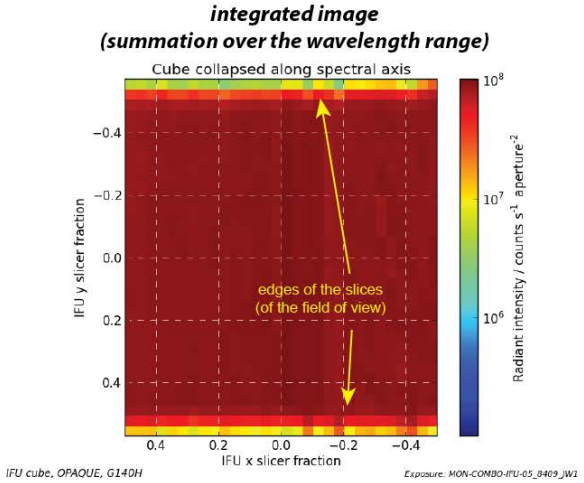
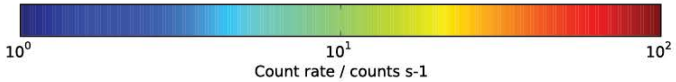
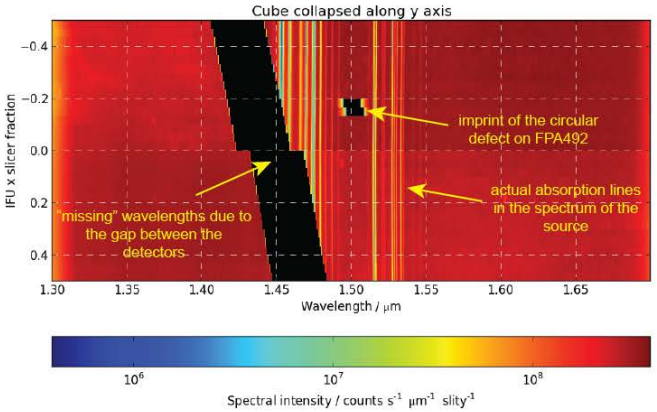
Integral field spectroscopy

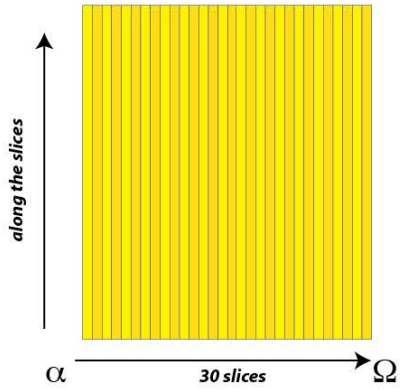








2D projection of the data cube (collapsing along one spatial direction)



Internal calibration source (reference Erbium filter)
Flat-field illumination - 1.3-1.7 micron range
High resolution grating (G140H)

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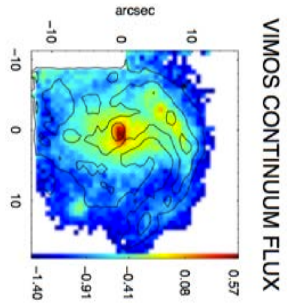
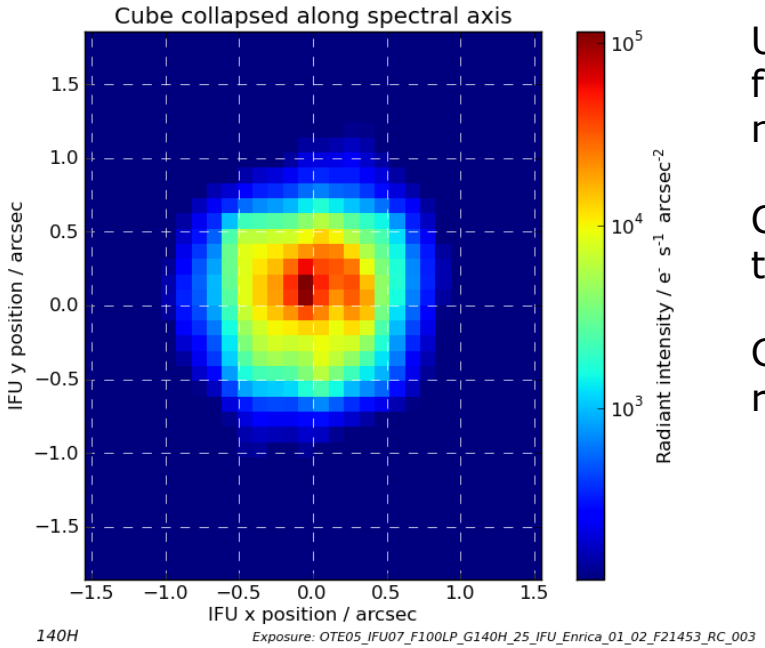
Integral field spectroscopy

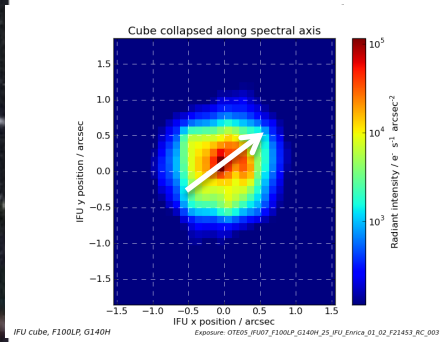


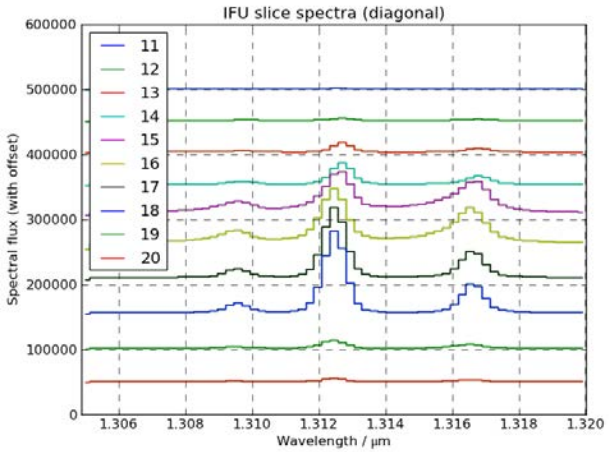


Using VIMOS [NII]+Ha data from Bellocchi et al. 2012 of a nearby galaxy.

Crudely redshifting the spectra to z=1.

Giving the object a size of roughly 1”.

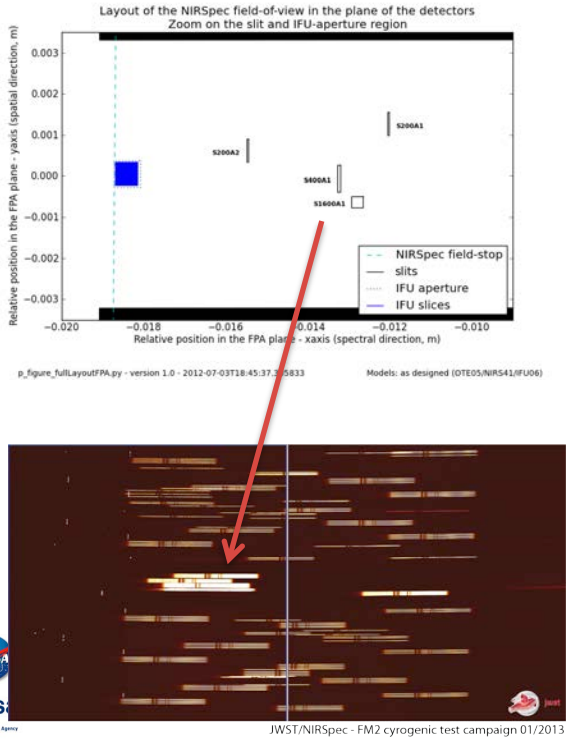




Velocity structure is still clearly visible as we progress diagonally through the cube.

JWST/NIRSpec "high-contrast" slit spectroscopy

- **A set of 5 "fixed" slits for high-contrast spectroscopy of individual objects**
  - Specific detector real estate (can be used in parallel to the other modes).
  - 3 x 0.2" + 1 x 0.4" + aperture of 1.6"x1.6"



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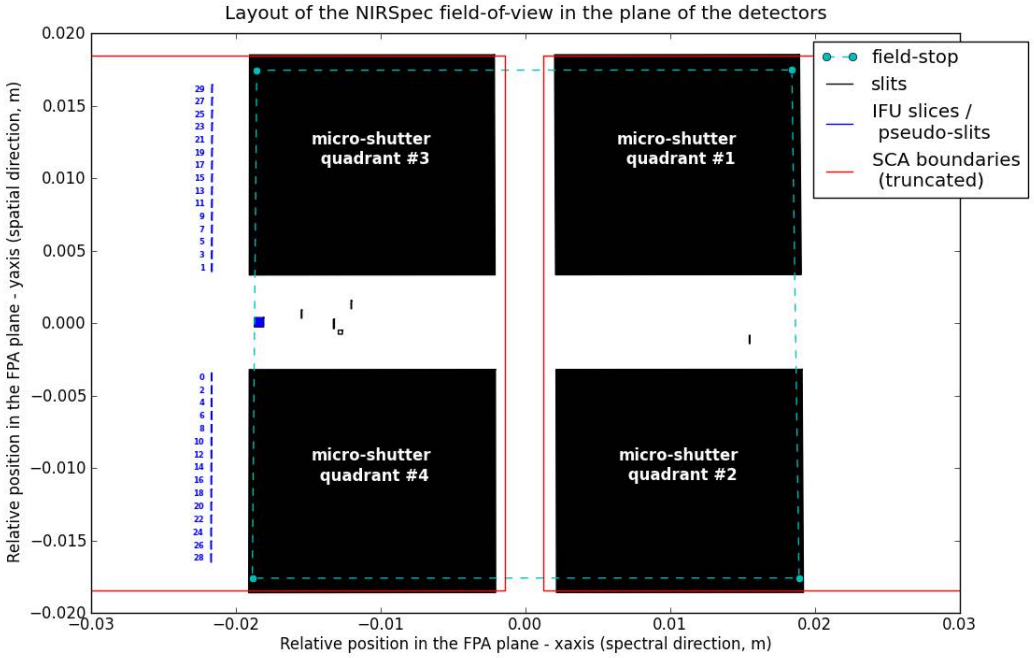

JWST/NIRSpec exoplanet transit spectroscopy

- **While optimized for faint target multi-object spectroscopy, NIRSpec features a dedicated large aperture (1.6” x 1.6”) for exoplanet transit spectroscopy.**
  - In a more general way, exoplanet atmosphere characterisation.
- **Ironically, one of the main worry for this mode was the saturation limit!**
  - Note that the other near-infrared instrument also have modes dedicated to exoplanet transit spectroscopy. ➔ pick the one best suited for your needs.
- **Some references.**
  - PASP white paper: Beichman et al. 2014 (PASP,126,1134).
  - SPIE paper: Nielsen et al. 2016 (soon available).

Conclusion

- **JWST/NIRSpec**
  - A very versatile near-infrared spectrograph with an unprecedented combination of sensitivity and spatial resolution.
- **In the coming years…**
  - NIRSpec together with the other instruments will go through JWST's remaining integration and test steps.
  - The teams will continue working on the suite of tools necessary to prepare the observations, execute them, process the data and archive them!

Thanks for your attention!