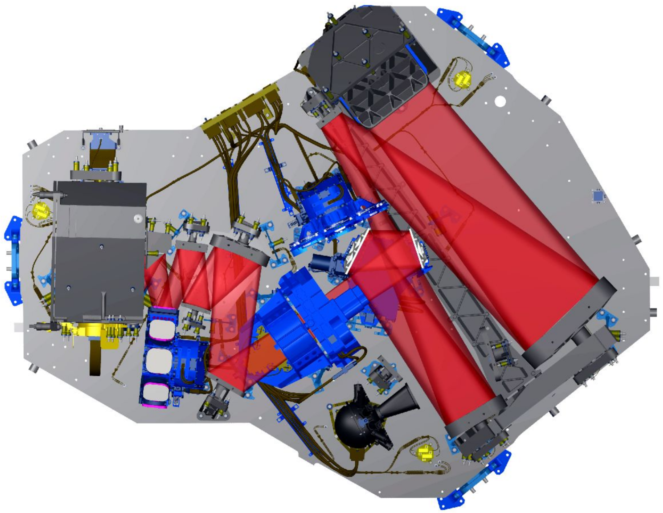
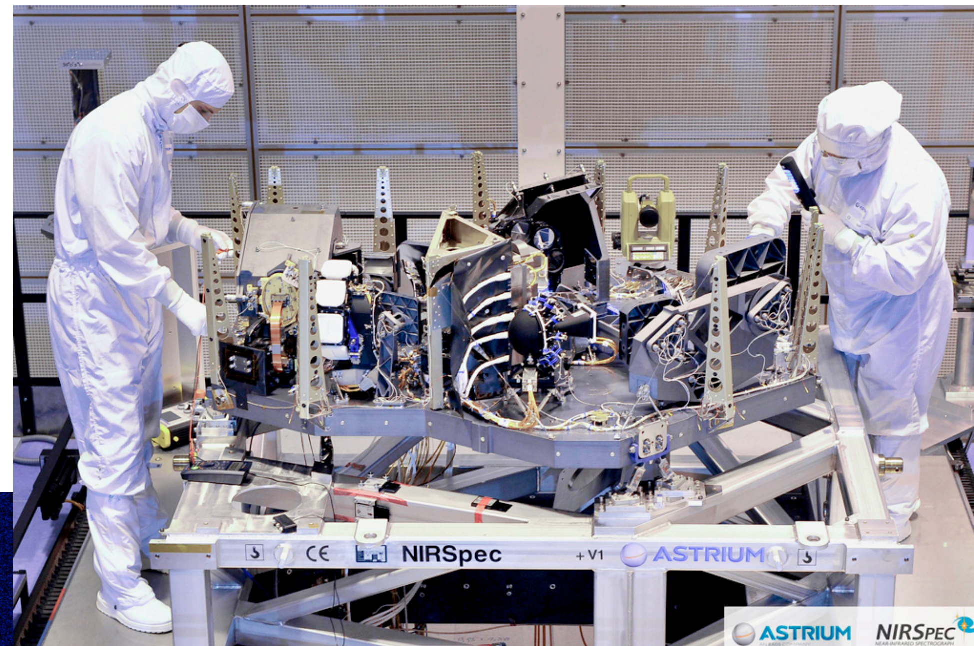
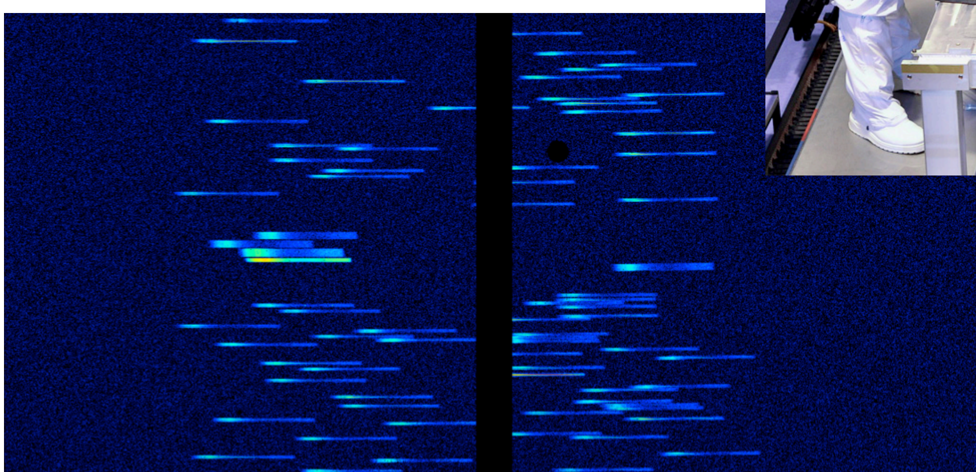
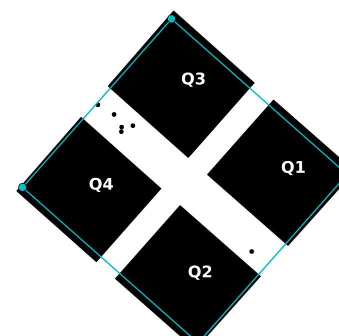
James Webb Space Telescope

The JWST/NIRSpec spectrograph: raw data and observing modes









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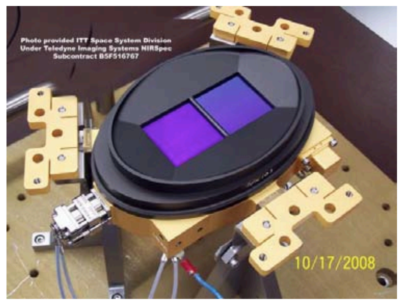
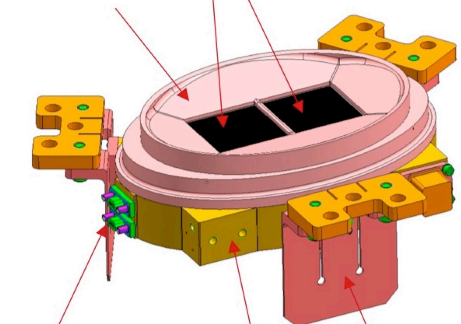
- The end…

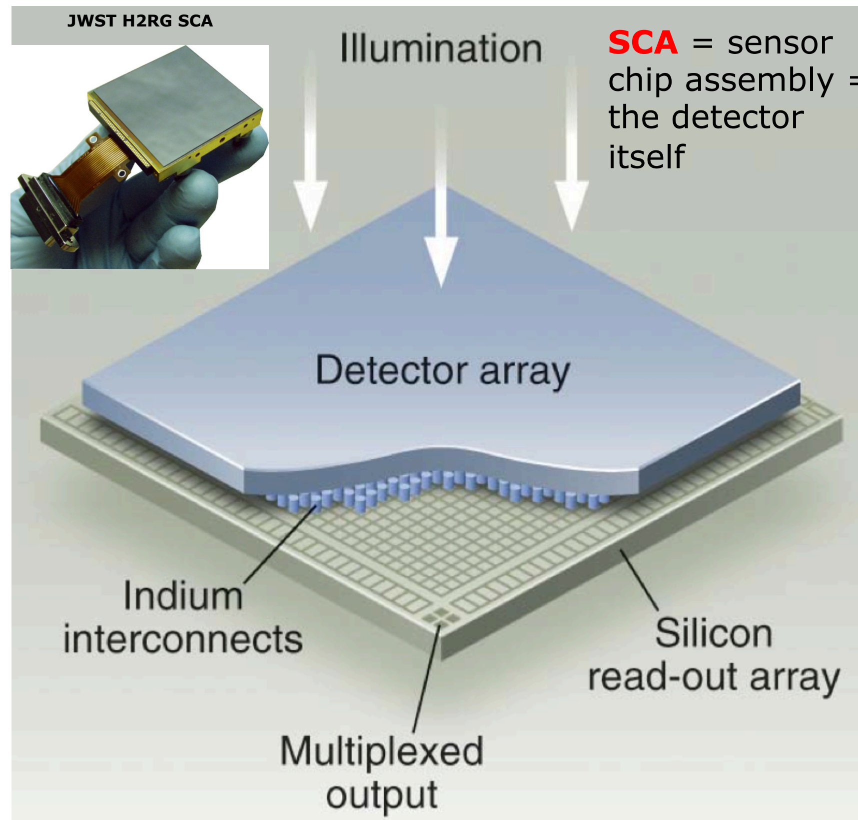
NIRSpec detector system – the detectors

- Two 2048x2048 H2RG detectors from Teledyne.
  - Hg-Cd-Te detector arrays with 18-micron pixels





FPA = focal plane assembly = the detectors and the surrounding structure.

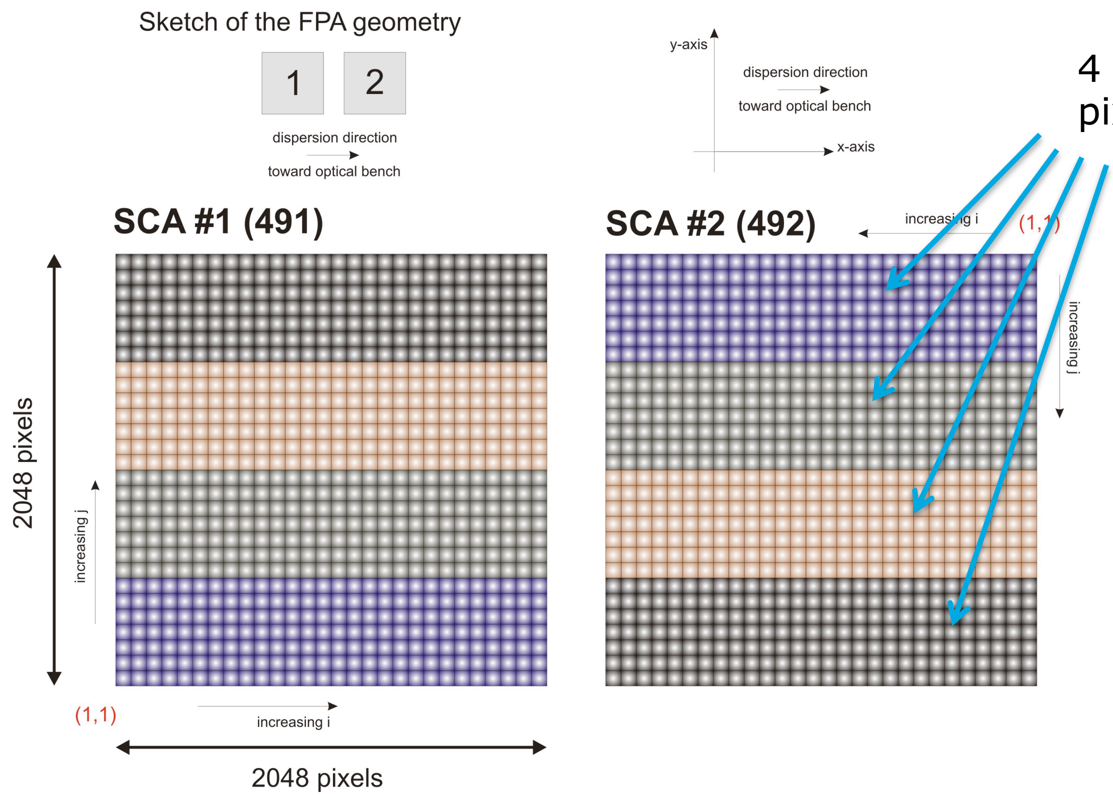


SCA = sensor chip assembly = the detector itself

Image credit: James Beletic (TIS).

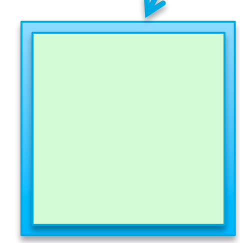
NIRSpec detector system – the detectors

- So-called "long wavelength" JWST detectors
    - Sensitivity up to 5 microns with a cut-off around 5.3 microns.
    - Typical QE between 70 and 85%.
    - Low dark current levels (typically < 0.01 e /s).



4 outputs (2048x512 pixels) read in parallel

4 rows / columns of reference pixels at the edges of the SCAs

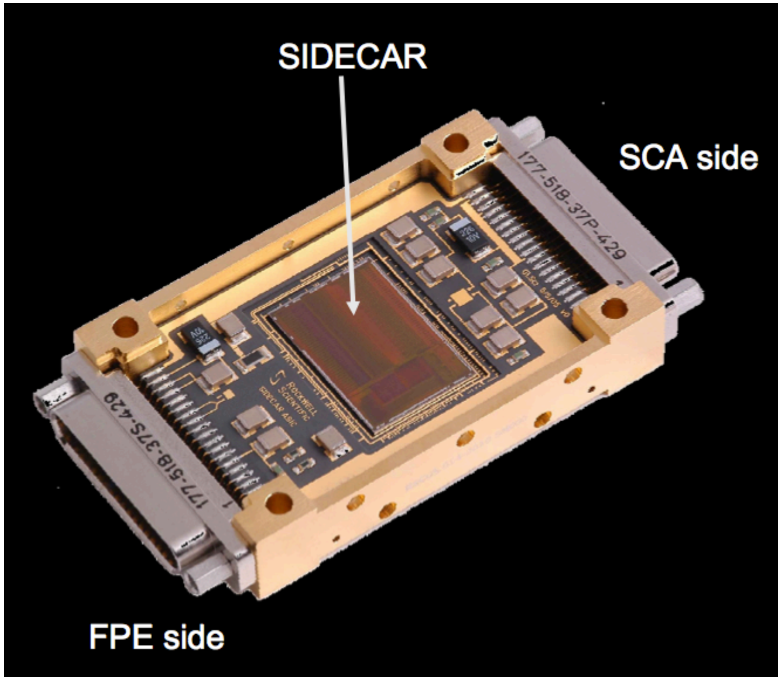


Reference pixel = pixel that is not sensitive to light and that can be used to track drifts in detector signal.

NIRSpec detector system – the ASICs

- Each SCA is paired with an ASIC.
  - Cold proximity electronics that (among many other things) performs the analog-to-digital conversion.
  - Interface between the SCA and the FPE.

Each pair of ASIC + SCA need to undergo “tuning” to make sure we achieve the right performance levels (in particular the total noise level).



FPE = focal plane electronics

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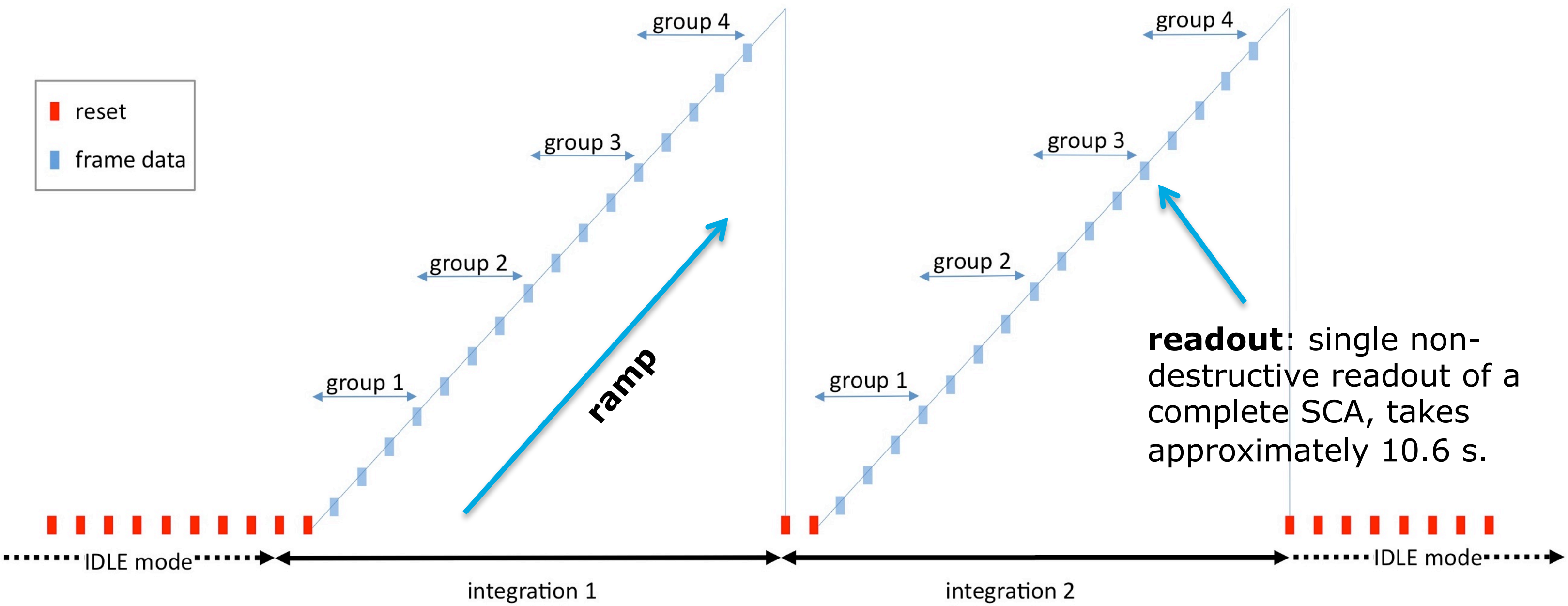
Readout scheme (…and associated "jargon")

- Making a full use of the **non-destructive readout** capability.
  - Following the accumulation of electrons in each pixel during an **integration**, "a ramp".
  - Multiple **integrations** (ramps) during an **exposure**.



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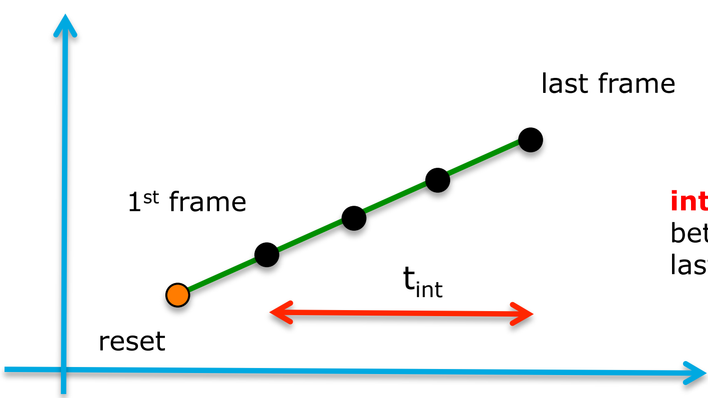
Readout scheme (...and associated "jargon")

- Getting the best out of your observation of **faint objects**. → get as many **readouts** as possible.
  - Helps minimizing the contribution of the readout noise of the detectors to the variance of the slope estimation.
  - Helps minimizing the amount of data lost due to cosmic rays.

$$Variance_{detector\ readout} = \frac{12 \times \sigma^2_{readout}}{t^2_{int}} \times \frac{(n_{readout} - 1)}{n_{readout} \times (n_{readout} + 1)}$$

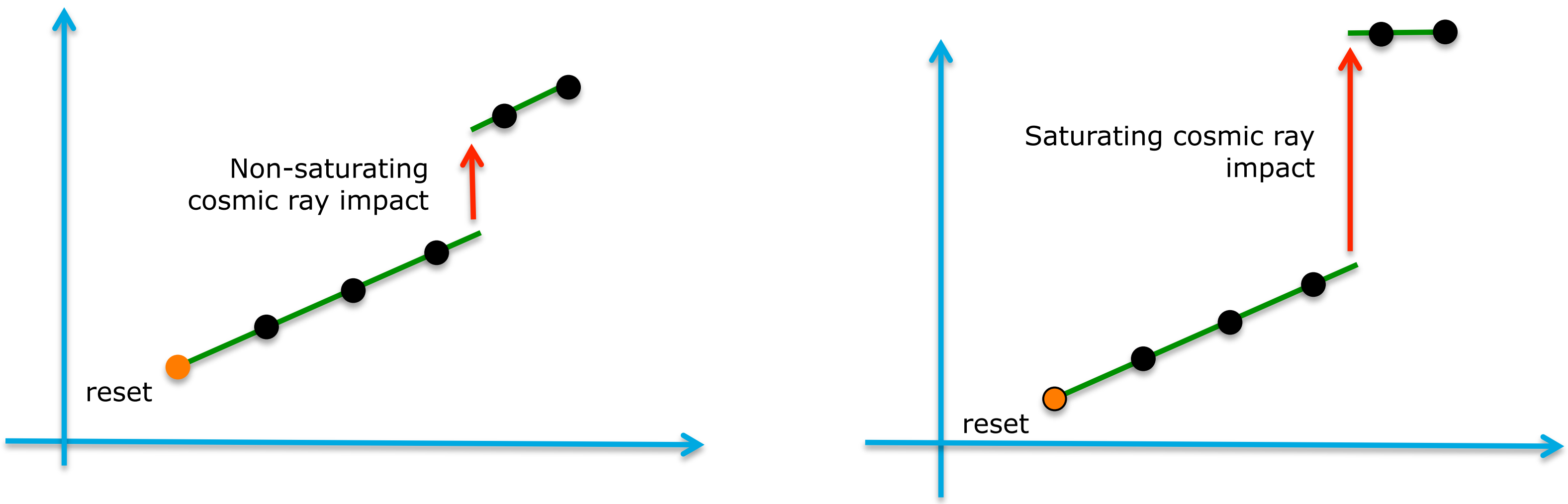


integration time = time between the first and the last frame of an integration

nreadout	variance factor	sigma factor
2	2.00	1.41
3	2.00	1.41
4	1.80	1.34
5	1.60	1.26
6	1.43	1.20
7	1.29	1.13
8	1.17	1.08
9	1.07	1.03
10	0.98	0.99
20	0.54	0.74
30	0.37	0.61
40	0.29	0.53
50	0.23	0.48
60	0.19	0.44
70	0.17	0.41
80	0.15	0.38
90	0.13	0.36
100	0.12	0.34
200	0.06	0.24

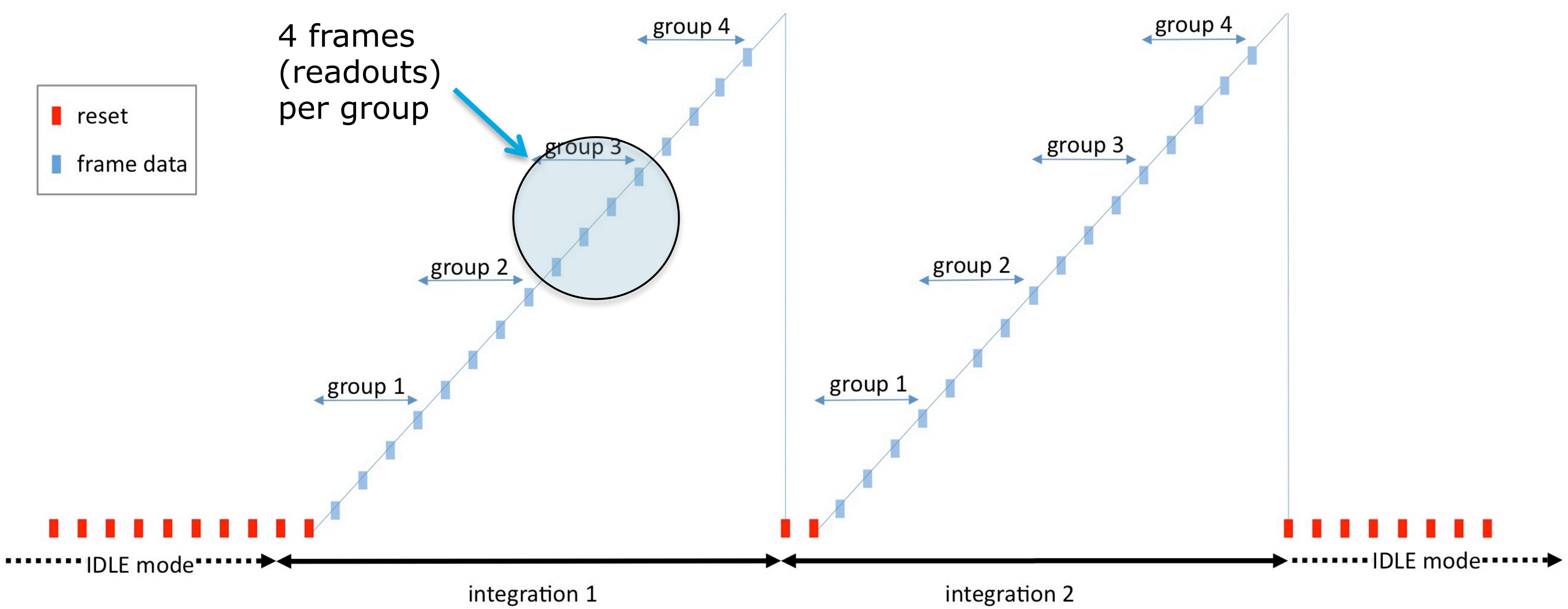
Readout scheme (…and associated "jargon")

- Getting the best out of your observation of **faint objects**. → get as many **readouts** as possible.
    - Helps minimizing the contribution of the readout noise of the detectors to the variance on the slope estimation.
    - Helps minimizing the amount of data lost due to cosmic rays.



Readout scheme (…and associated "jargon")

- But reality hits back… We cannot record one readout every 10.6 s and send all of them back to Earth (limited data rate).
    - **On-board** averaging of **groups** of **individual readouts** called **frames**.
    - Typically, we will use 4 **frames** per **group**.



Readout scheme (...and associated "jargon")

- By using 4 frames per group, we gain a factor 4 in data rate.
- Is there something like a "free lunch"?

$$Variance_{detector\ readout} = \frac{12 \times \sigma^2_{readout}}{n_f t^2_{int}} \times \frac{(n_g - 1)}{n_g \times (n_g + 1)}$$

nf = number of frames per group
ng = number of group per integration

nf	ng	variance factor	after tint correction	sigma factor	tf (s)	tg (s)	tint (s)	tot(s)
1	40	0.29	0.29	0.53	10.6	10.6	413.4	425
2	20	0.27	0.29	0.52	10.6	21.2	402.8	425
4	10	0.25	0.29	0.50	10.6	42.4	381.6	425
1	80	0.15	0.15	0.38	10.6	10.6	837.4	849
2	40	0.14	0.15	0.38	10.6	21.2	826.8	849
4	20	0.14	0.15	0.37	10.6	42.4	805.6	849
1	88	0.13	0.13	0.37	10.6	10.6	922.2	933.8
2	44	0.13	0.13	0.36	10.6	21.2	911.6	933.8
4	22	0.12	0.13	0.35	10.6	42.4	890.4	933.8

typical in-orbit integration

same level of "damping" of the readout noise

time relevant for the signal to noise computation

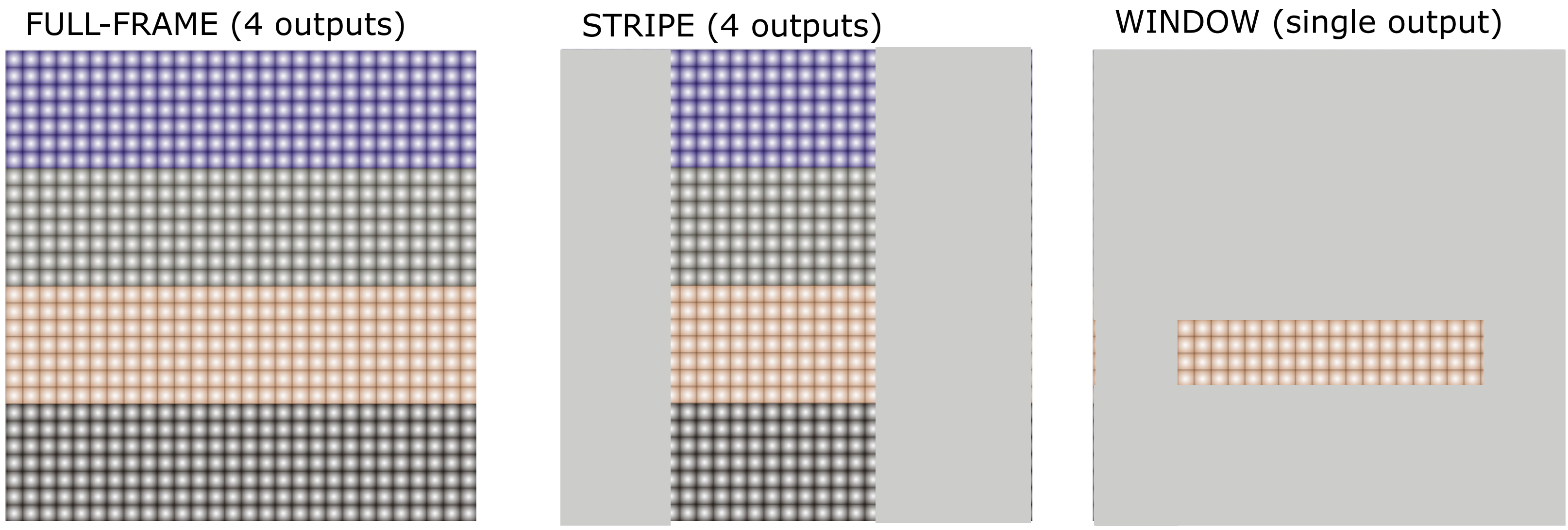
same time needed to take the data

No, we loose 3-4% in the final S/N because of the decrease of t_{int}.

Full-frame, stripe, window…

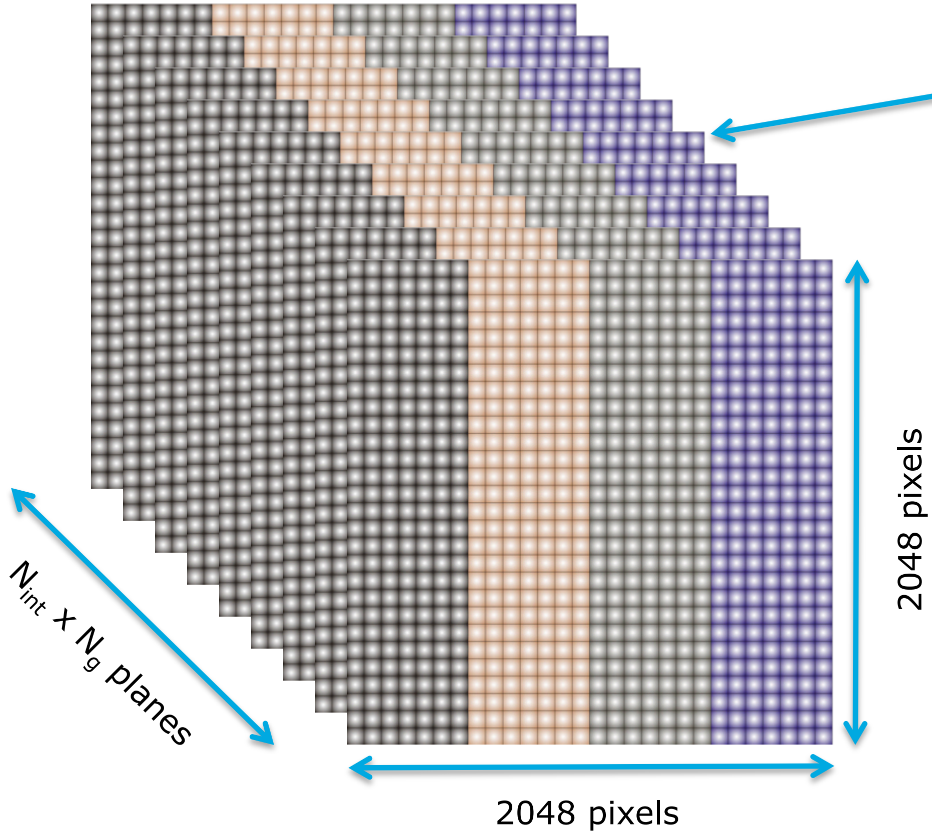
- It takes approximately 10.6 s to read a complete SCA with the four outputs running in parallel.
- This defines a minimum integration time that can be too long for some (bright) sources.

➔ It is possible to read only part of a SCA to achieve much faster "cadences".



NIRSpec raw data

- Two FITS file per exposure (one for each SCA).
- Each file will contain a data cube generated by stacking the **groups** one after each other.

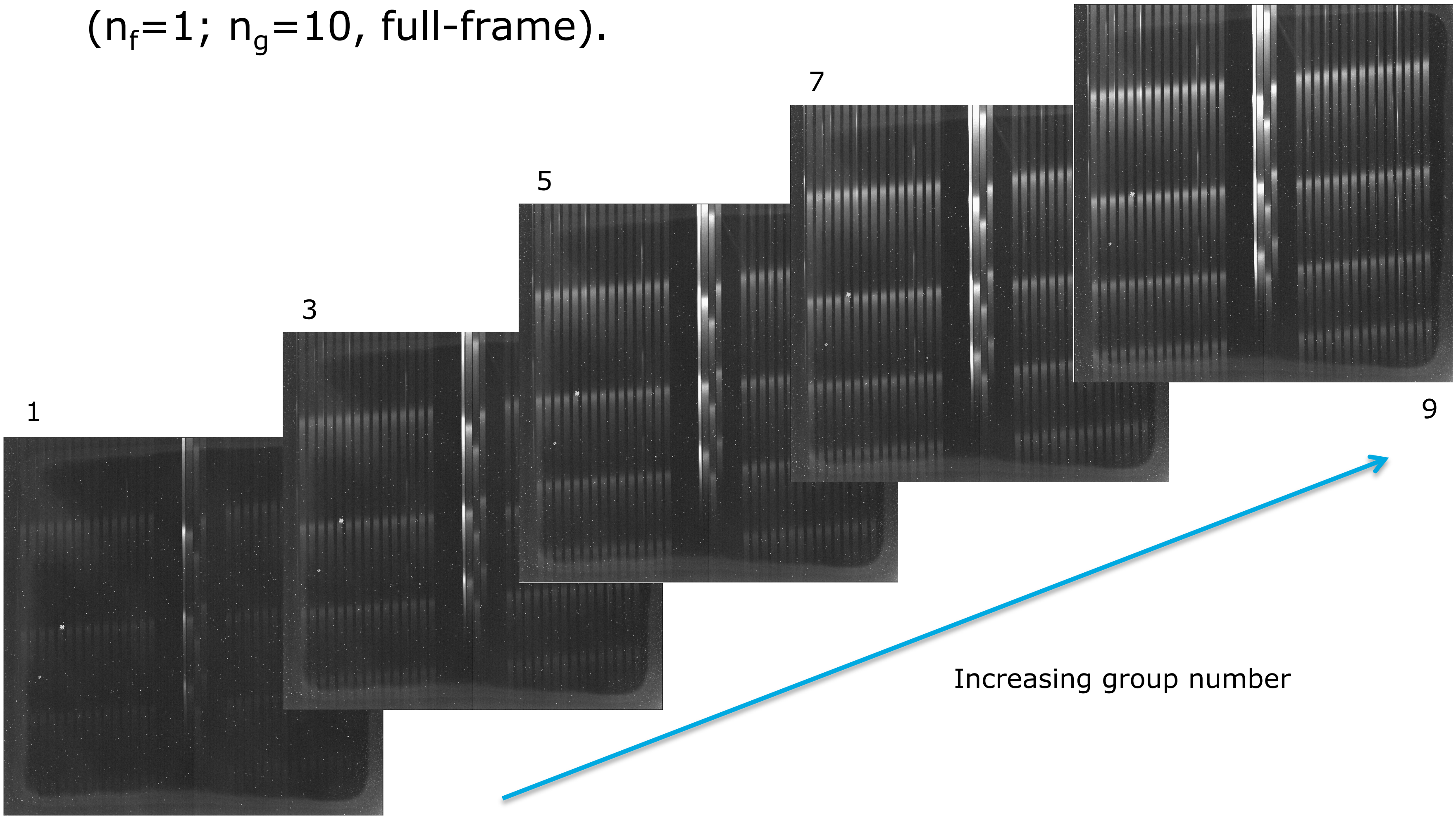


Each plane correspond to one group with values obtained by averaging n_f frames (readouts).

CAUTION: if multiple integrations are present in an exposure they are all stacked together (multiple ramps in a single cube)

NIRSpec raw data - example

- Slices from a NIRSpec raw data FITS file obtained during testing (n_f=1; n_g=10, full-frame).



Readout scheme and raw data – summary

- What do you need to remember?
  - A NIRSpec **exposure** can be made of several **integrations** (ramps).
  - Each **integration** is made of **groups** of **frames**. The frames within a group are **averaged on-board**.
  - A typical NIRSpec exposure will be made of 22 groups of 4 frames.
  - NIRSpec has "**full-frame**", "**window**" and "**stripe**" readout modes.
  - The **raw data** for an exposure consists in **two FITS** files (one per SCA) containing a **data cube** with all the successive non-destructive readouts stacked along the 3rd axis.

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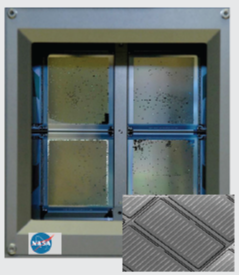
Overview – modes, spectral bands and configurations

JWST/NIRSpec

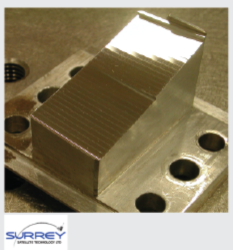
MOS



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.

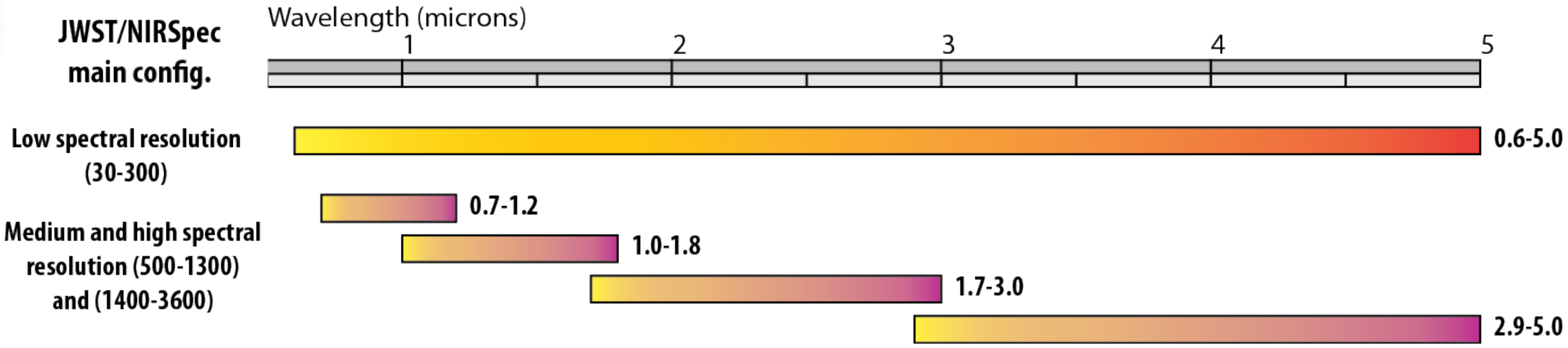
(including with a 1.6"x1.6" square aperture for extra-solar planet transit observation)

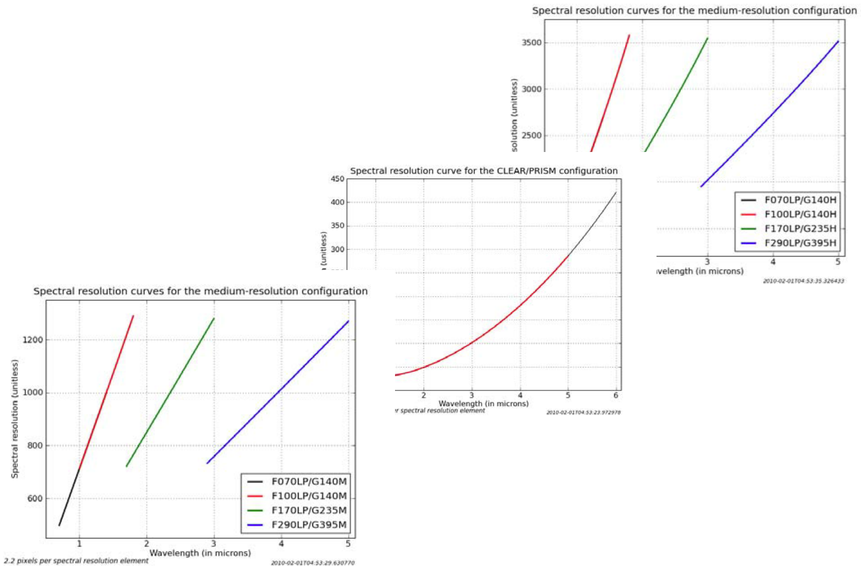
- 5 slits available

All spectral resolution modes available.

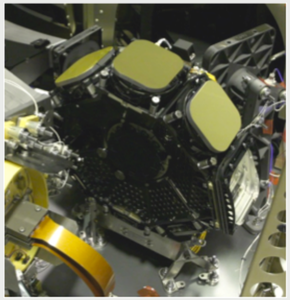
- SLIT can be used simultaneously to IFU or MOS.

Overview – modes, spectral bands and configurations

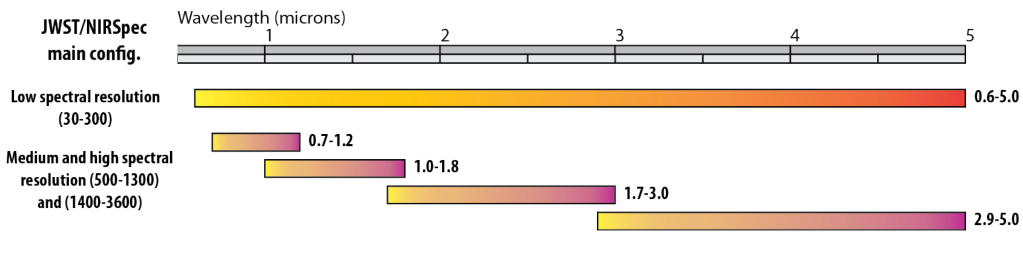


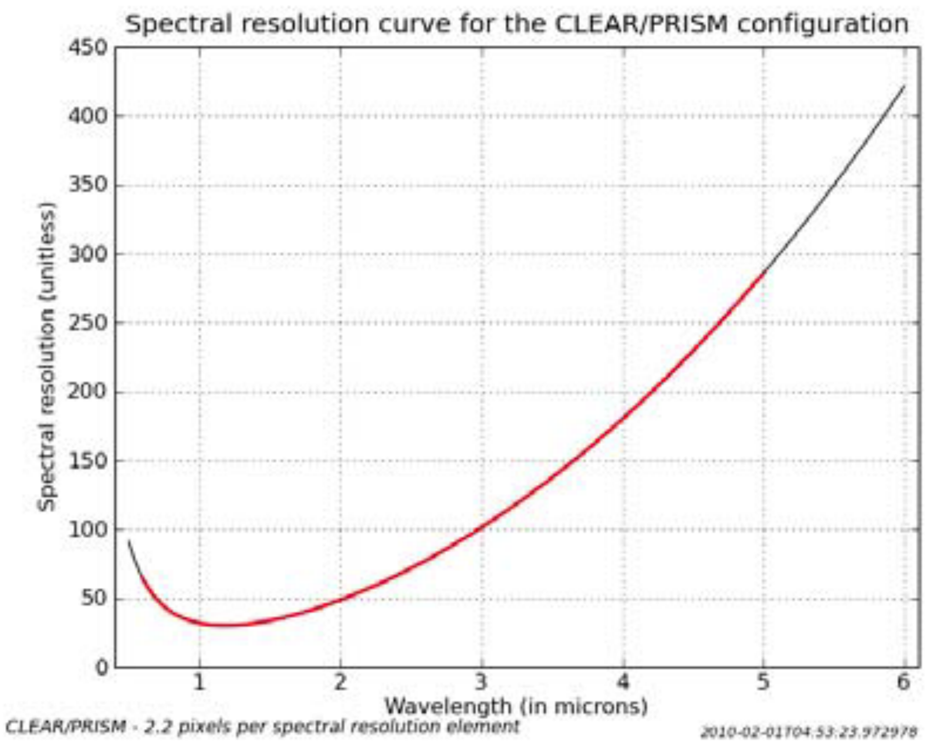


Configurations that can be obtained thanks to a combination of filters and dispersers installed on two wheels (FWA and GWA)



Overview – modes, spectral bands and configurations

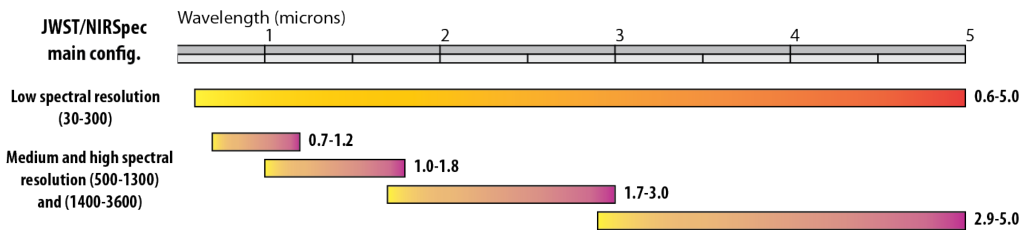


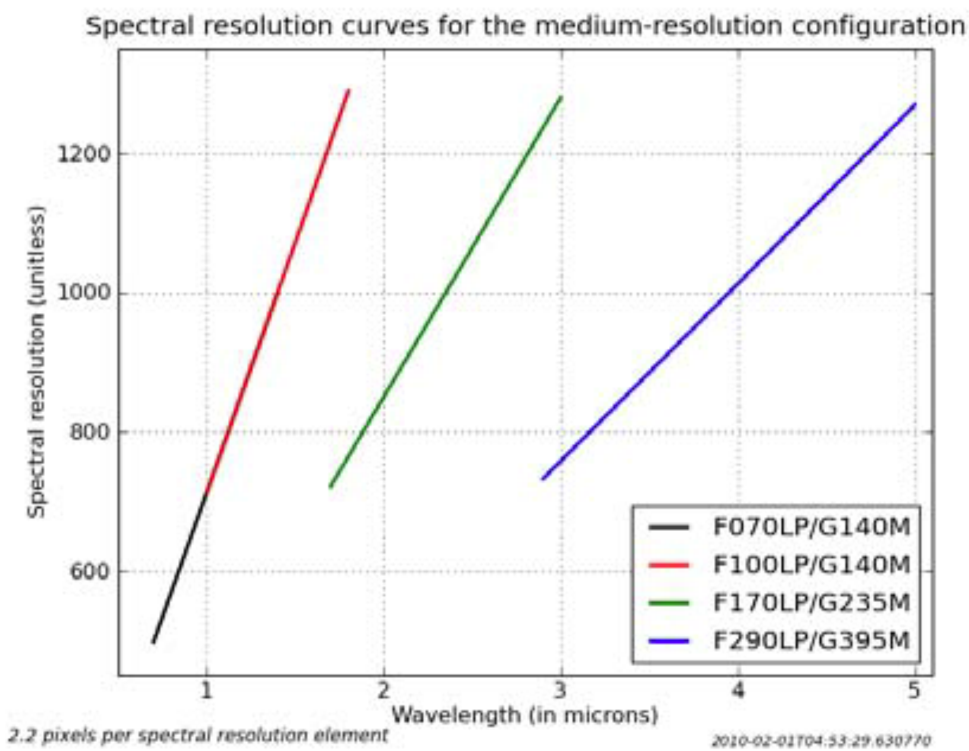


Low spectral resolution

- Can cover the full 0.6-5.0 spectral range in a single exposure
- Variable spectral resolution (30-300).
- It is possible to restrict the spectral domain to small regions.
- CaF2 prism used in double pass (PRISM).

Overview – modes, spectral bands and configurations



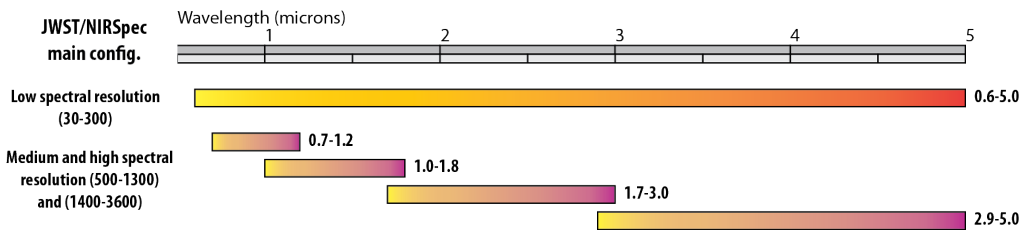


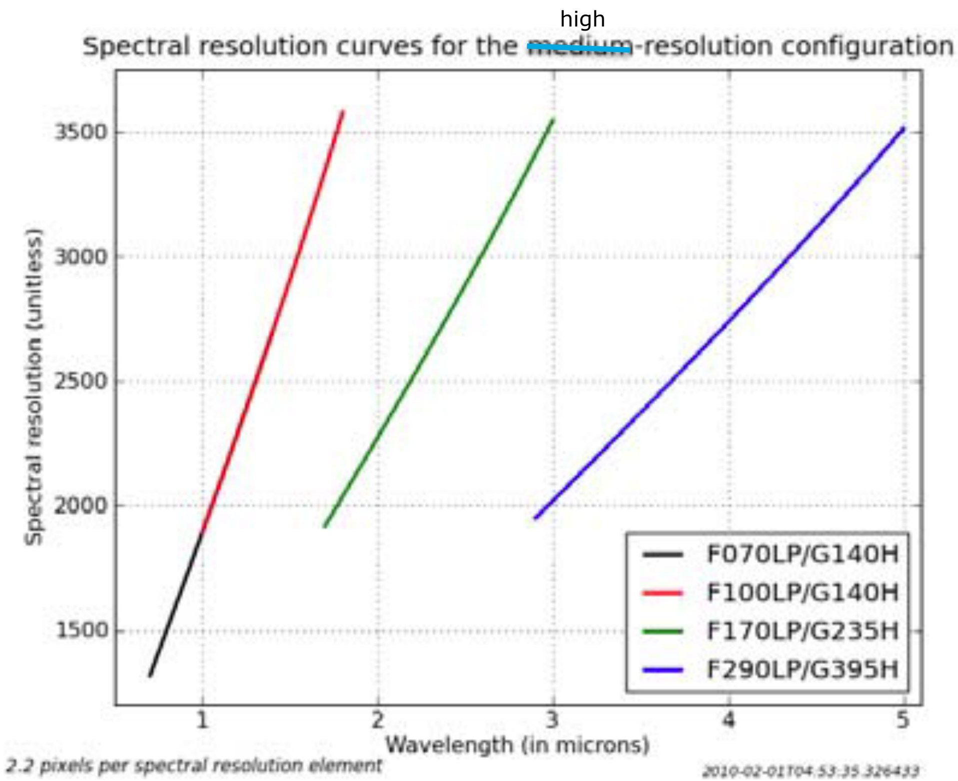
Medium spectral resolution

- Full-spectral range covered in 4 exposures
- Spectral resolution ranging from 500 to 1300.

- 3 gratings (G140M, G235M and G395M).
- Long-pass filters (F070LP, F100LP, F170LP and F290LP)

Overview – modes, spectral bands and configurations





High spectral resolution

- Full-spectral range covered in 4 exposures
- Spectral resolution ranging from 1400 to 3600.

- 3 gratings (G140H, G235H and G395H).
- Long-pass filters (F070LP, F100LP, F170LP and F290LP)

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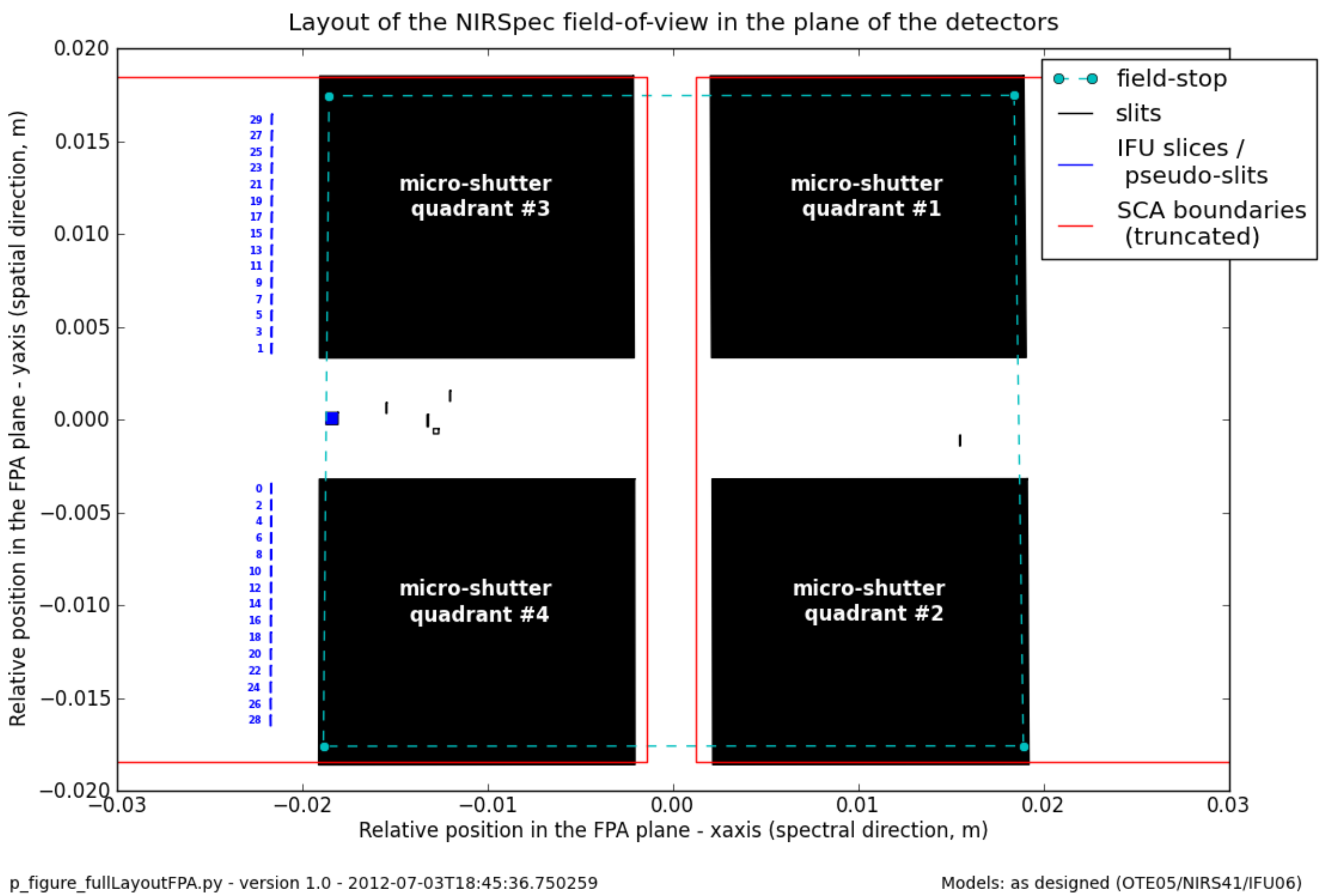
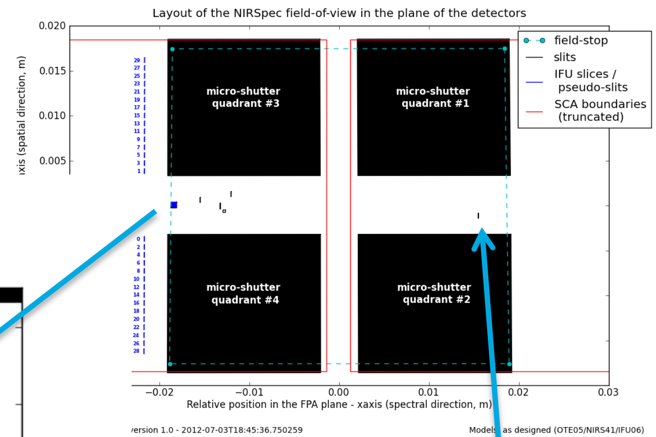
A complex field of view layout: How does one put 3 spectrographs in one?

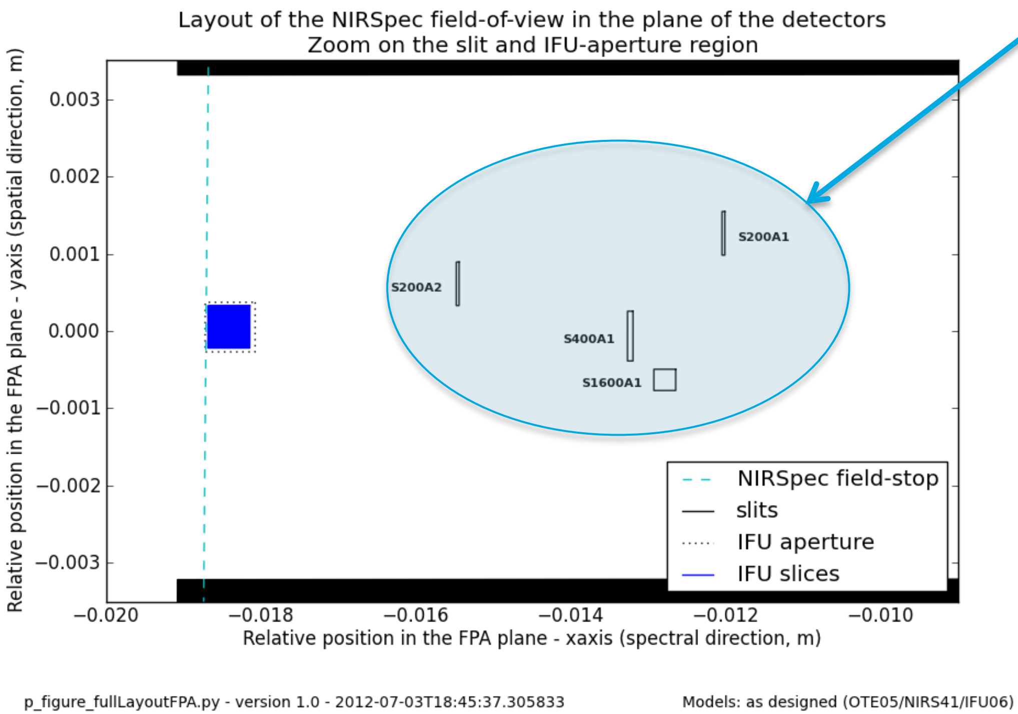
- **4 micro-shutter quadrants for the MOS mode.**



A complex field of view layout: How does one put 3 instruments in one?

- **5 slits for the "SLIT" mode.**

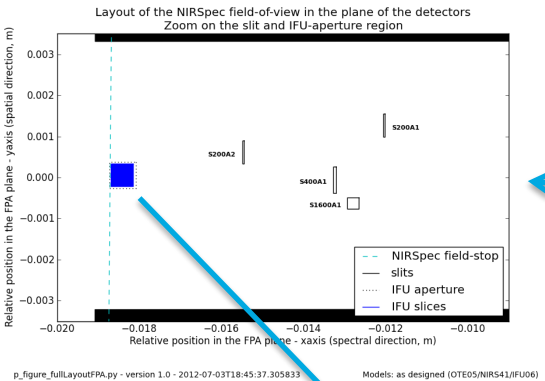


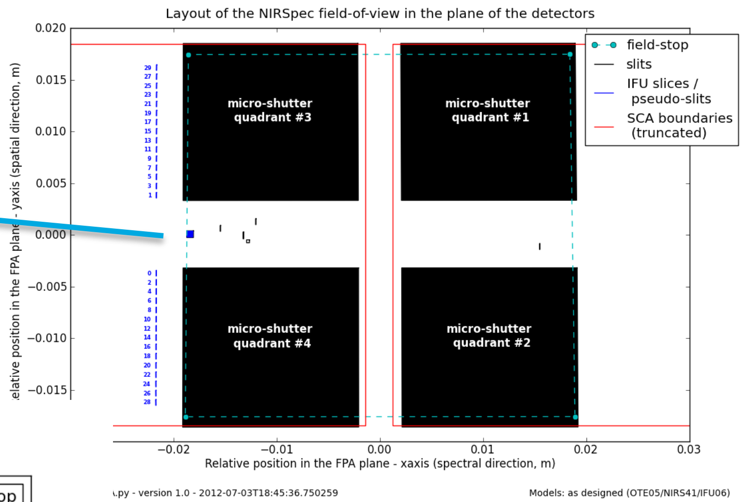


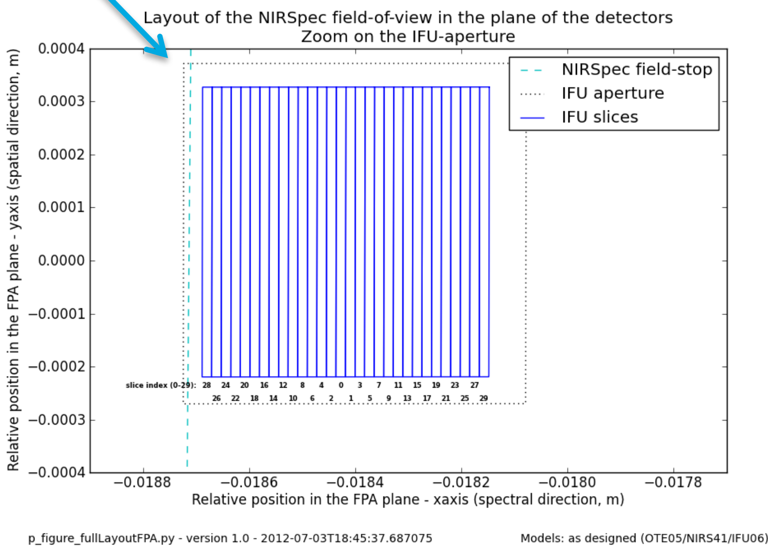
The fifth slit is on the other side

A complex field of view layout: How does one put 3 instruments in one?

- **A small aperture for the IFU mode.**







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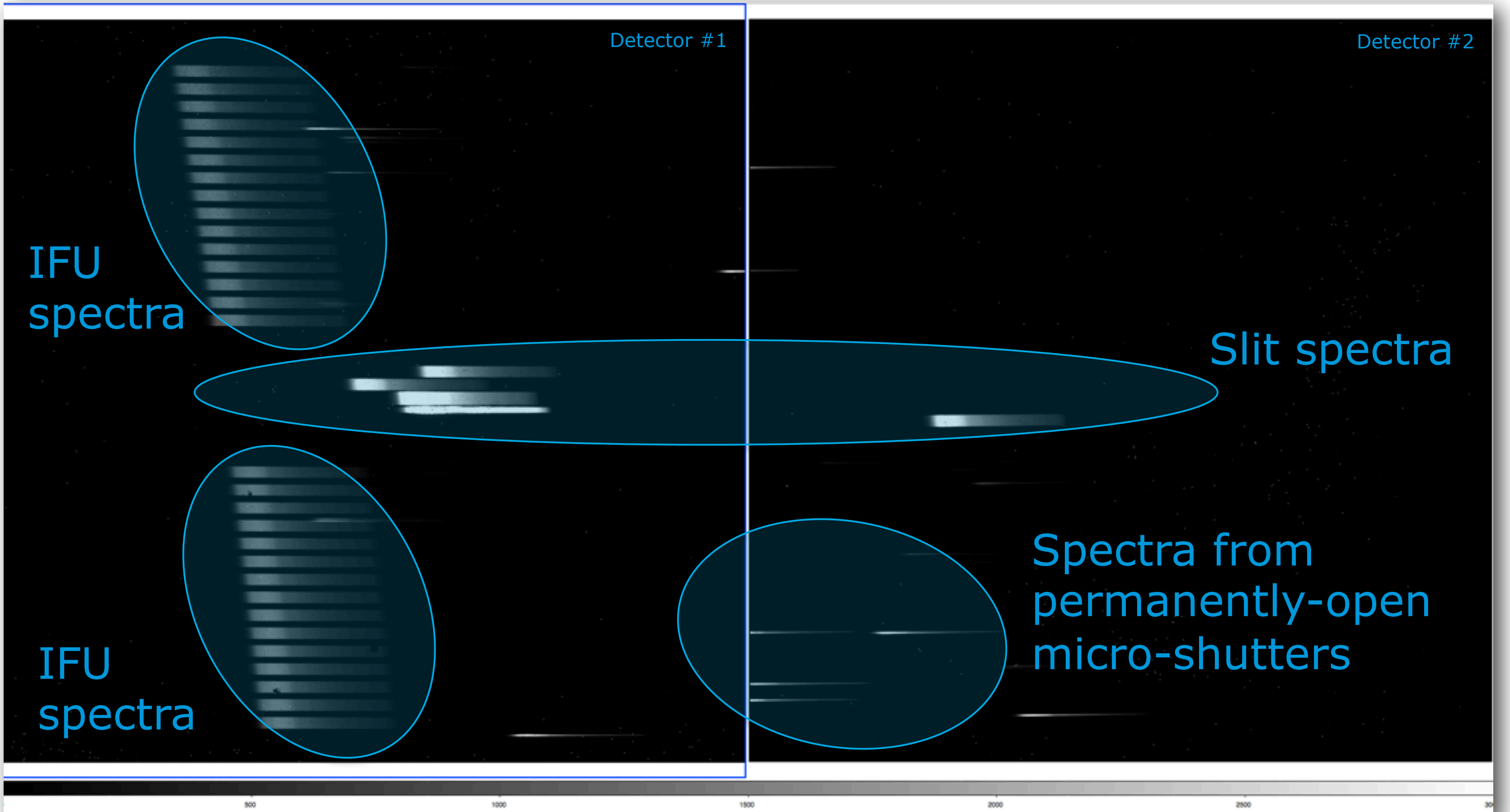
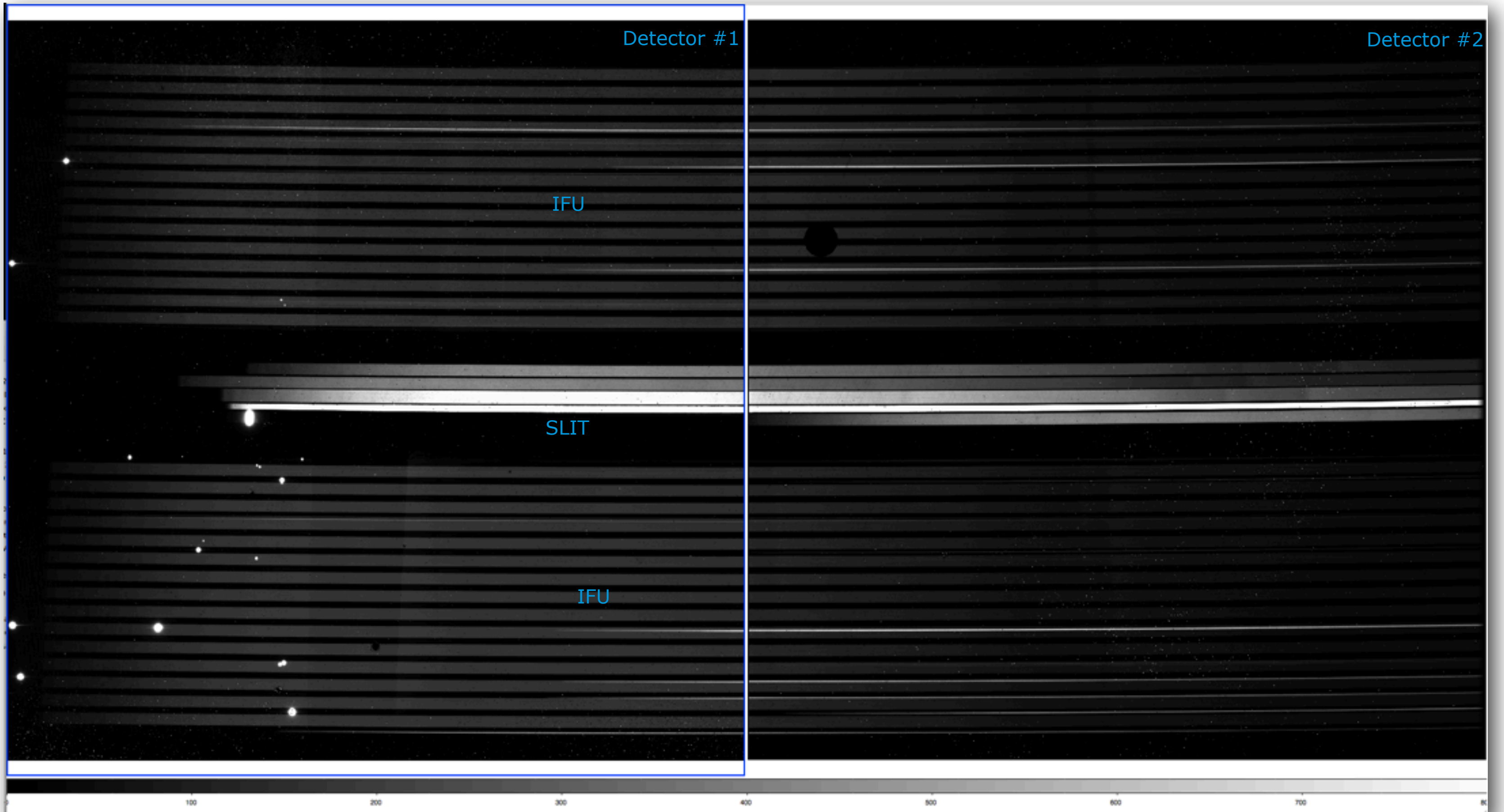
Managing the detector real estate: Where do we put all these spectra?



Short continuum spectra obtained with the prism during cryogenic testing in 2011. Only IFU and SLIT modes were available.

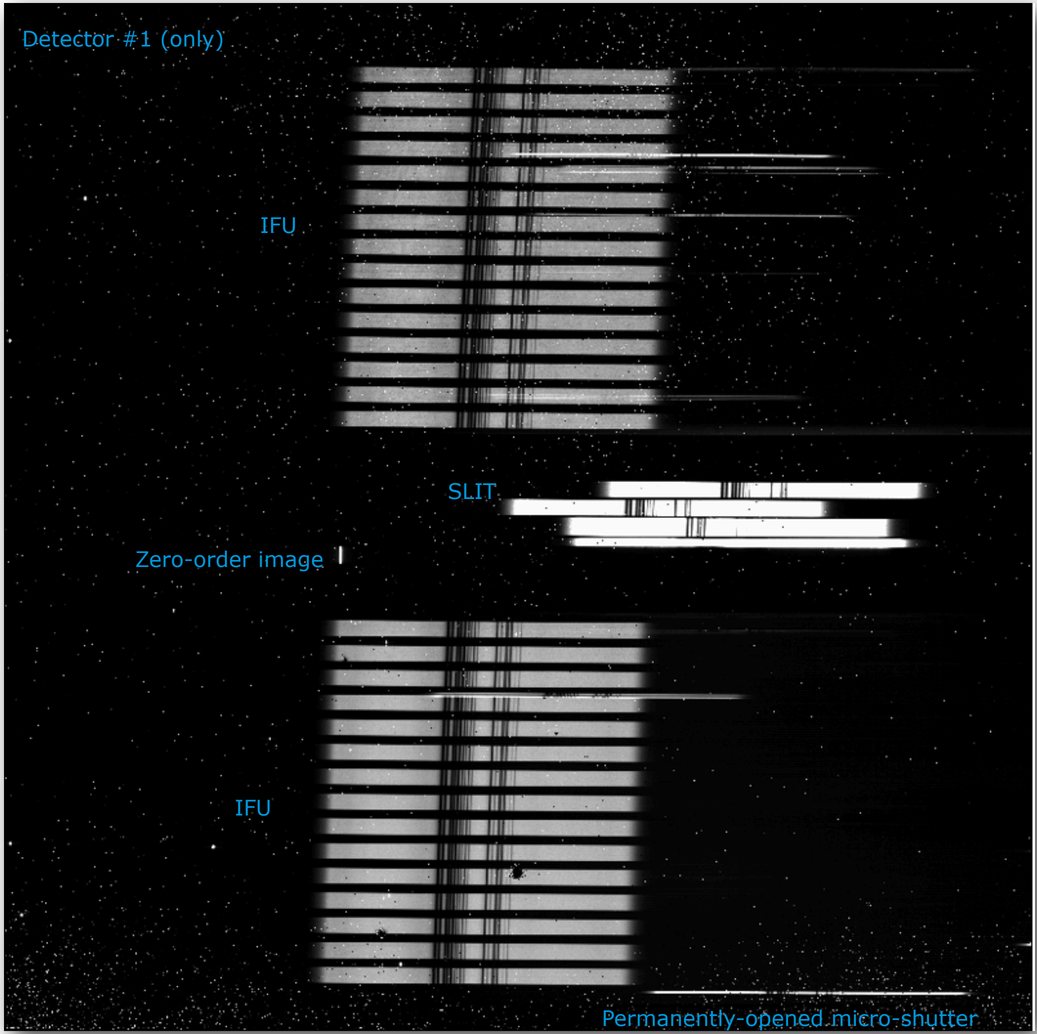
Managing the detector real estate: Where do we put all these spectra?



Medium (R=700-1300) continuum spectra obtained with the IFU during cryogenic testing in 2011. Only IFU and SLIT modes were available.

Managing the detector real estate: Where do we put all these spectra?

Medium resolution (R=700-1300) spectra of a continuum source with absorption features obtained with the IFU during cryogenic testing in 2011.



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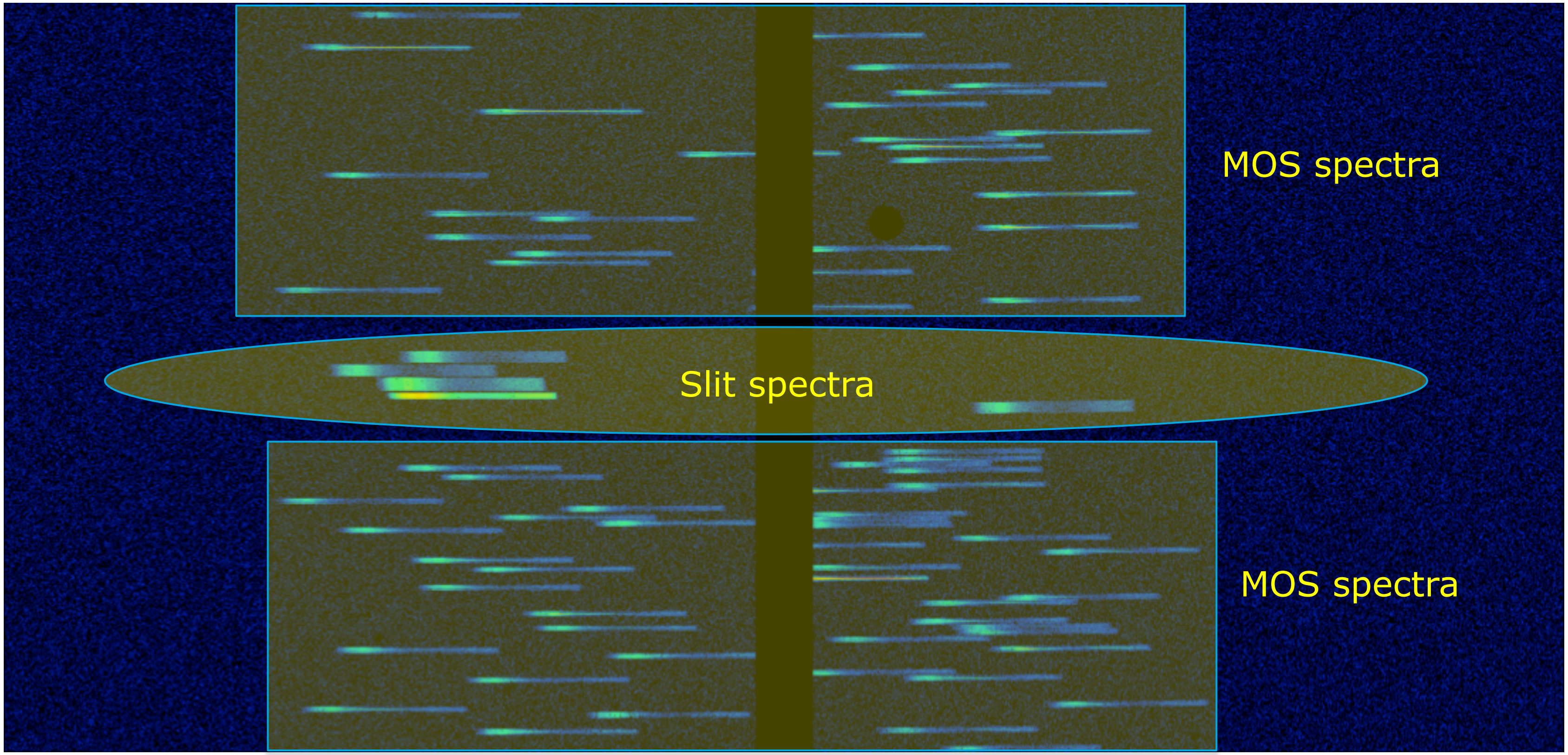
Managing the detector real estate: Where do we put all these spectra?



Simulation of MOS low resolution (R=30-300) spectra of a point-like galaxies with the zodiacal light background.

See presentation by B. Dorner.

Managing the detector real estate: Where do we put all these spectra?

- What do you need to remember?
  - The SLIT mode has been allocated its own detector real estate and can be used simultaneously to the MOS and IFU modes.
  - The MOS and IFU modes share the same detector real-estate and cannot be used simultaneously.
    - One has to close all the micro-shutters before taking a spectroscopic exposure with the IFU.
    - One has to block the IFU aperture before taking a MOS exposure.
  - Permanently open (called failed-open) or simply “leaky” micro-shutters will generate permanent “parasitic” spectra that can overlap with the IFU spectra.
    - Failed open micro-shutters are BAD!

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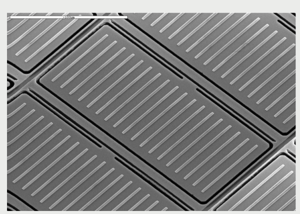
More on the MOS mode…

- **The challenge of multi-object spectroscopy**
  - Letting the light from selected objects (> 100) go through while blocking the light from all the other objects.

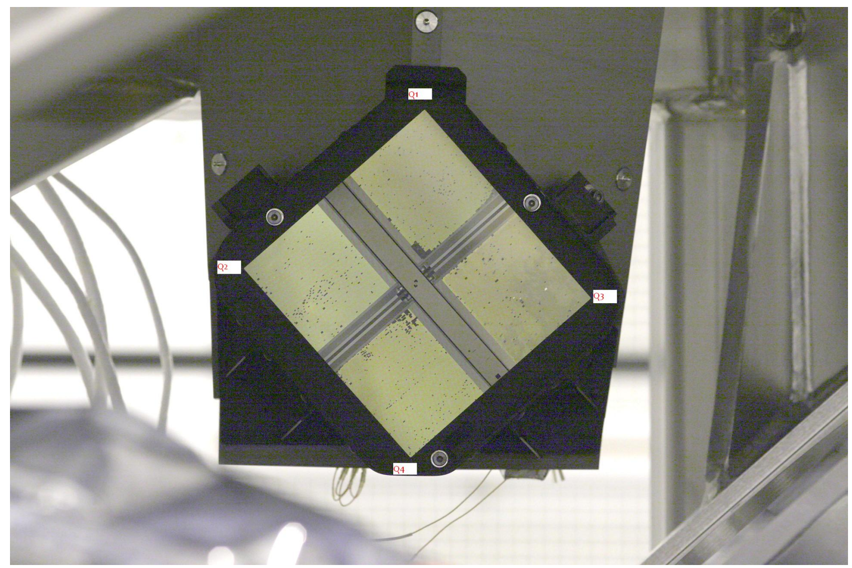
➔ **The micro-shutter array.**

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



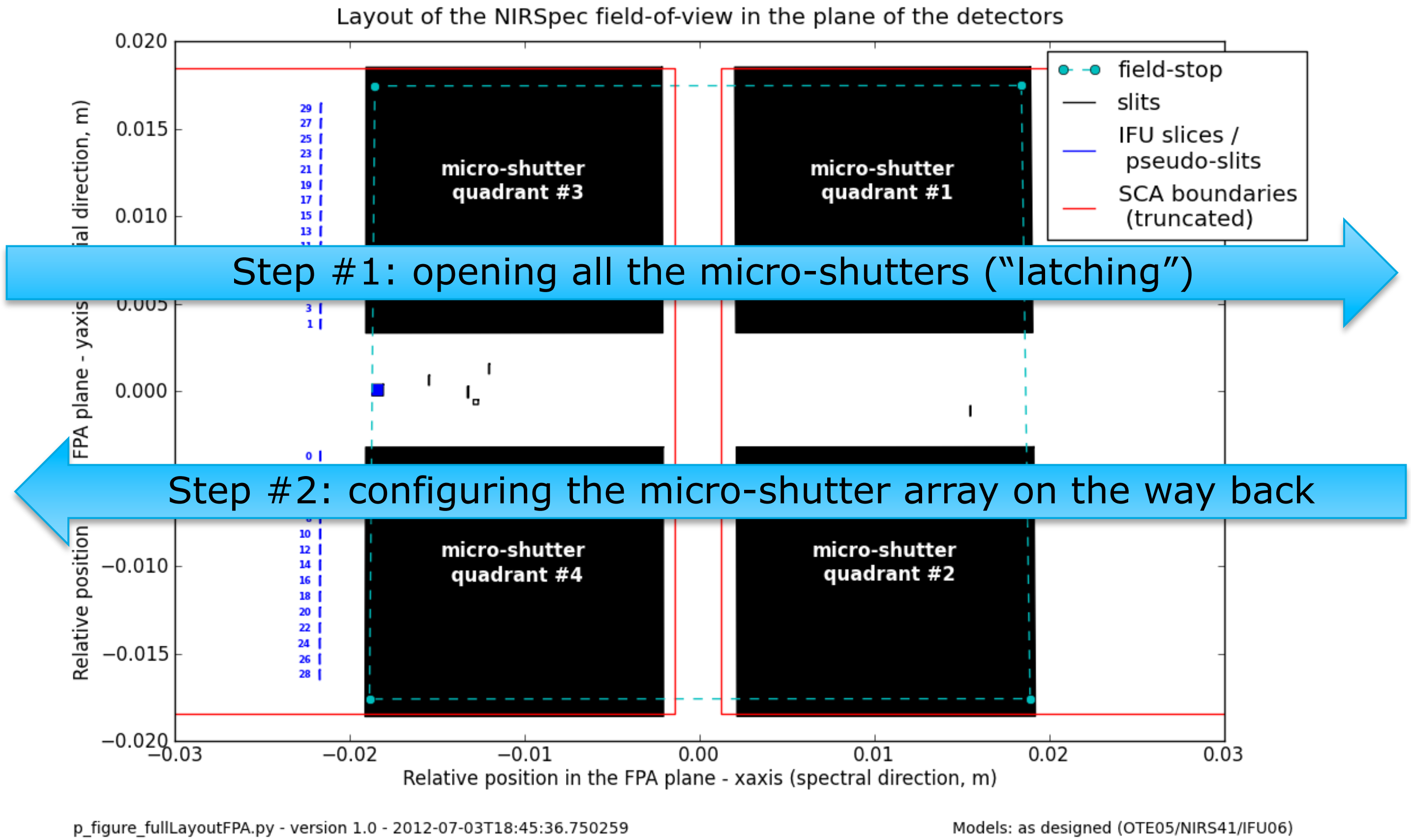
MEMS device – 105x206 micron shutters



The micro-shutter array seen through NIRSpec fore-optics.

More on the MOS mode…

- **Operating the micro-shutter array.**
    - Using a magnet to open the micro-shutters.

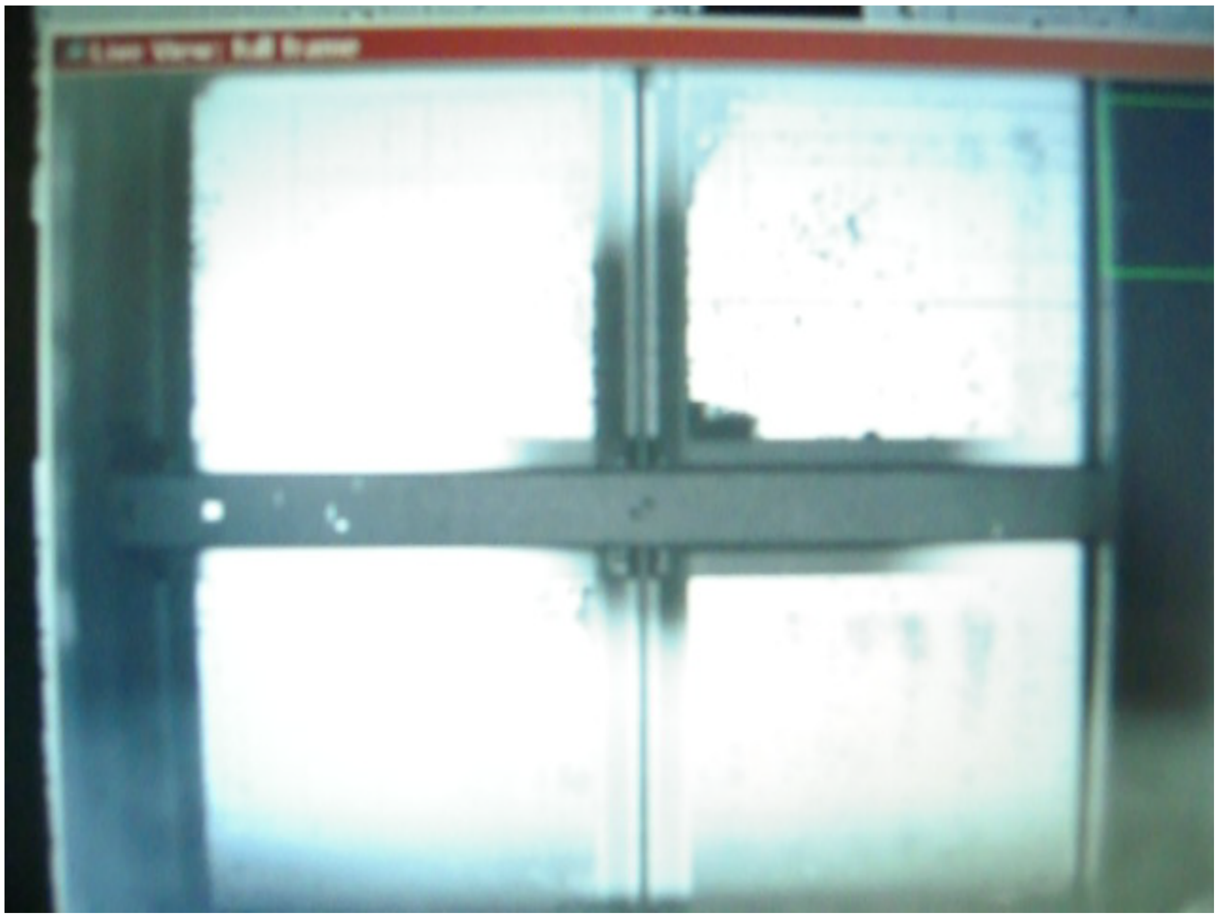


More on the MOS mode…

- **Step #1 – Opening all the micro-shutters ("latching").**

More on the MOS mode…

- **Step #2 – Configuring the micro-shutter array.**



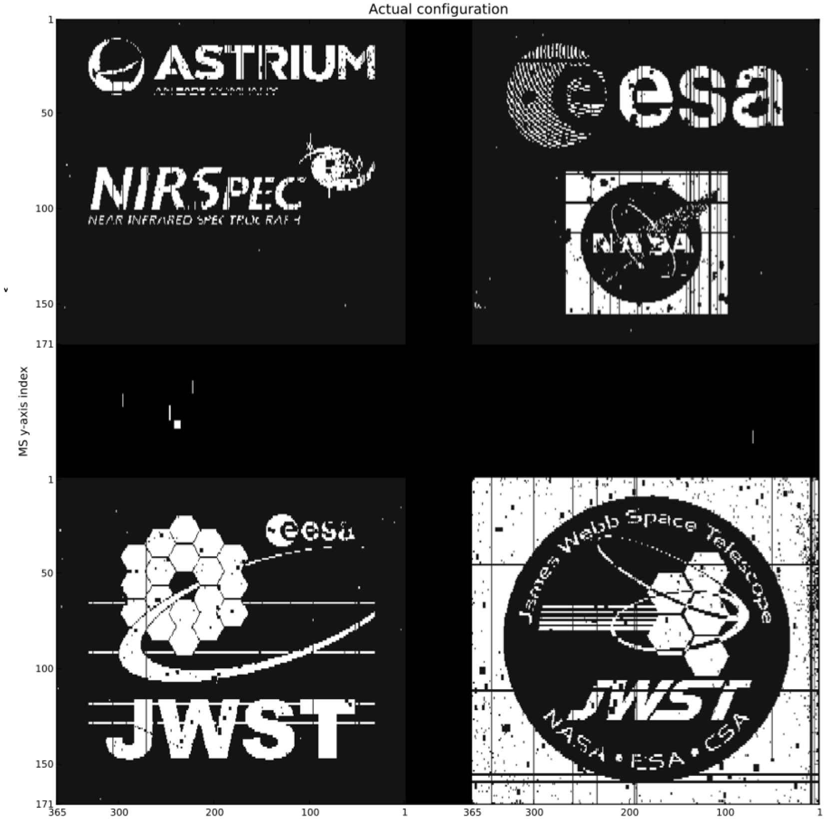
More on the MOS mode…

The real thing…

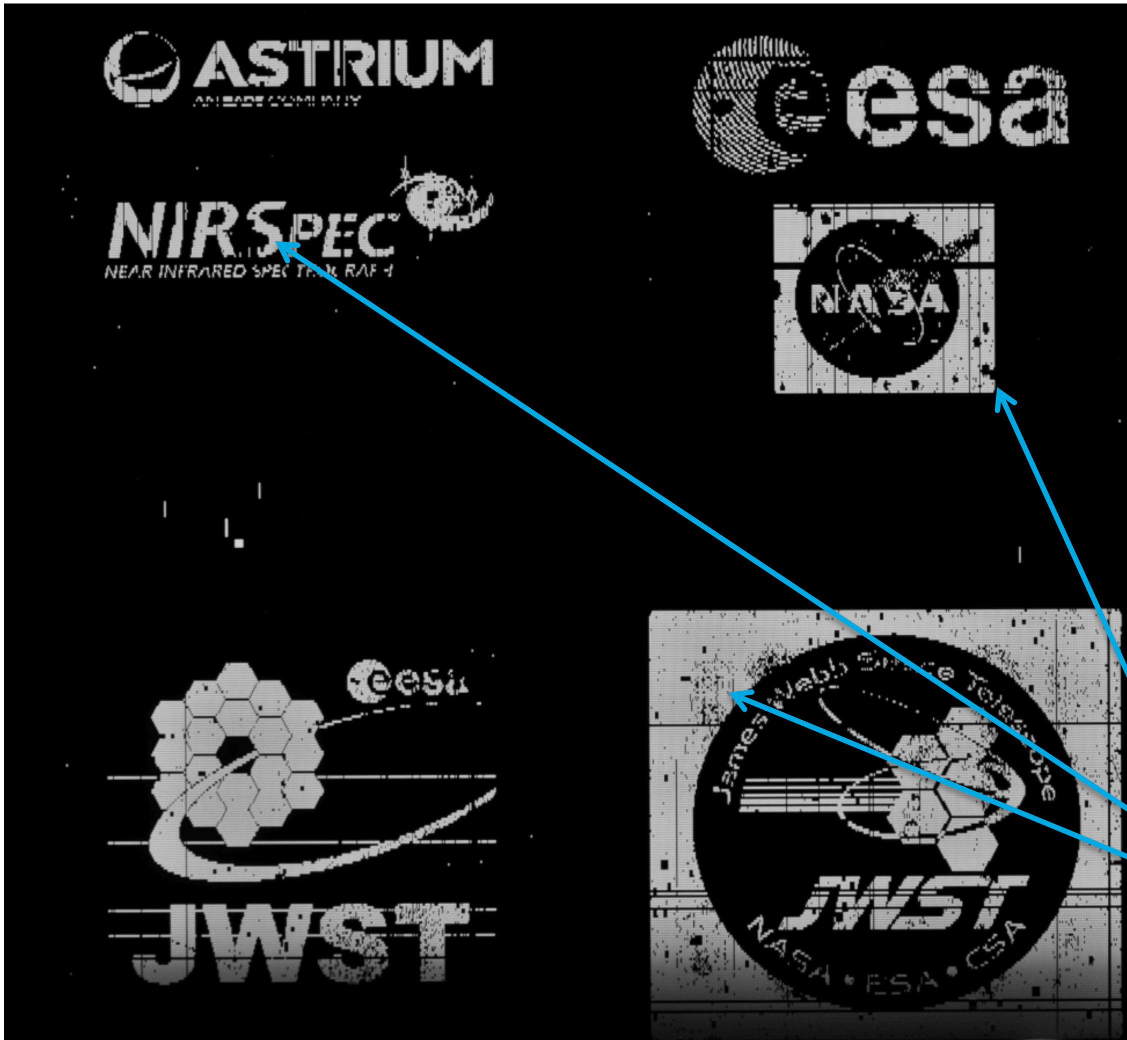
Picture of the configured MSA in the dewar with back-illumination

The simulated one…

Programmed pattern + maps of failed closed/open



More on the MOS mode…



Not all the shutters are operable. We want the fraction of "failed-closed" shutters to remain below 10-15%.

Remember: we only open ~300-400 of them per exposure (i.e. < 2%).

Examples of failed-closed shutters.

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The imaging mode for target acquisition.

- **In order to accurately place the targets in the micro-shutters, we need to obtain a target acquisition image.**
  - One of positions of the grating wheel is occupied by a mirror.
  - Image of the sky **through** the micro-shutter array can be obtained.

See presentation by T. Böker.

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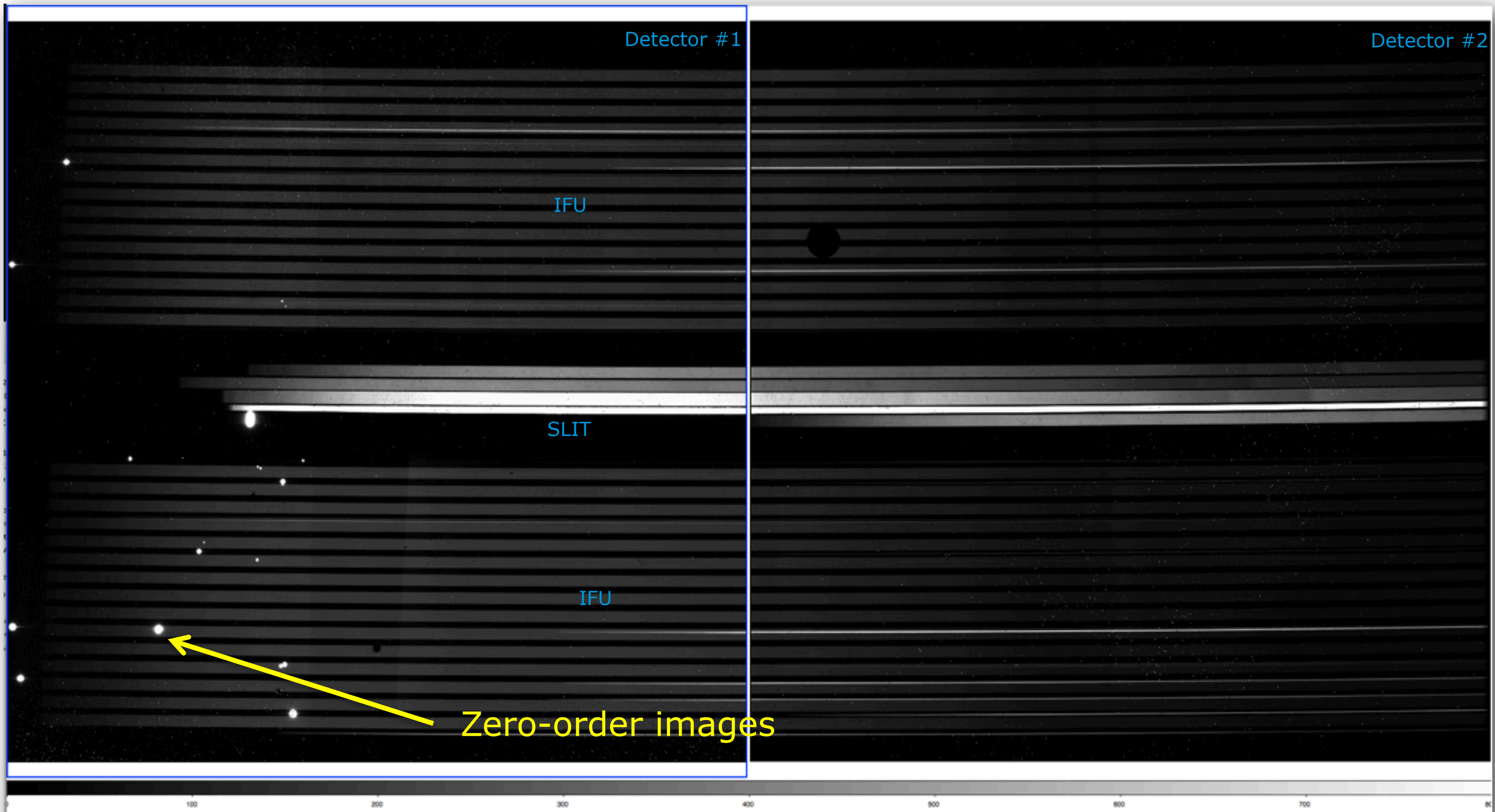
- **A few NIRSpec features.**
- The end…

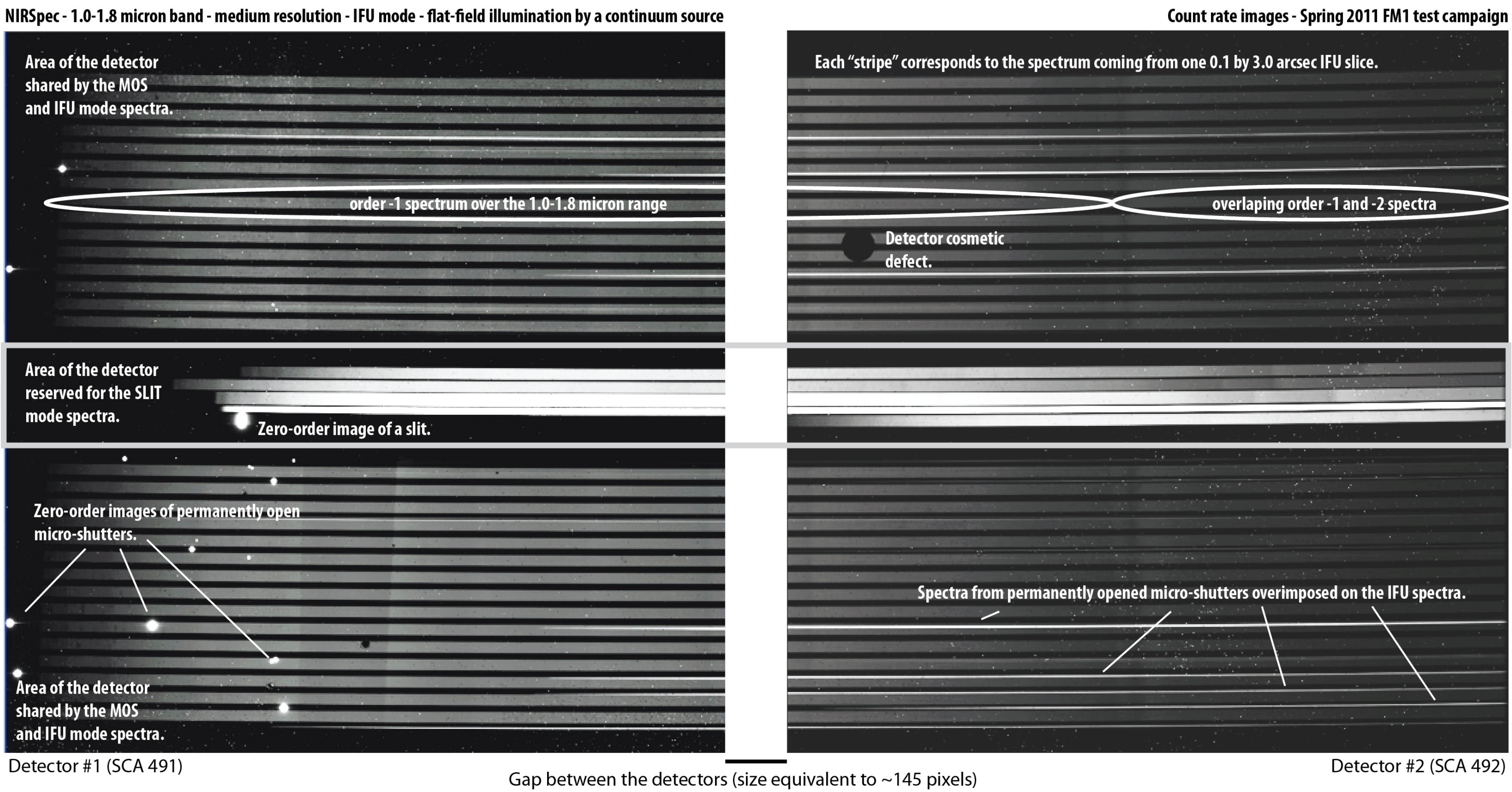
This is were one can place the word "idiosyncrasies".

A few NIRSpec features: Orders 0 and -2 when using the gratings



Contamination by the orders 0 (image of the field of view) and -2 (outside for the scientific band of the spectra).

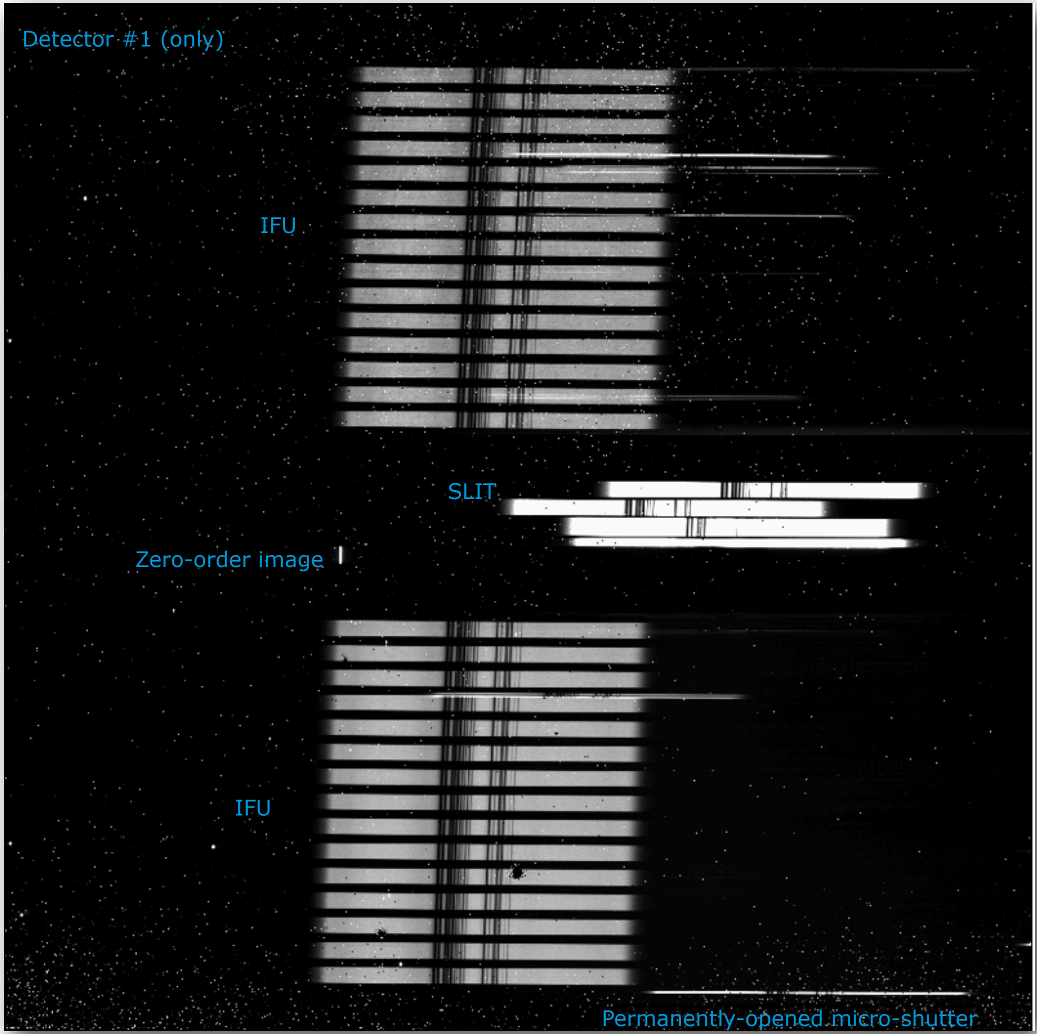
A few NIRSpec features:
Orders 0 and -2 when using the gratings



A few NIRSpec features: The "slit tilt"

Notice the tilt of the "iso-wavelength" lines that can be traced using the absorption lines.

This is an intrinsic property of NIRSpec optical design and is referred as the "slit tilt" because the monochromatic image of a vertical slit appears tilted on the detectors.



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