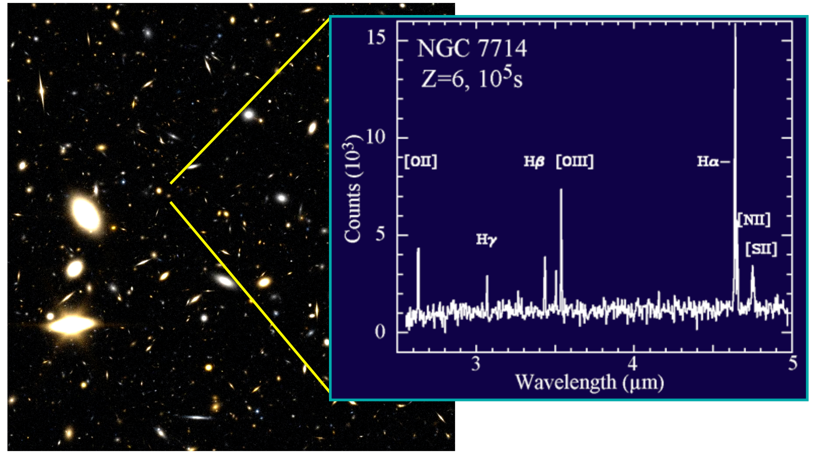
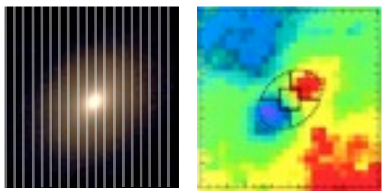
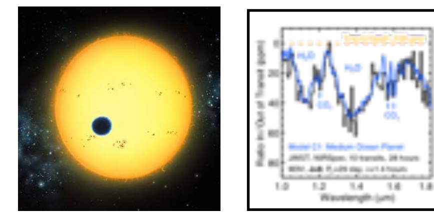


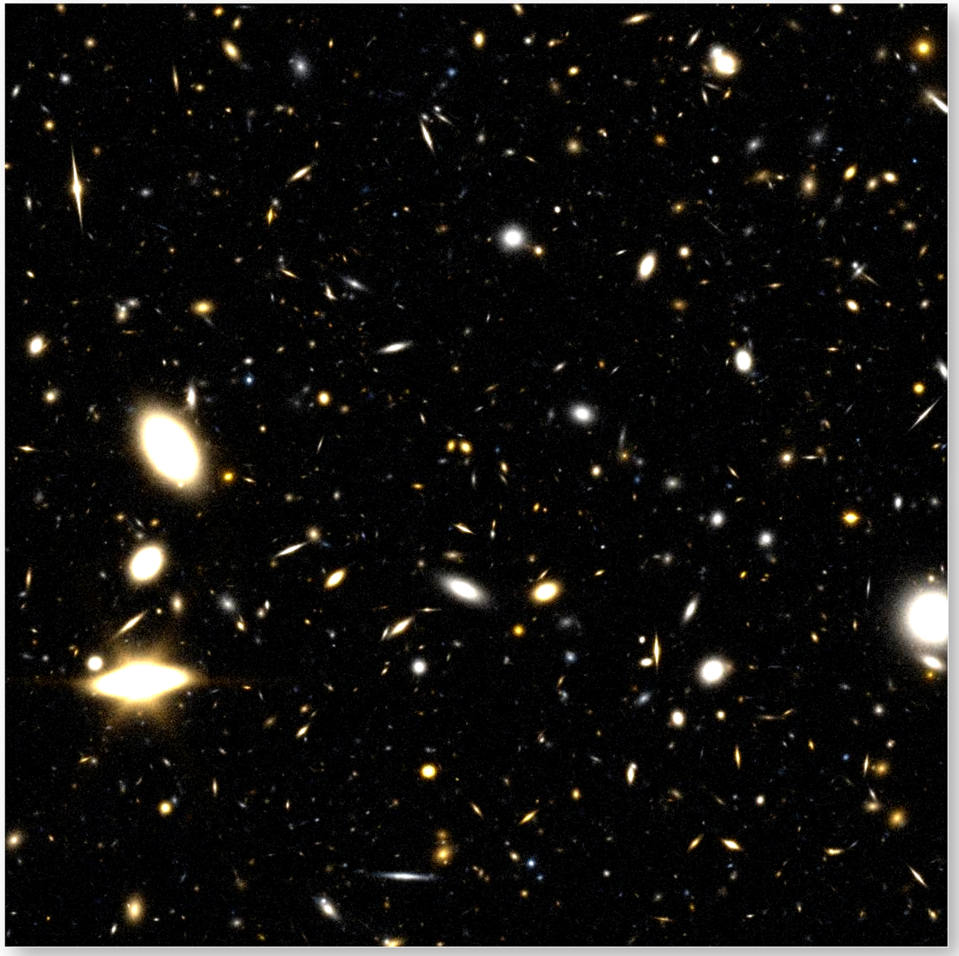




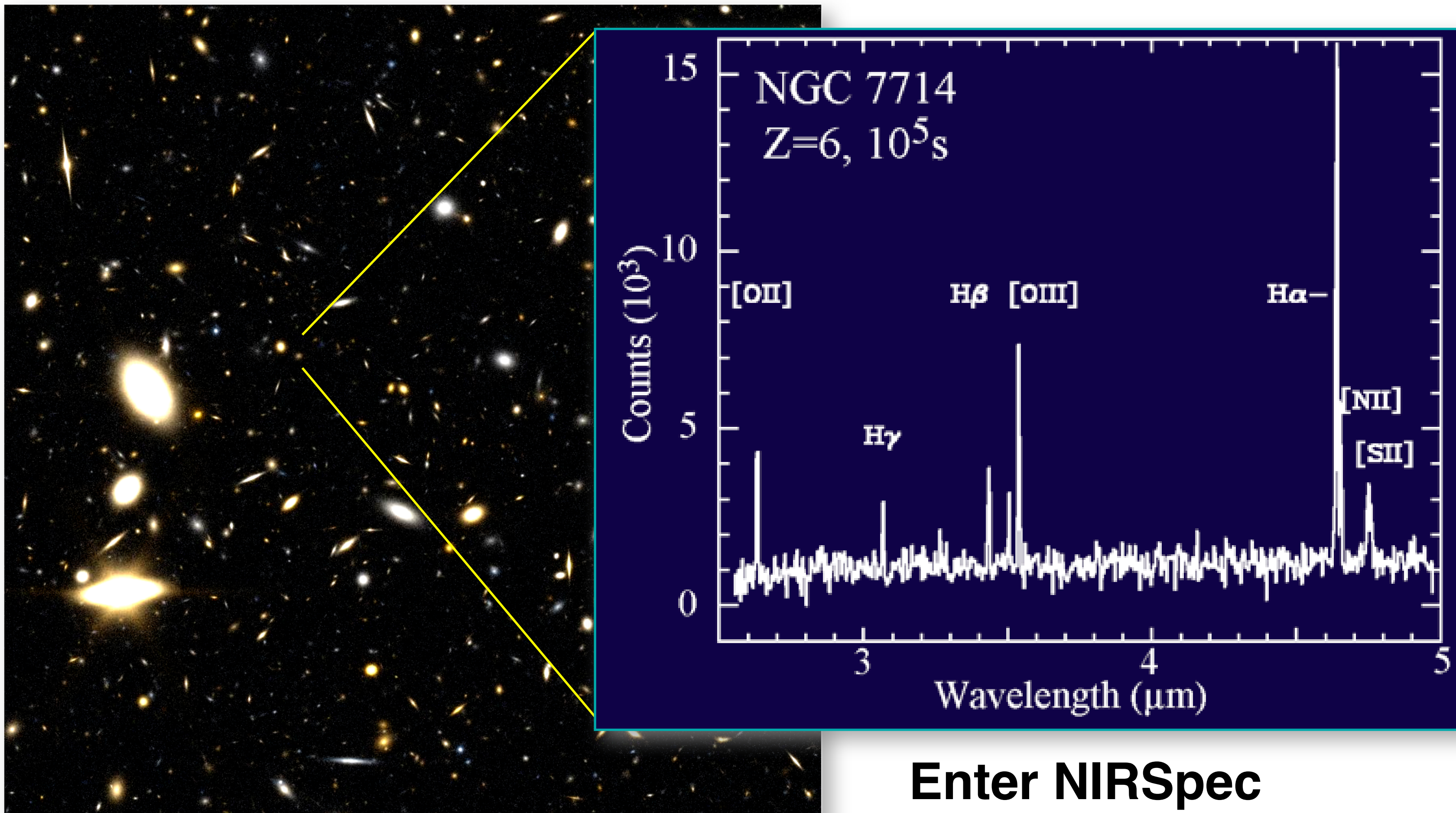
Short Introduction to NIRSpec and its Scientific Objectives

Peter Jakobsen
ESA JWST Project Scientist

A Pretty Picture Is Not Enough



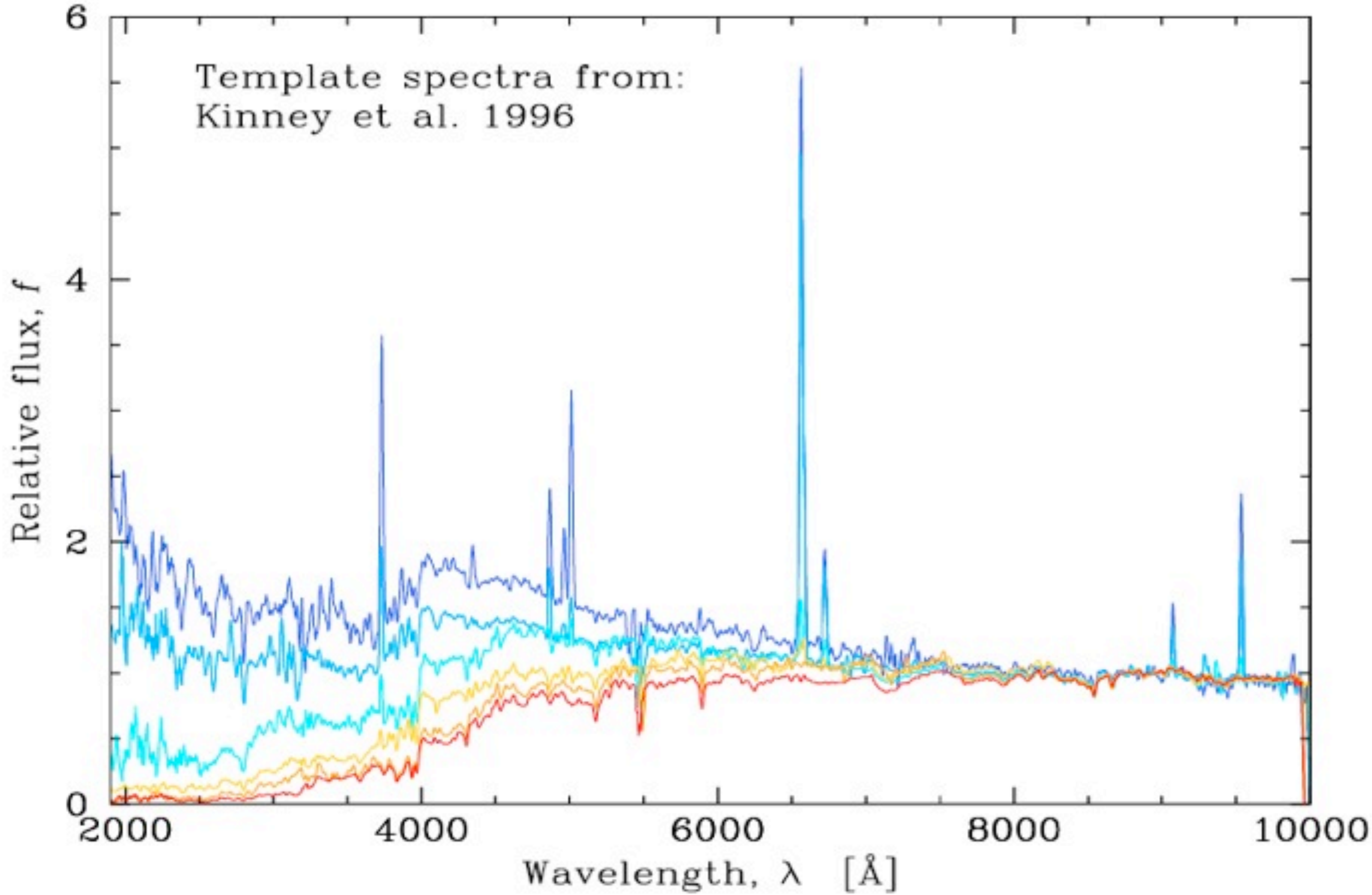
A Pretty Picture Is Not Enough



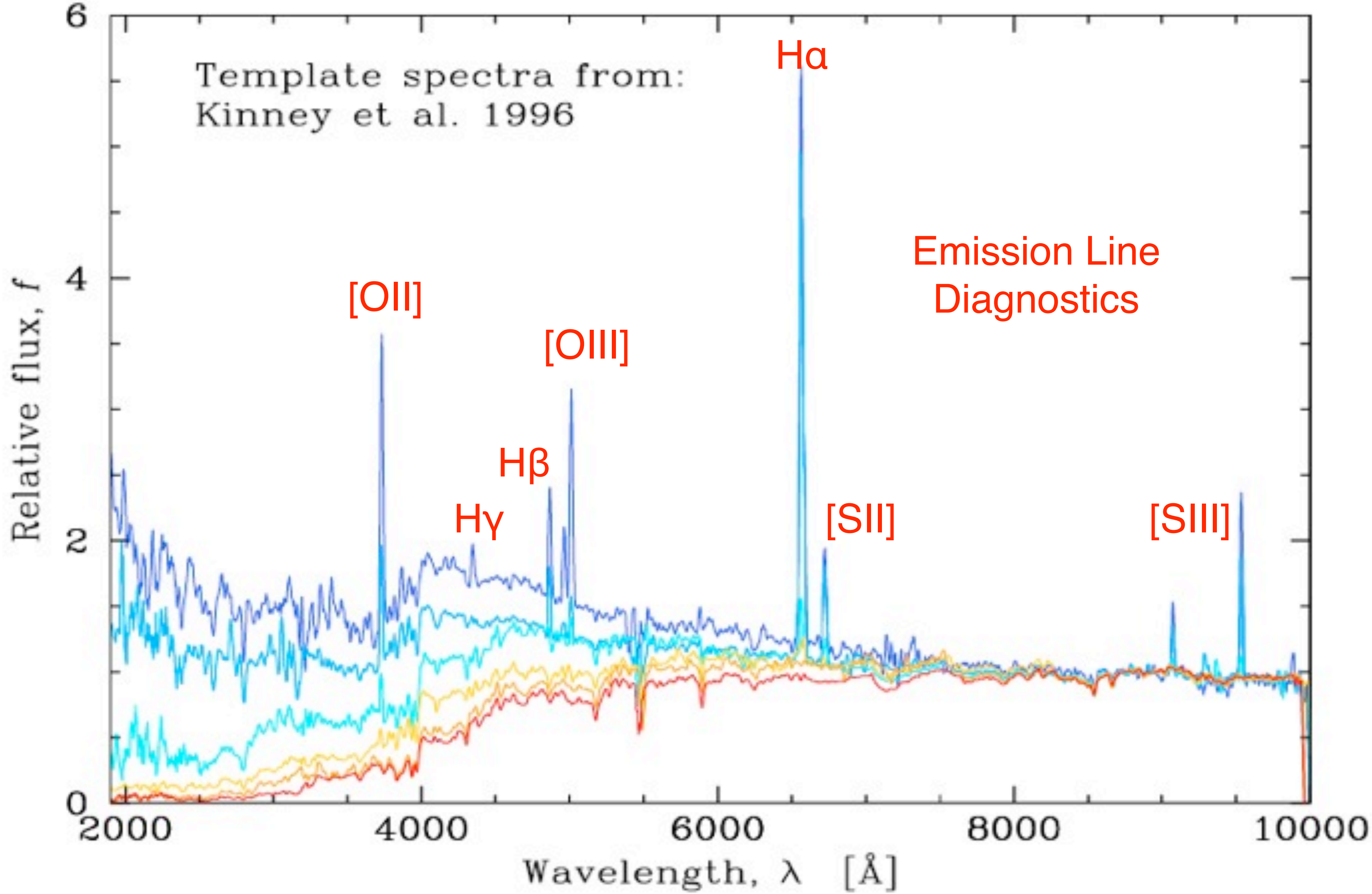
Enter NIRSpec

Imaging is Astronomy - Spectroscopy is **Astrophysics**

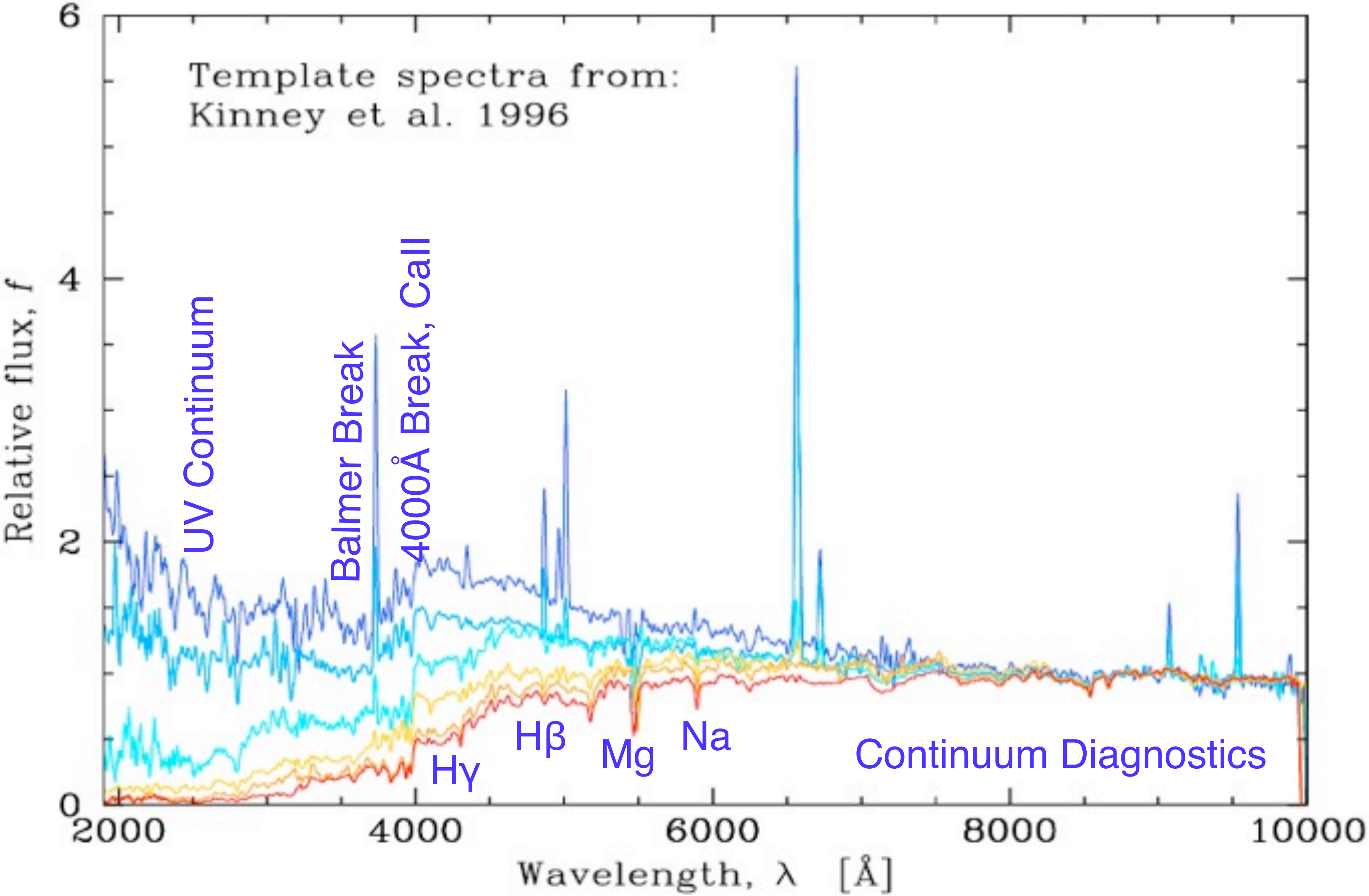
Spectroscopic Diagnostics



Spectroscopic Diagnostics



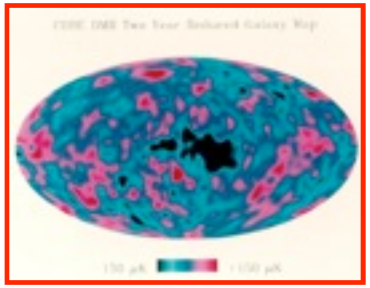
Spectroscopic Diagnostics

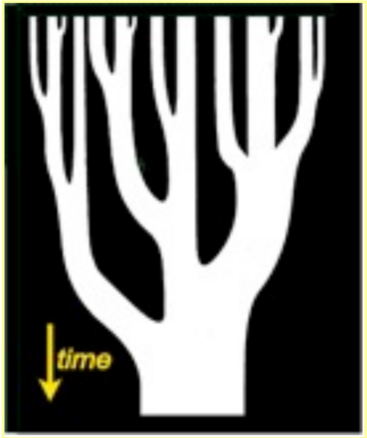


James Webb Space Telescope

The Key NIRSpec Driver

- Understanding how galaxies assembled and evolved is at heart a *statistical* problem
- Need to measure ages, masses, star formation rates and abundances of many different types of galaxies at different redshift
- Need large samples spanning thousands of galaxies
- **NIRSpec must be a dispersive *Multi-Object Spectrograph***





Level 1 Science Requirement

From JWST Program Plan:

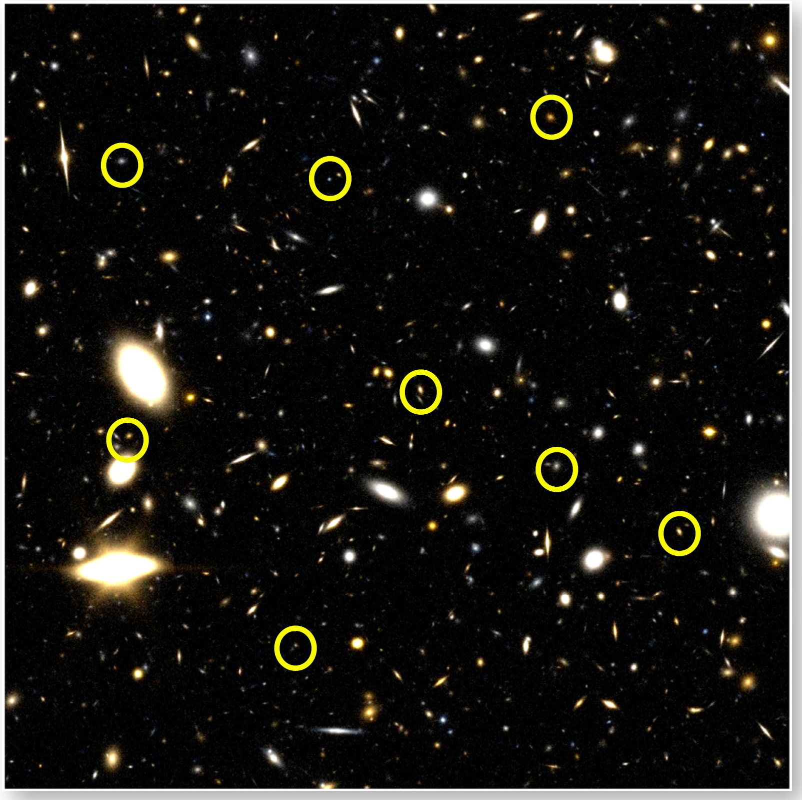
Mission Success: L1-2: Measure the spectra of at least 2500 galaxies with spectral resolutions of approximately R=100 (over 0.6 to 5 micrometers) and R=1000 (over 1 to 5 micrometers) and to a 2 micrometer emission line flux limit of 5.2×10^{-22} Wm^{-2} to enable determination of their redshift, metallicity, star formation rate, and ionization state of the intergalactic medium.

- ~2500 galaxies sorted into ~10 subclasses each sorted into ~10 redshift (time) bins
- ~25 samples per bin gives ~20% statistical sampling uncertainty per bin

Dispersive Multi-Object Spectroscopy

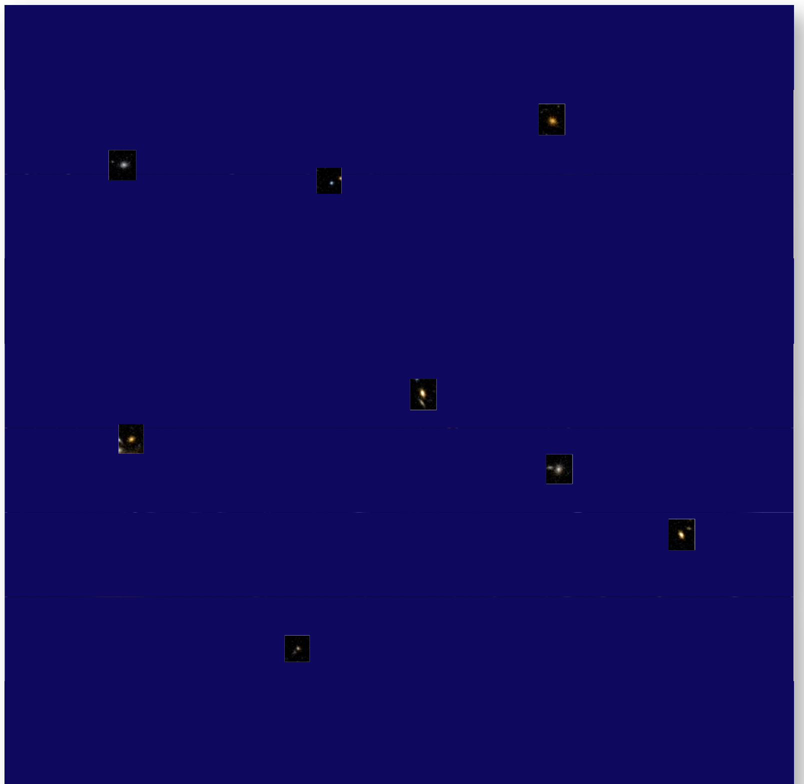
- Start with Image of Field

Dispersive Multi-Object Spectroscopy



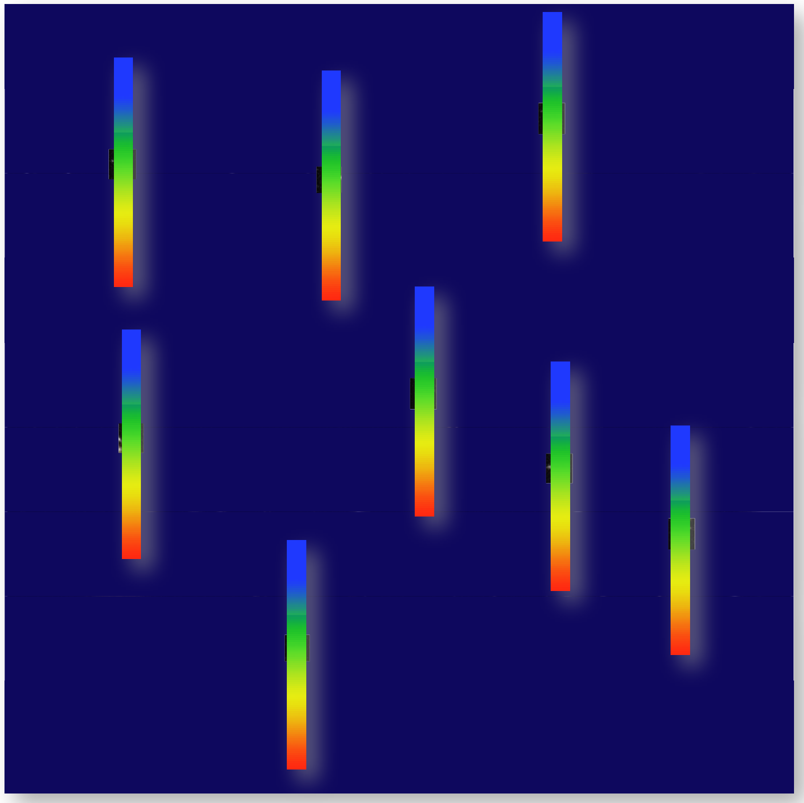
- Start with Image of Field
- Identify Targets of Interest

Dispersive Multi-Object Spectroscopy



- Start with Image of Field
- Identify Targets of Interest
- Mask off Remaining Field

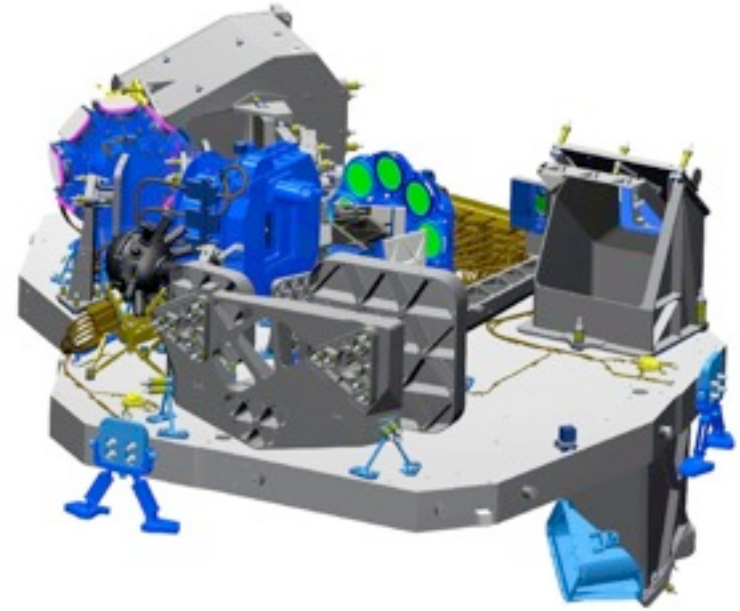
Dispersive Multi-Object Spectroscopy



- Start with Image of Field
- Identify Targets of Interest
- Mask off Remaining Field
- Take Dispersed Image

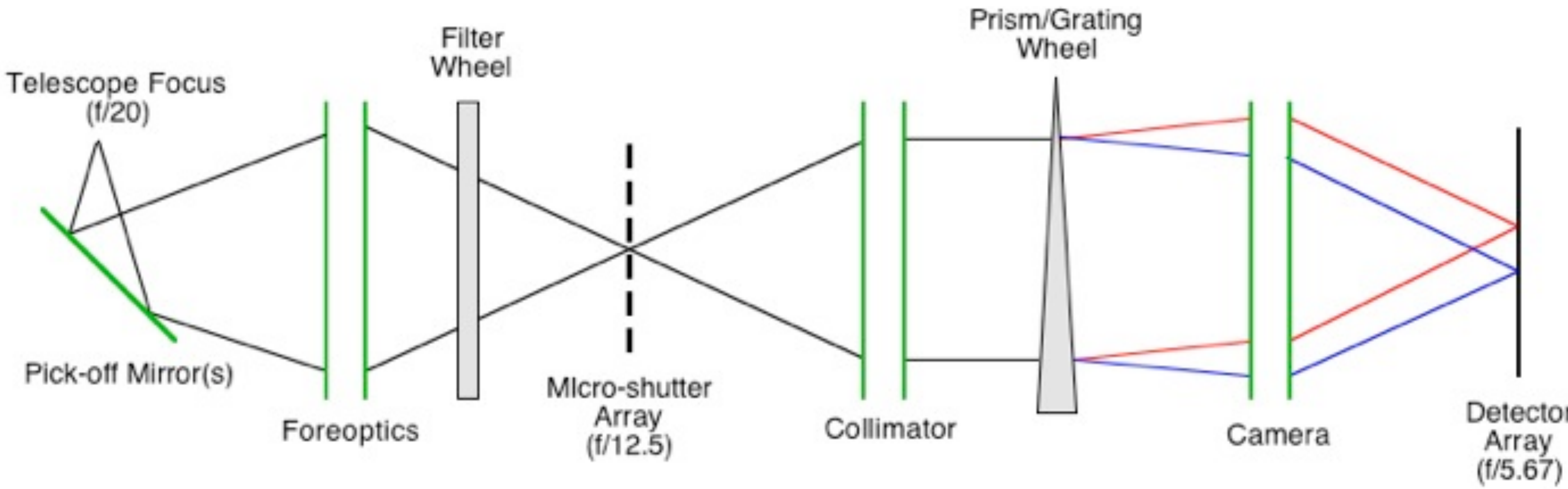
NIRSpec Vital Statistics

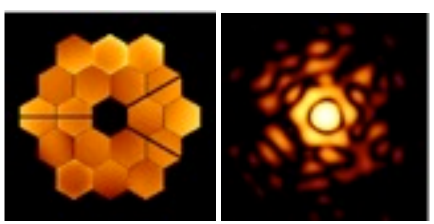
- All-Reflective Optics
- 3.4’ x 3.6’ FOV (9 arcmin^2 for MOS)
- 0.2” mas nominal slit width
- 3 slit selection devices:
  - Micro-Shutter Array
  - 3” x 3” Integral Field Unit
  - 5 high-contrast fixed slits
- 3 spectral resolutions:
  - R=100 (0.7 - 5.0 μm) Redshifts, Continuum Spectra
  - R=1000 (1.0 - 5.0 μm) Emission Line Diagnostics
  - R=2700 (1.0 - 5.0 μm) Kinematics
- 2 x 2k x 2k HgCdTe arrays



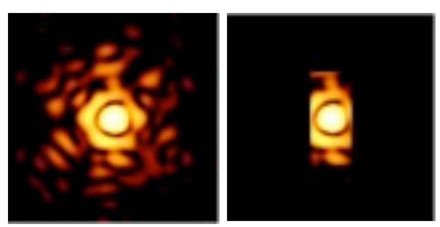
James Webb Space Telescope

NIRSpec Optical Schematic

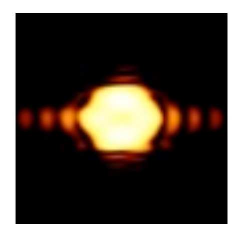




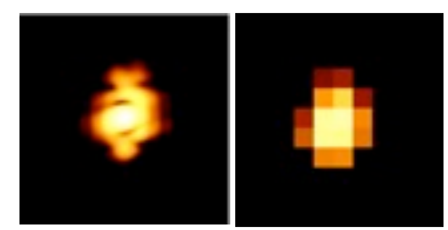
Telescope Focus



Slit Mask

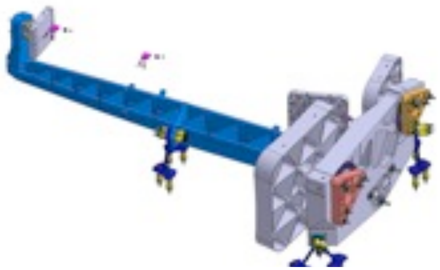


Pupil at Disperser

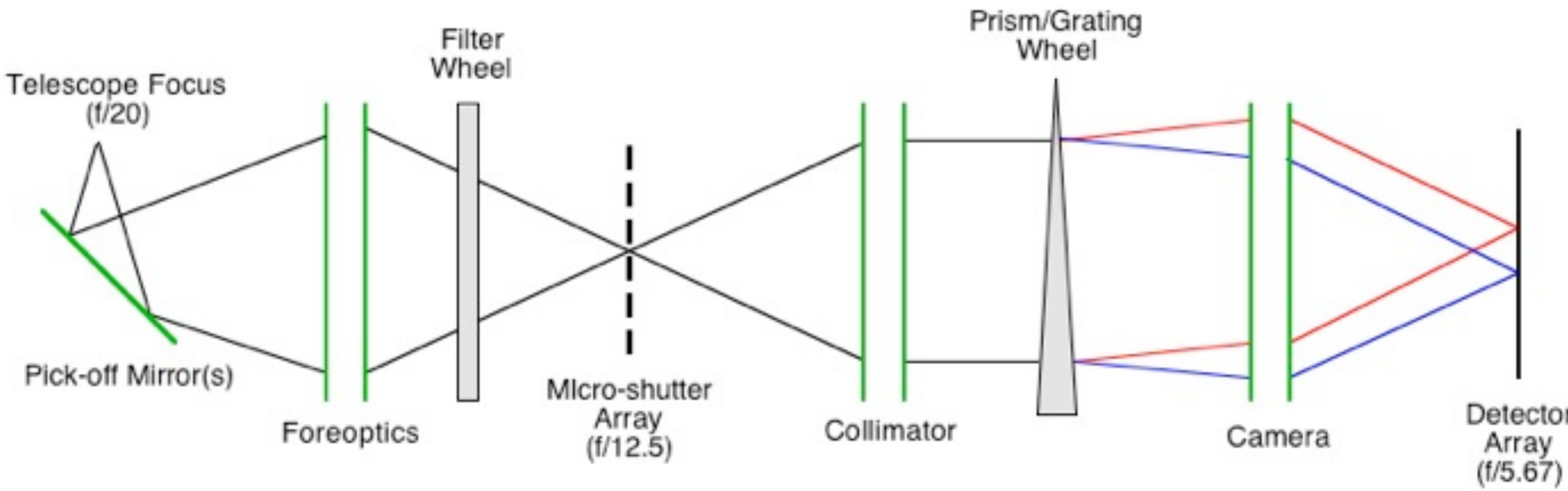


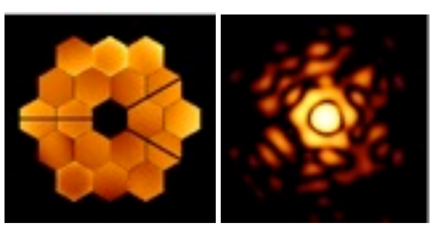
Detector Array

NIRSpec Foreoptics

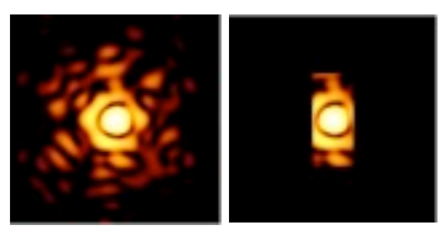


Images the curved telescope image onto the flat MSA in a telecentric manner at a demagnification of 0.625

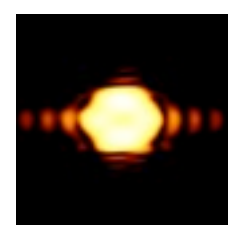




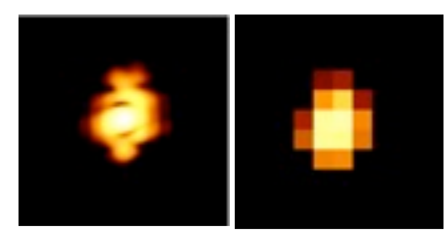
Telescope Focus



Slit Mask



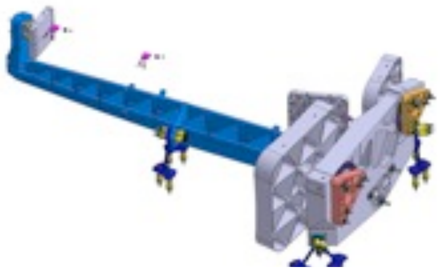
Pupil at Disperser



Detector Array

James Webb Space Telescope

NIRSpec Foreoptics



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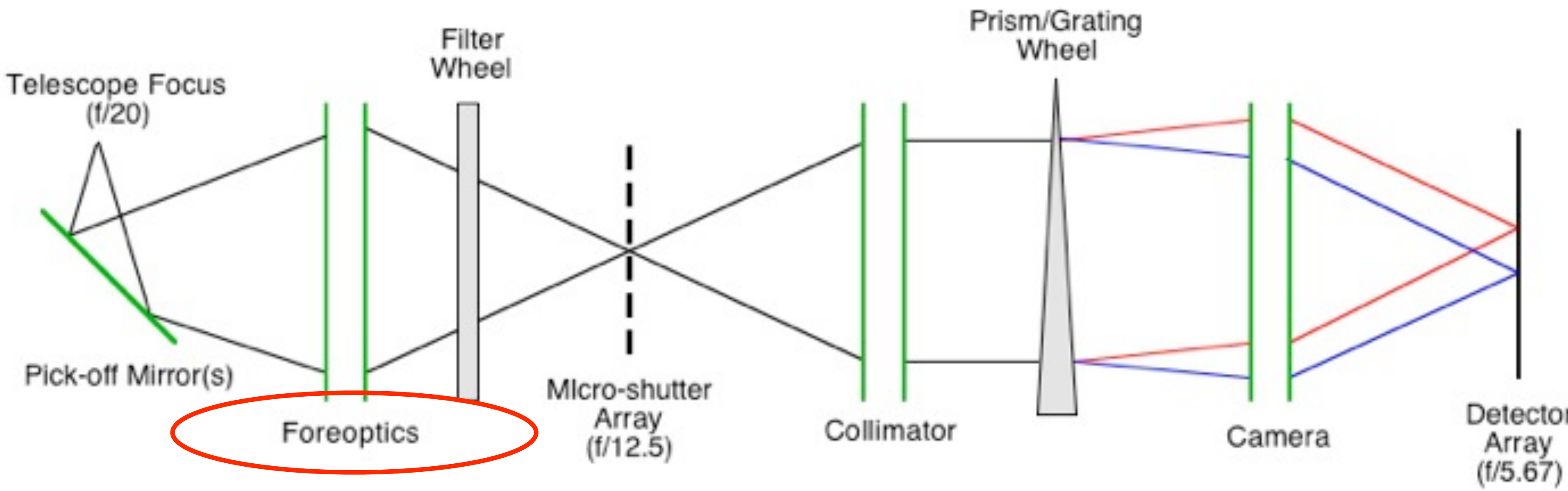
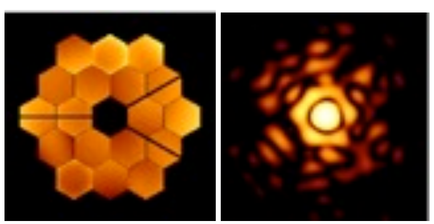
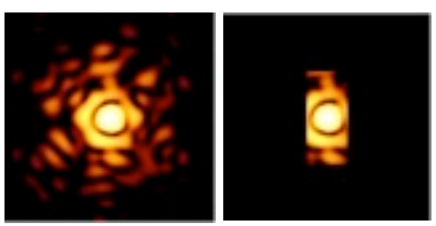
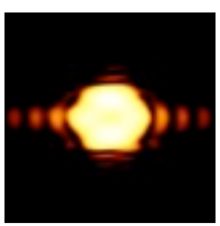




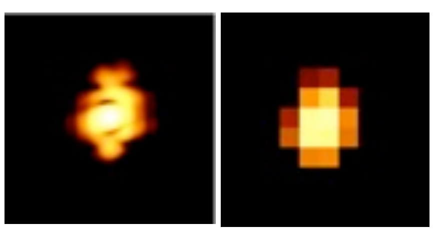
Telescope Focus



Slit Mask

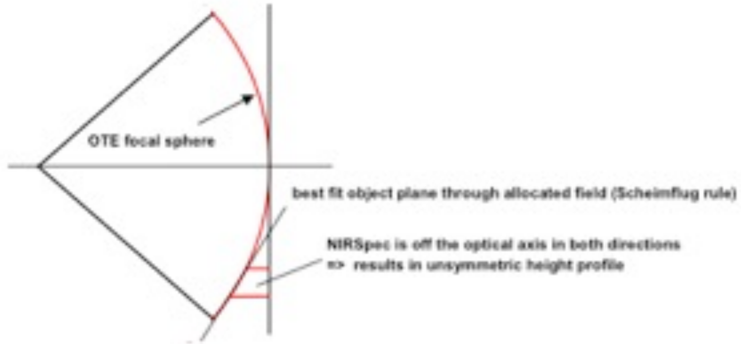


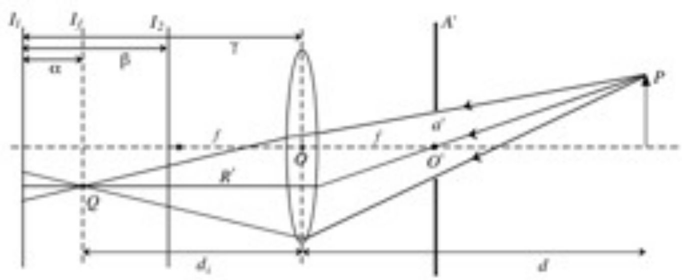
Pupil at Disperser

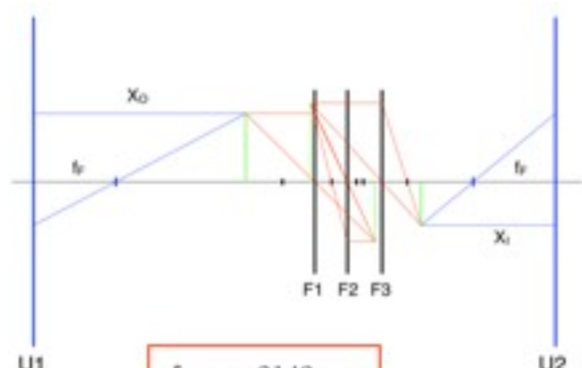


Detector Array

NIRSpec Foreoptics







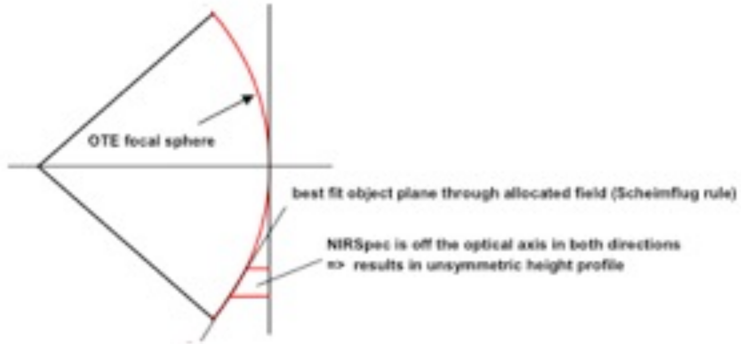
$$\boxed{f_F = -2143 \text{ mm}}$$

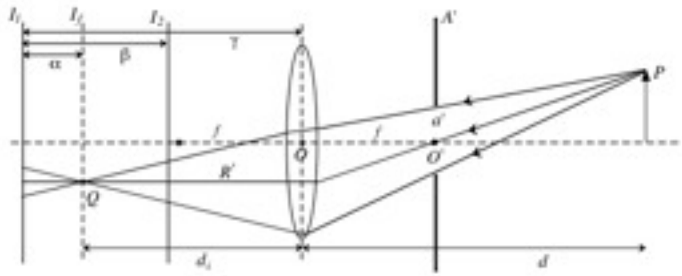
$$\frac{1}{X_o} + \frac{1}{X_I} = \frac{1}{f_F} \qquad m_F = \frac{f_F}{X_o - f_F} \qquad dm_F = \frac{m_F^2}{f_F} dX_o$$

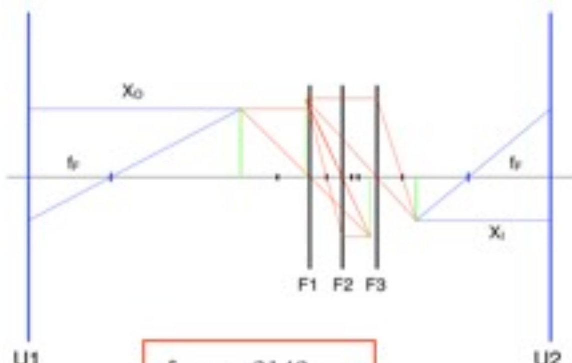
Decreasing Object Distance ⇒ Greater Demagnification

- Flattens curved telescope input image
- Provides telecentric illumination of MSA over entire FOV
- Partially compensates for telescope focal position drift

NIRSpec Foreoptics







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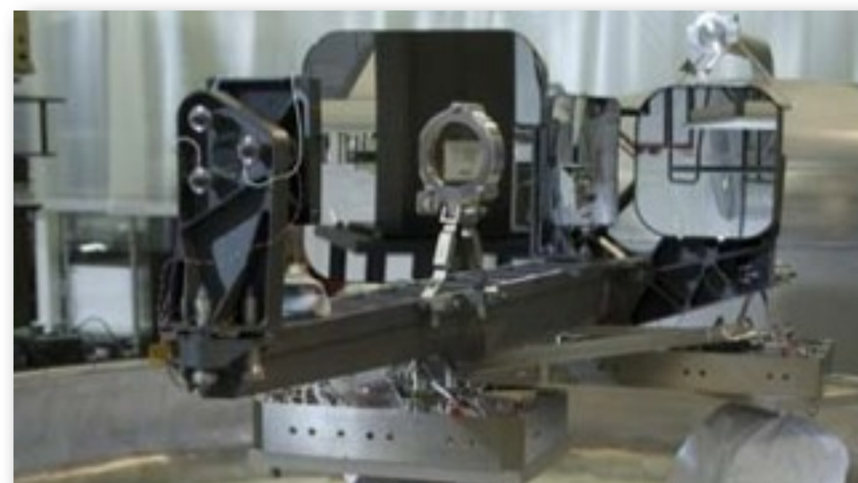
Decreasing Object Distance ⇒ Greater Demagnification

- Flattens curved telescope input image
- Provides telecentric illumination of MSA



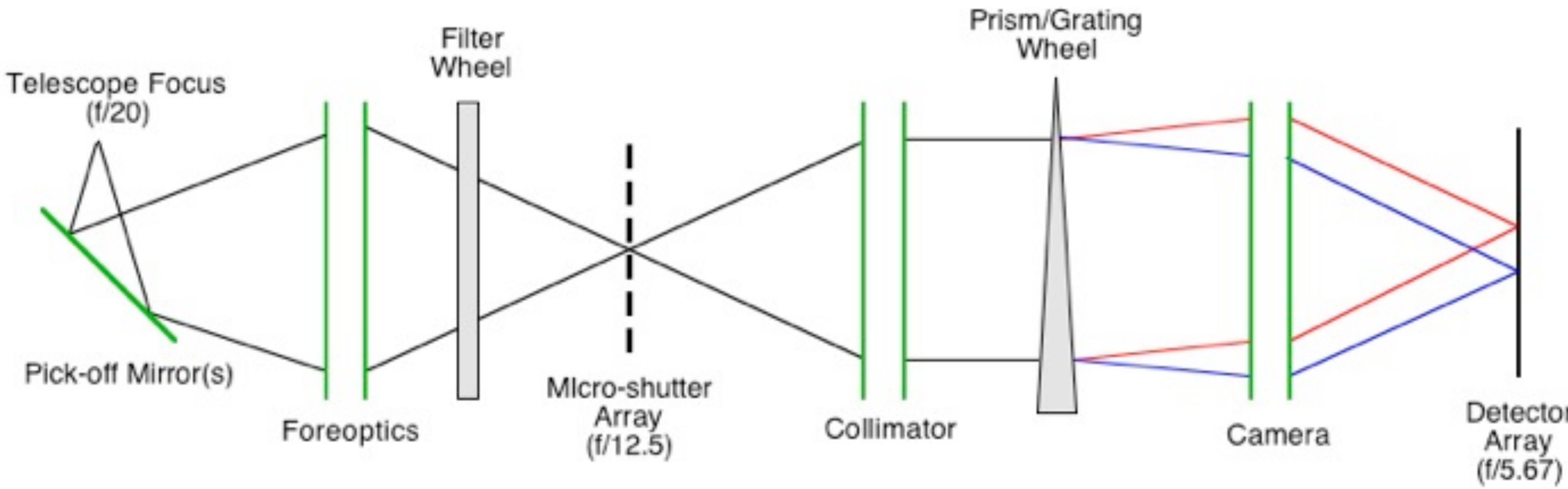
Truly a thing of beauty..

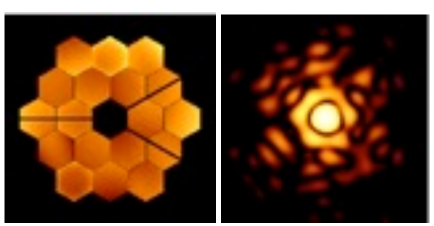
NIRSpec Filterwheel

Carries order-separation filters for gratings

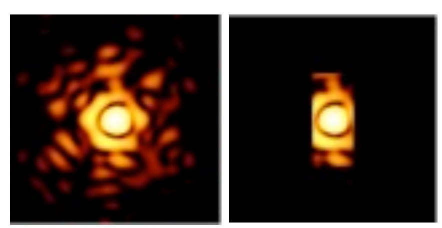
Calibration Unit

Refocus Mechanism

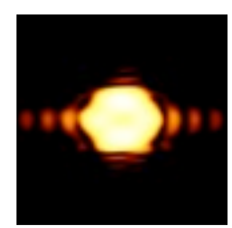




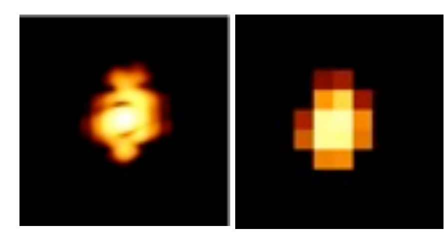
Telescope Focus



Slit Mask



Pupil at Disperser



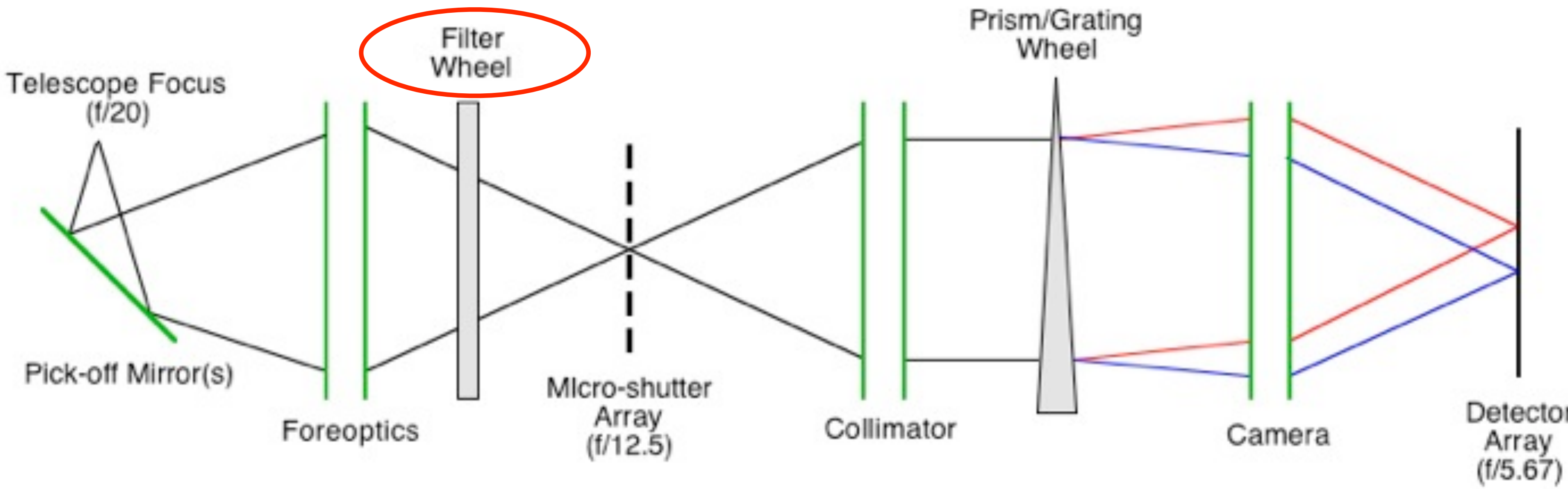
Detector Array

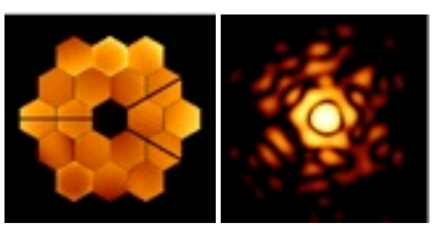
NIRSpec Filterwheel

Carries order-separation filters for gratings

Calibration Unit

Refocus Mechanism





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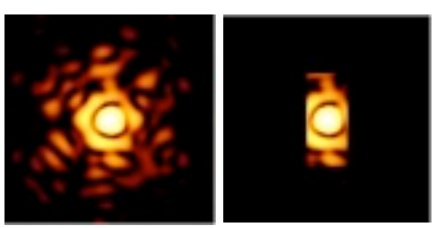
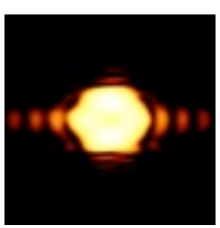


Slit Mask



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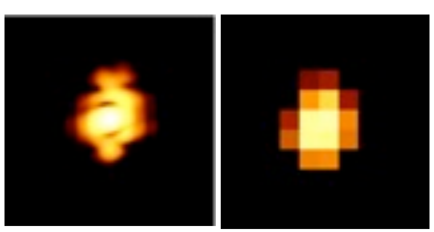
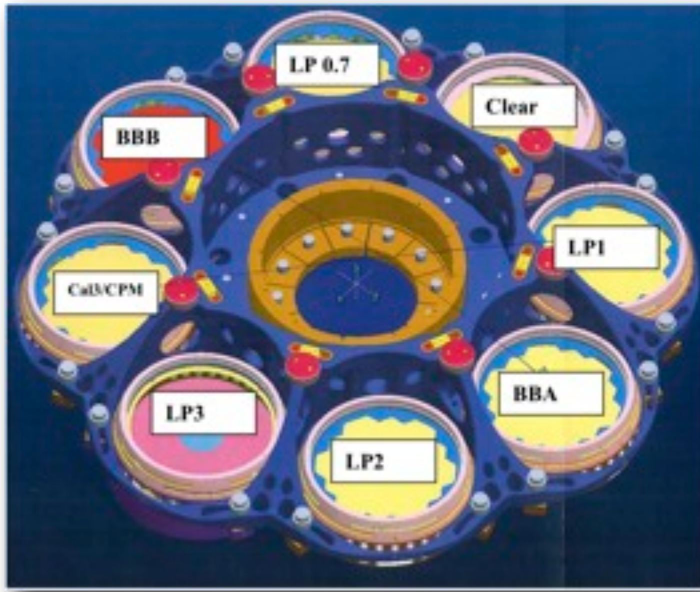
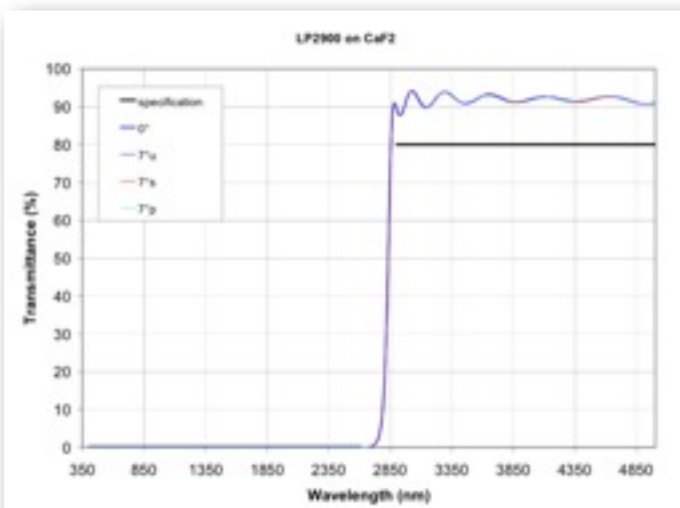


Detector Array

NIRSpec Filterwheel





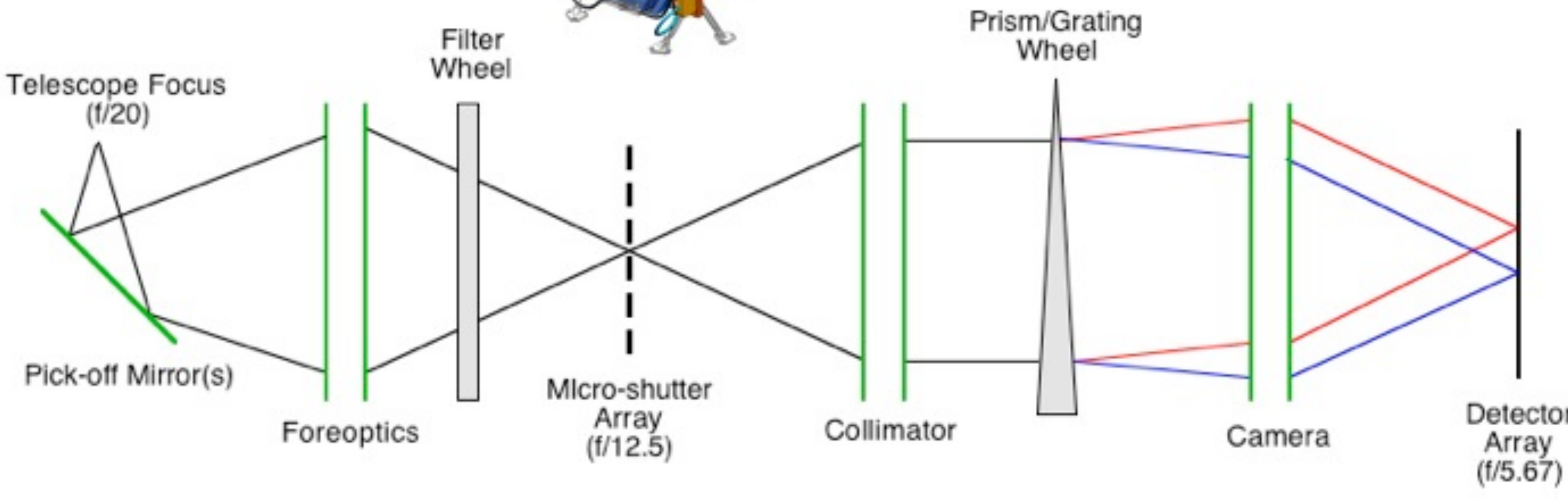
- 4 longpass order separation filters
- 2 finite band target acquisition filters
- 1 “clear” position
- 1 opaque position
  - Doubles as:
  - Instrument shutter
  - Calibration source reflector

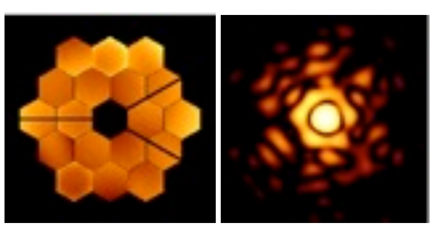
NIRSpec Slitmask

Isolates light of objects to be observed

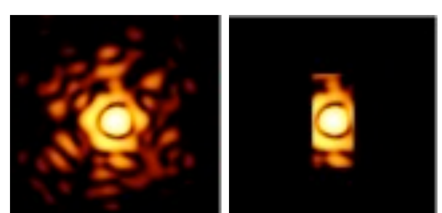
MSA doubles as ‘shutter’ for IFU

Fixed Slits always on

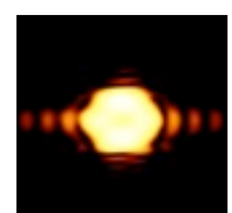




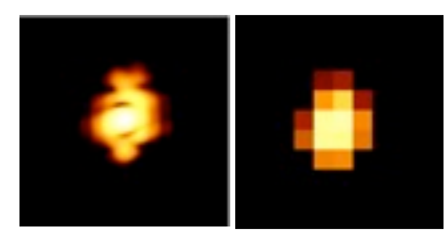
Telescope Focus



Slit Mask



Pupil at Disperser



Detector Array

NIRSpec Slitmask

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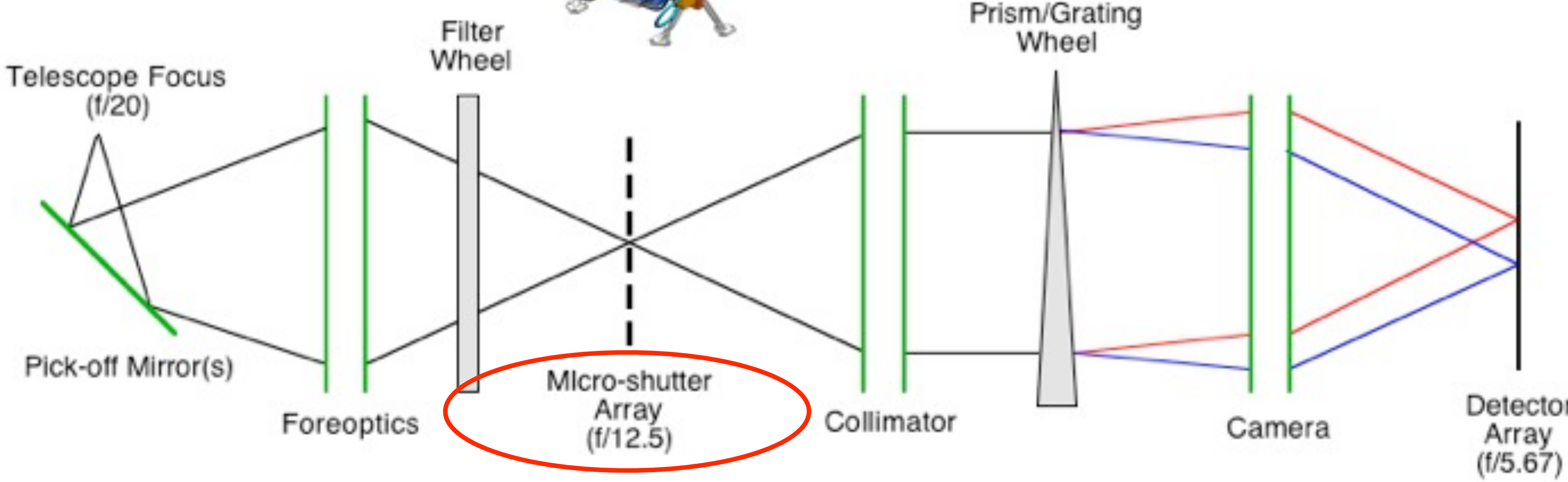
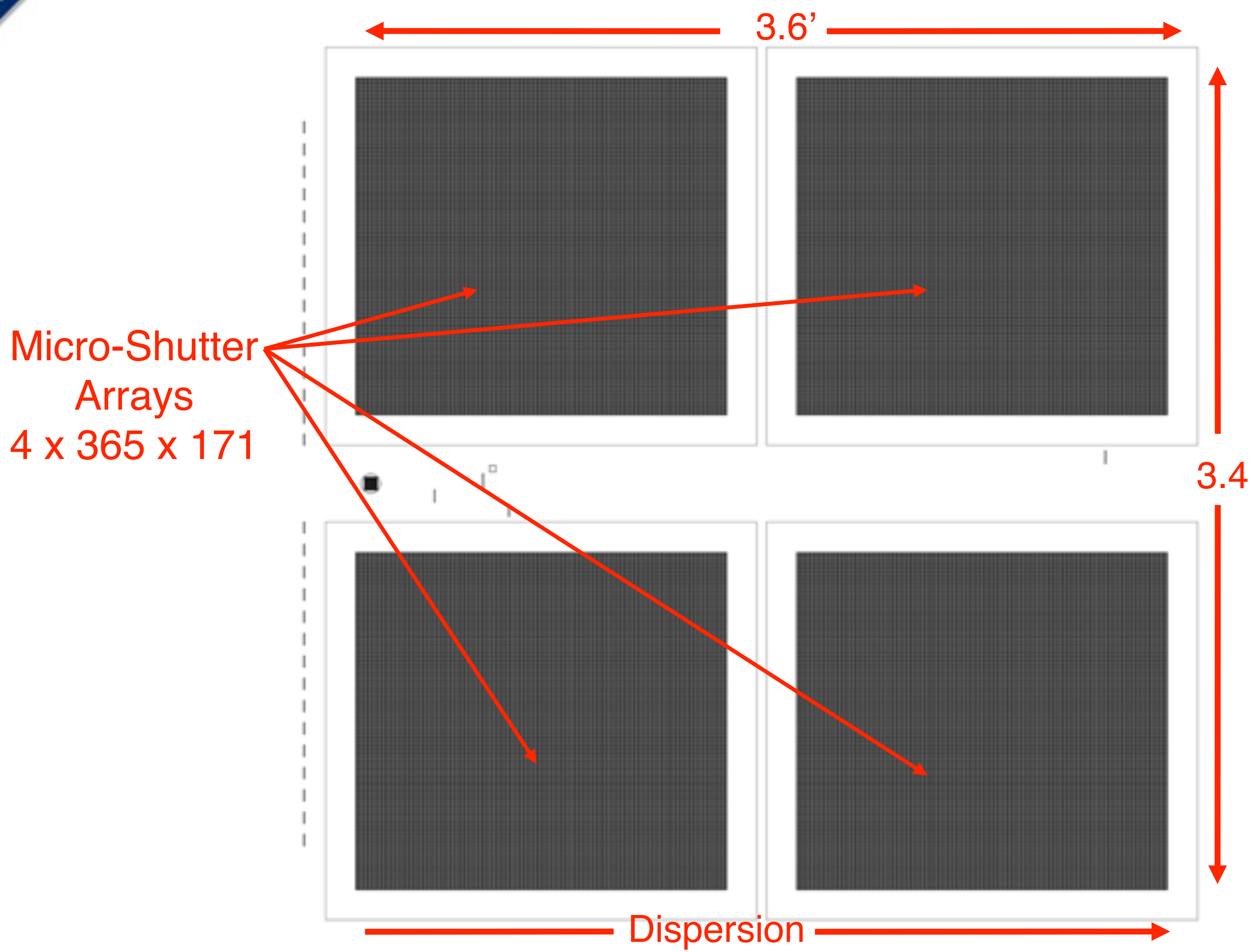
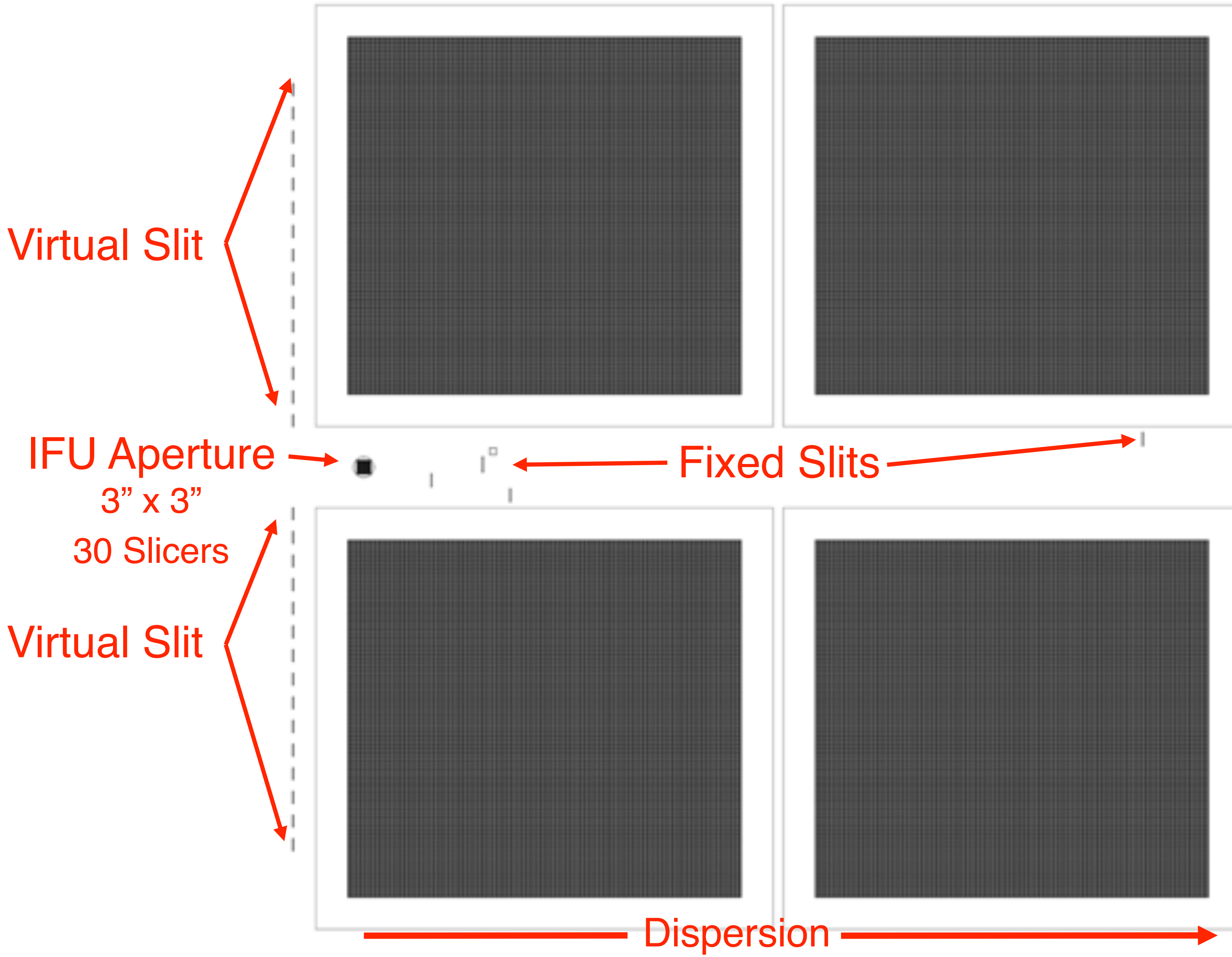


Telescope Focus | Slit Mask | Pupil at Disperser | Detector Array

NIRSpec Slit Mask In Detail



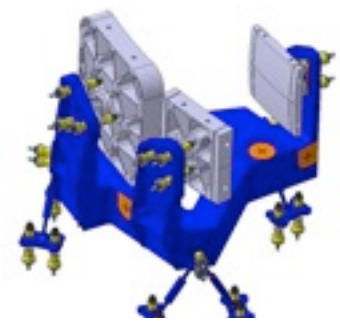
NIRSpec Slit Mask In Detail

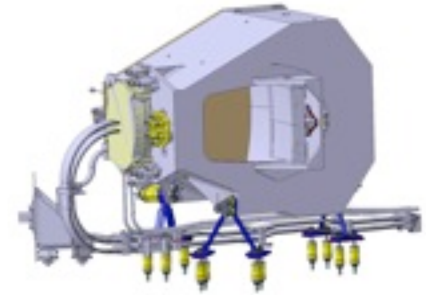


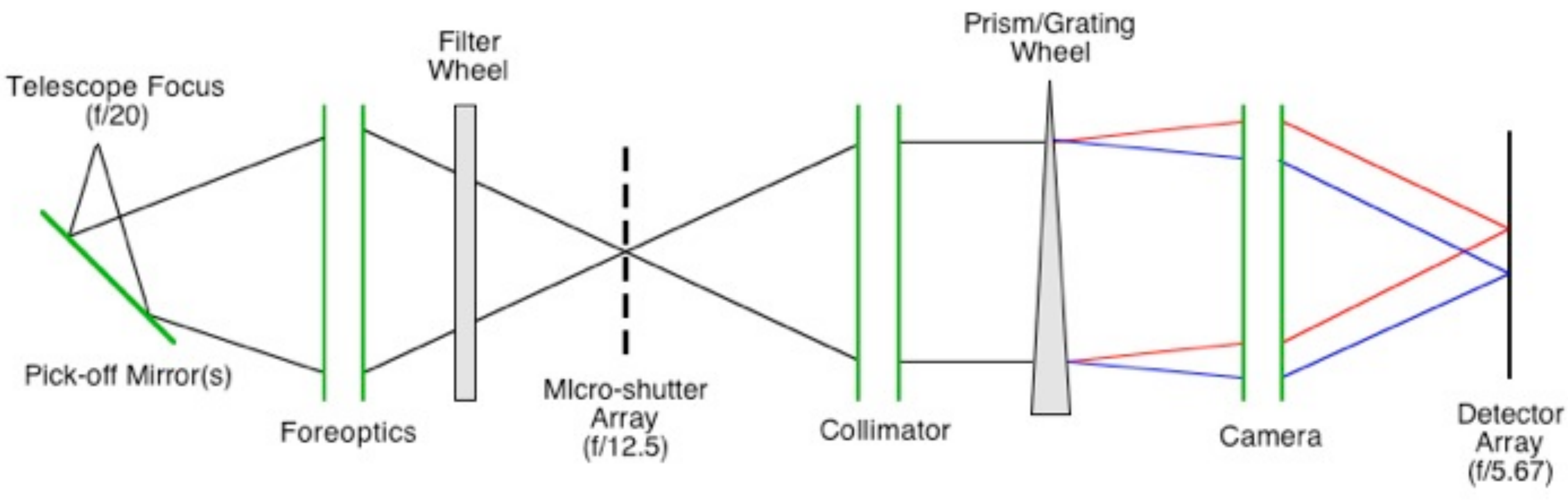
NIRSpec Collimator and Camera

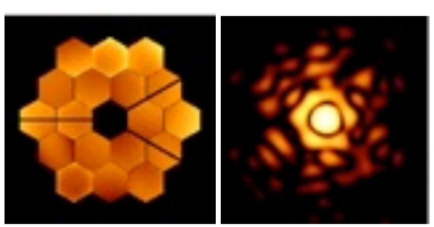
Collimator feeds dispersers parallel beams

Camera reimages dispersed beams onto detector array

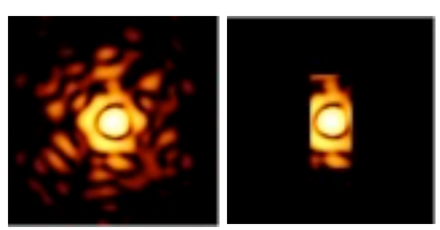




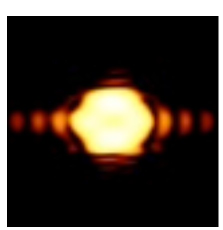




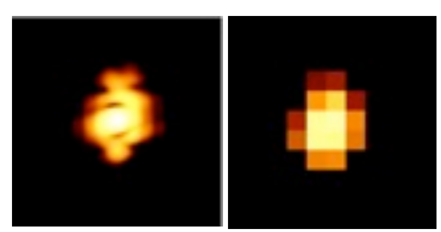
Telescope Focus



Slit Mask



Pupil at Disperser



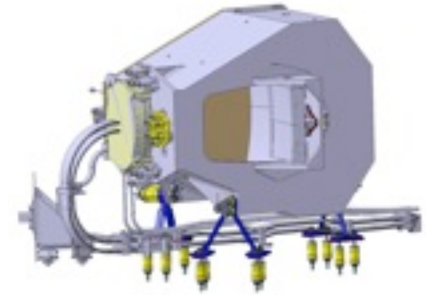
Detector Array

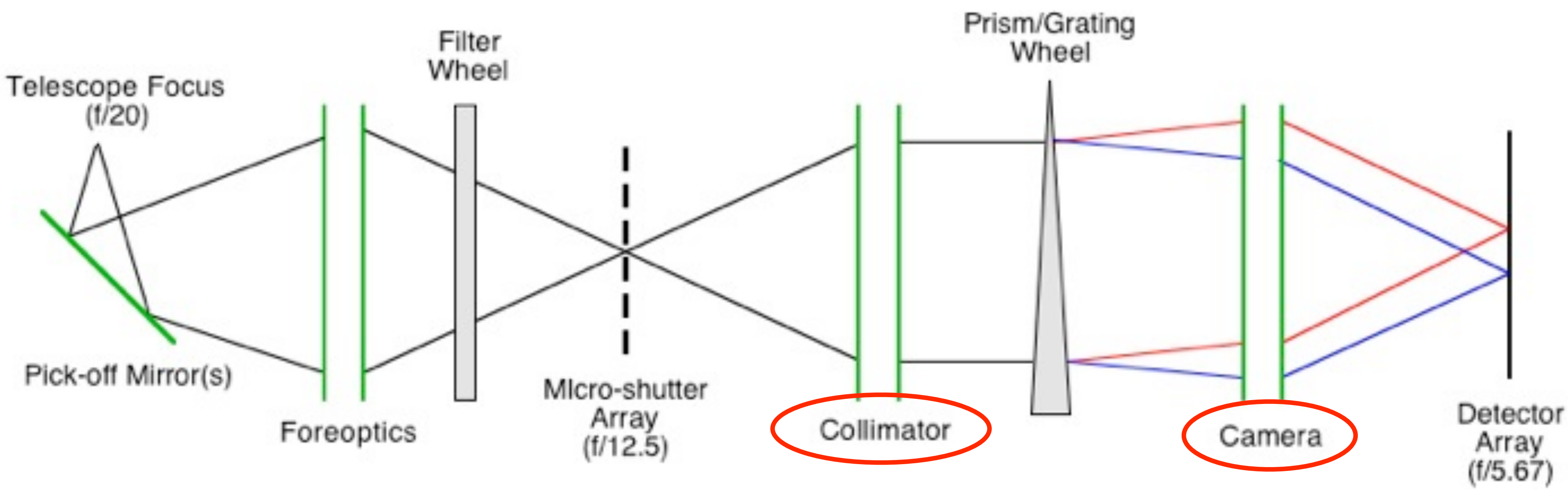
James Webb Space Telescope

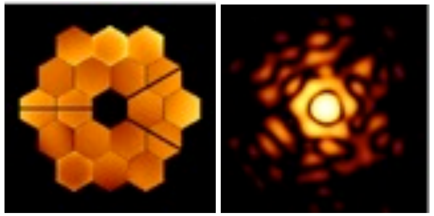
NIRSpec Collimator and Camera

Collimator feeds dispersers parallel beams

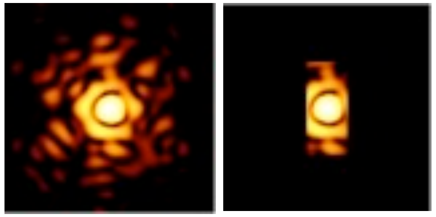
Camera reimages dispersed beams onto detector array



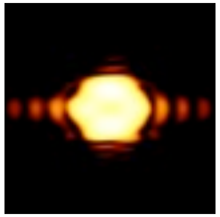




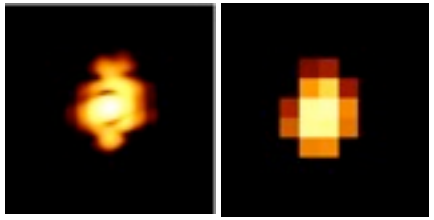
Telescope Focus



Slit Mask

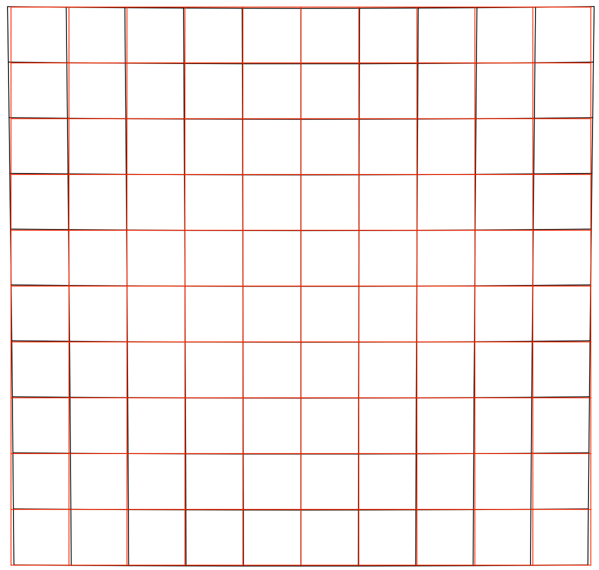


Pupil at Disperser

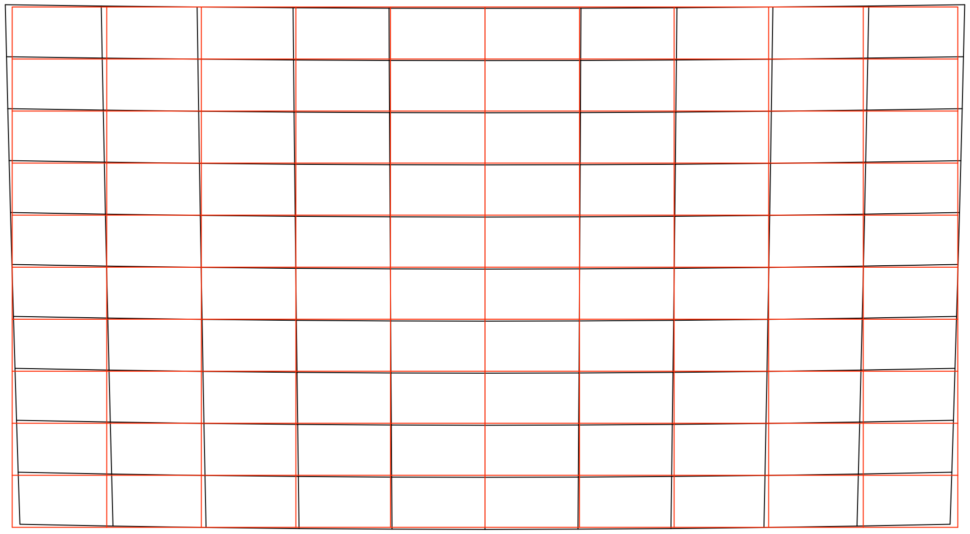


Detector Array

Collimator and Camera Distortion



Nominal collimator distortion
anamorphic + keystone
f_x=633 mm
f_y=657 mm

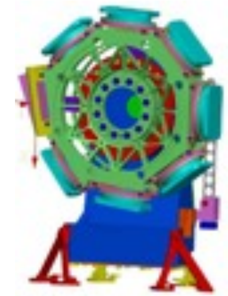


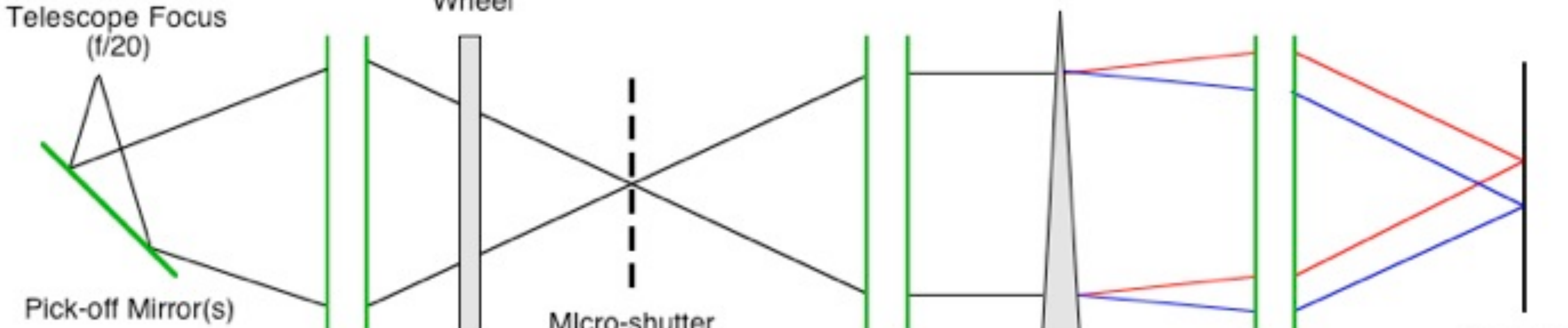
Nominal camera distortion
anamorphic + keystone
f_x=284 mm
f_y=292 mm

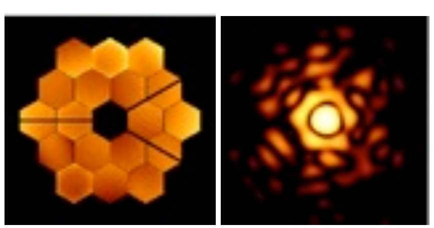
By design mainly different demagnifications in dispersion and spatial direction

NIRSpec Grating Wheel

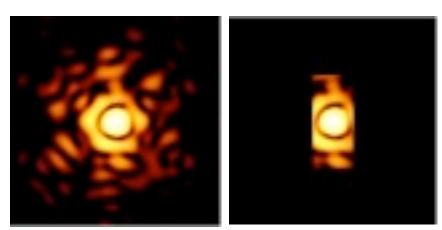
Carries NIRSpec dispersers
- six gratings (R=1000 and R=2700)
- double-pass CaF2 prism (R=100)
- flat mirror



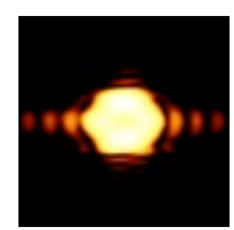




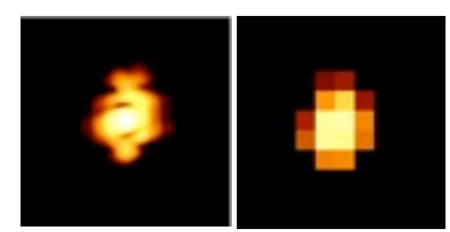
Telescope Focus



Slit Mask



Pupil at Disperser

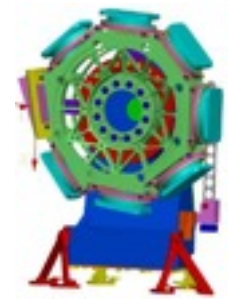


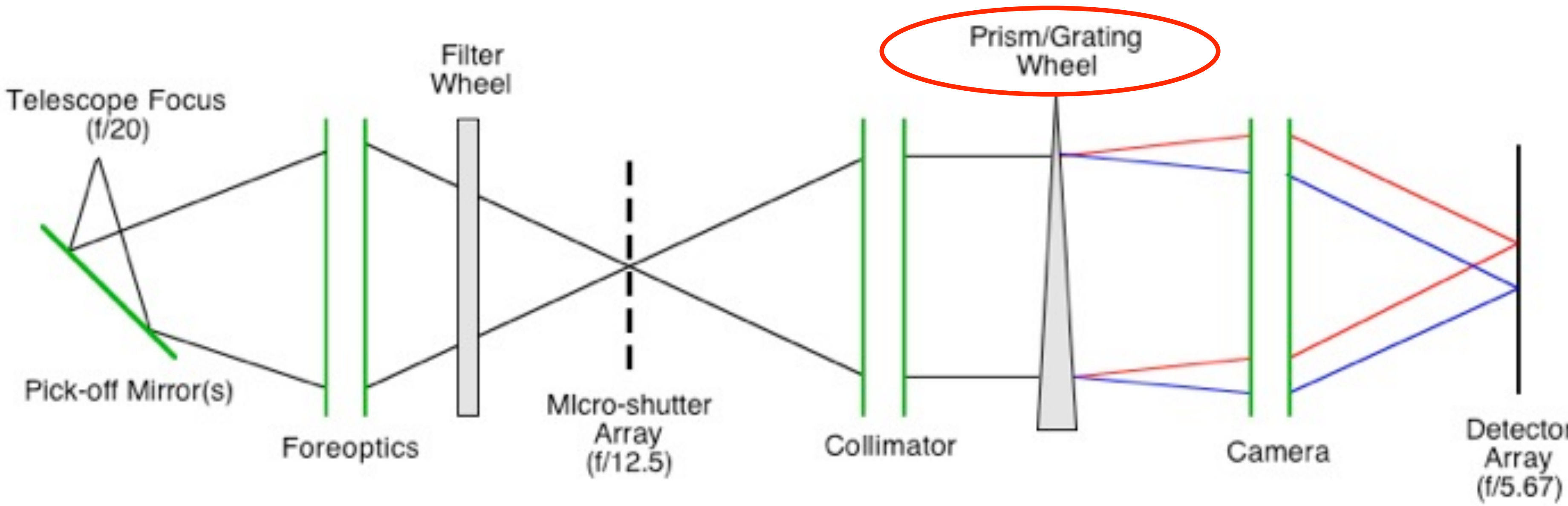
Detector Array

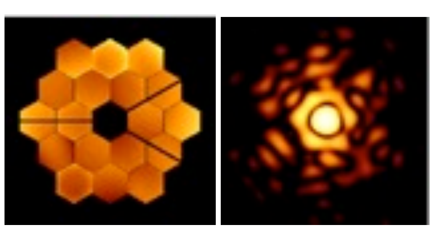
James Webb Space Telescope

NIRSpec Grating Wheel

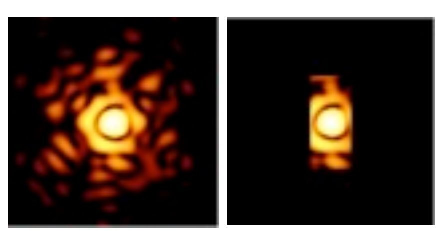
Carries NIRSpec dispersers
- six gratings (R=1000 and R=2700)
- double-pass CaF_2 prism (R=100)
- flat mirror



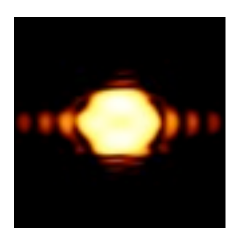




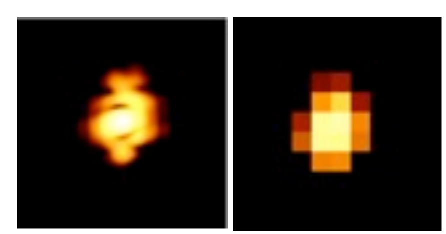
Telescope Focus



Slit Mask

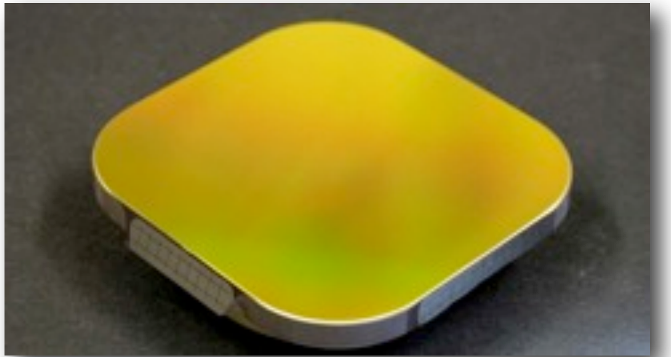


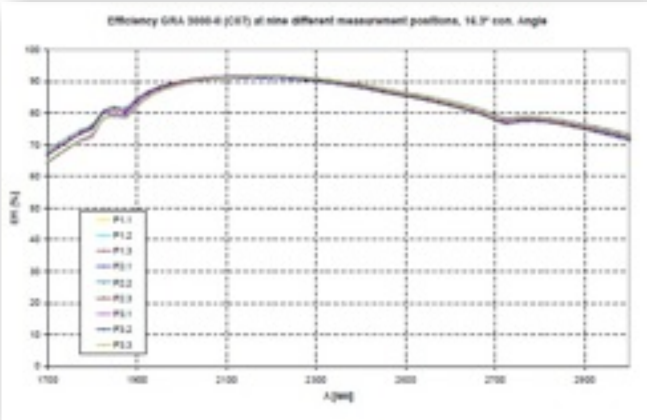
Pupil at Disperser

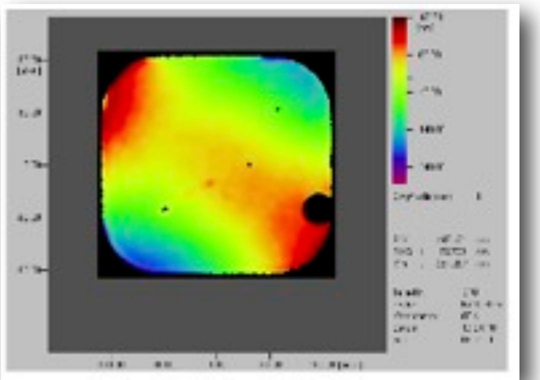


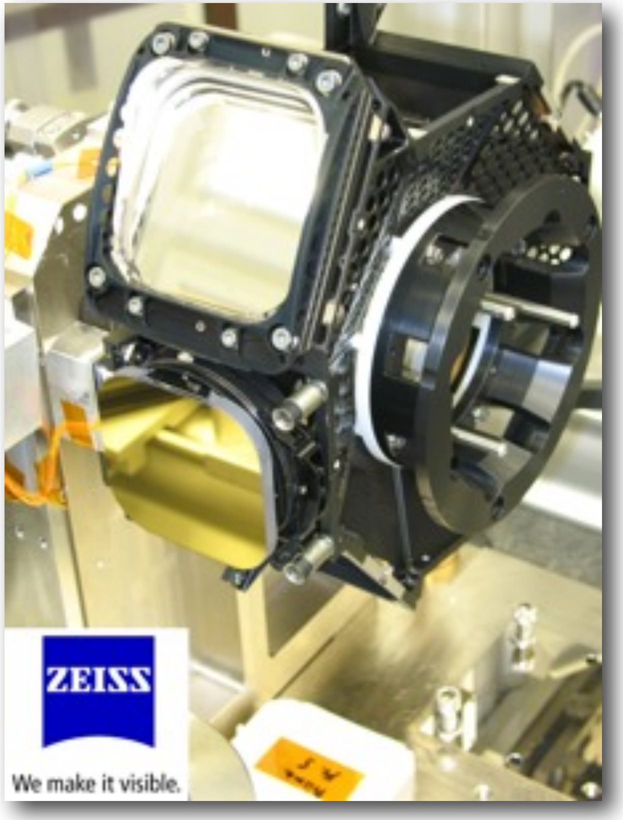
Detector Array

NIRSpec Gratings









- Directly ruled on thick gold layer
- Very high efficiency
- Sadly, mounts giving problems

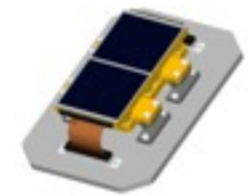
NIRSpec Detector Arrays

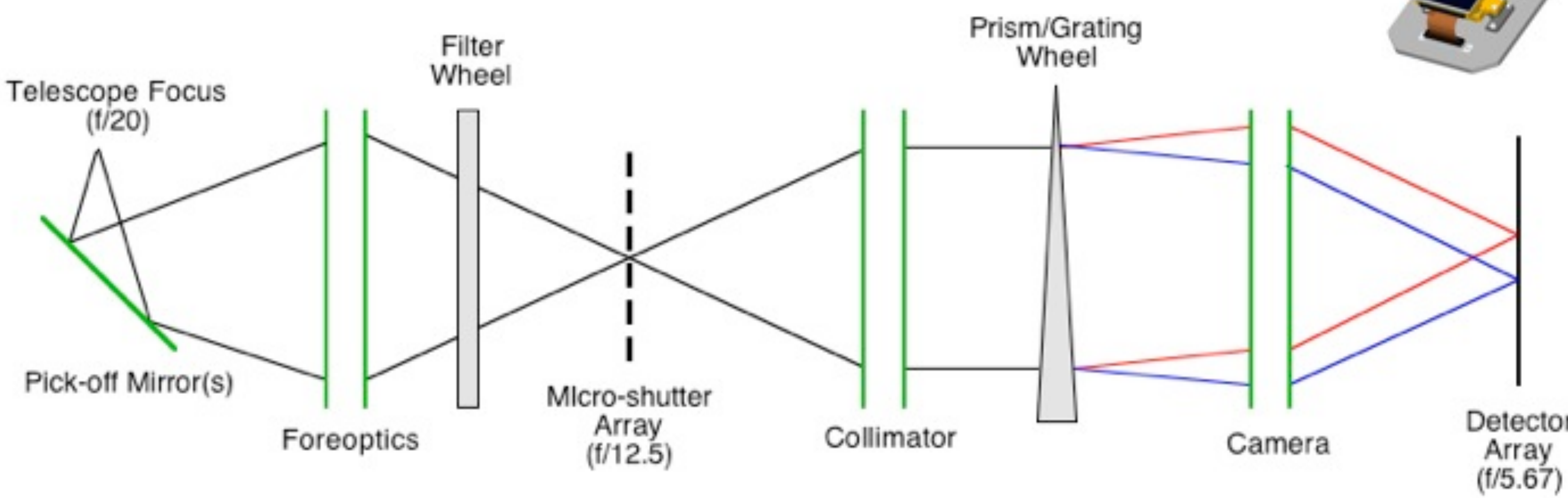
2k x 2k substrate-removed HgCdTe Arrays

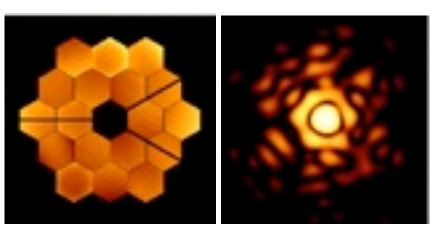
Controlled by custom cryogenic ASICs

Operating temperatur ~39 K

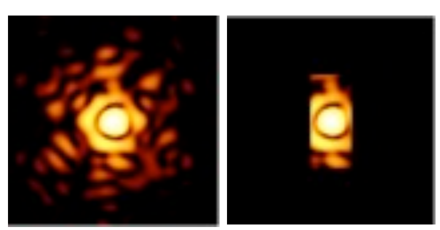
ASIC



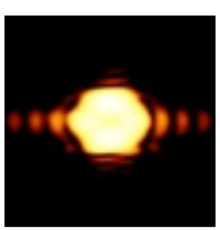




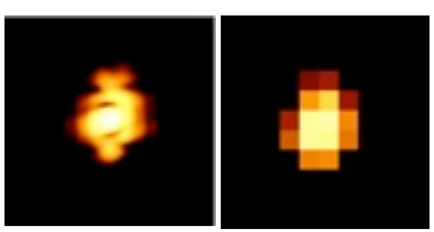
Telescope Focus



Slit Mask



Pupil at Disperser



Detector Array

James Webb Space Telescope

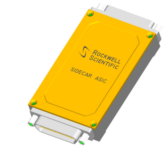
NIRSpec Detector Arrays

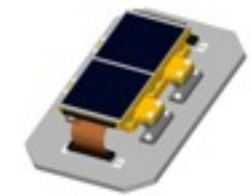
2k x 2k substrate-removed HgCdTe Arrays

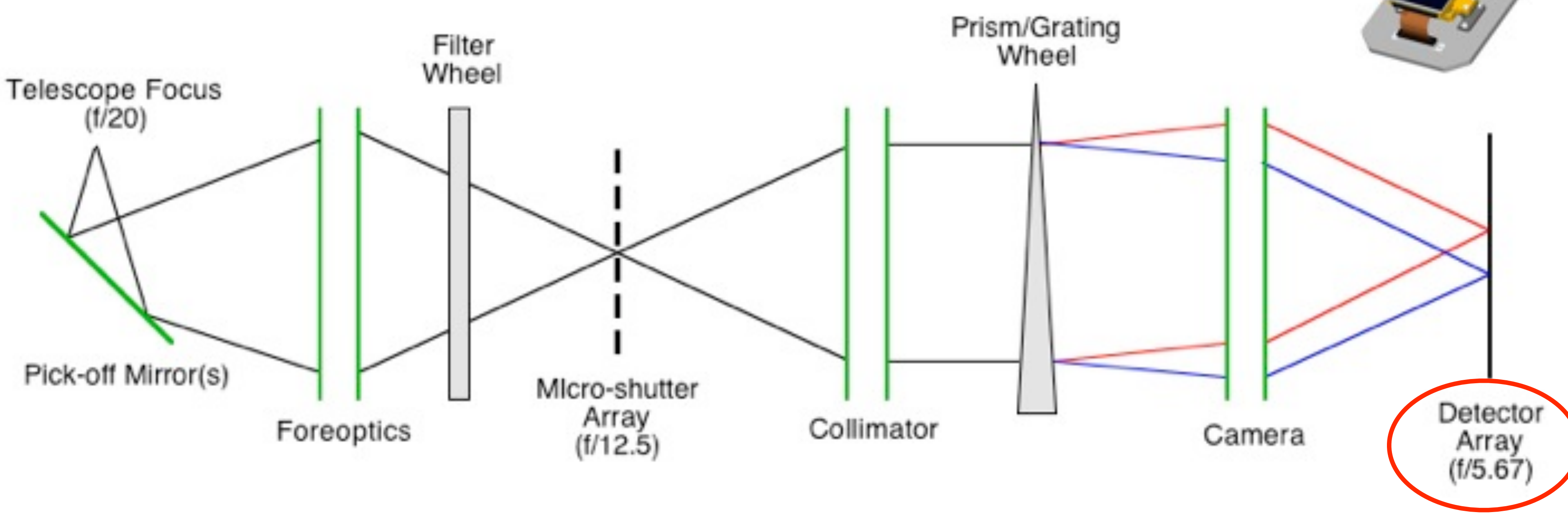
Controlled by custom cryogenic ASICs

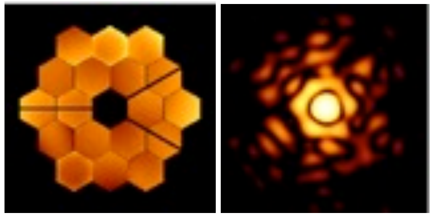
Operating temperatur ~39 K

ASIC

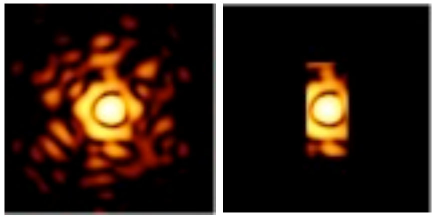




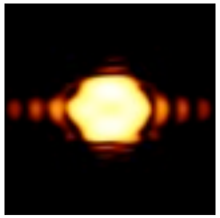




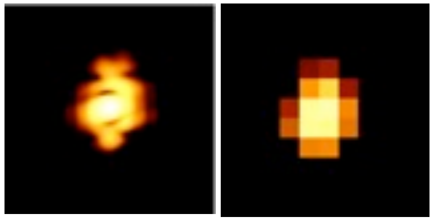
Telescope Focus



Slit Mask



Pupil at Disperser

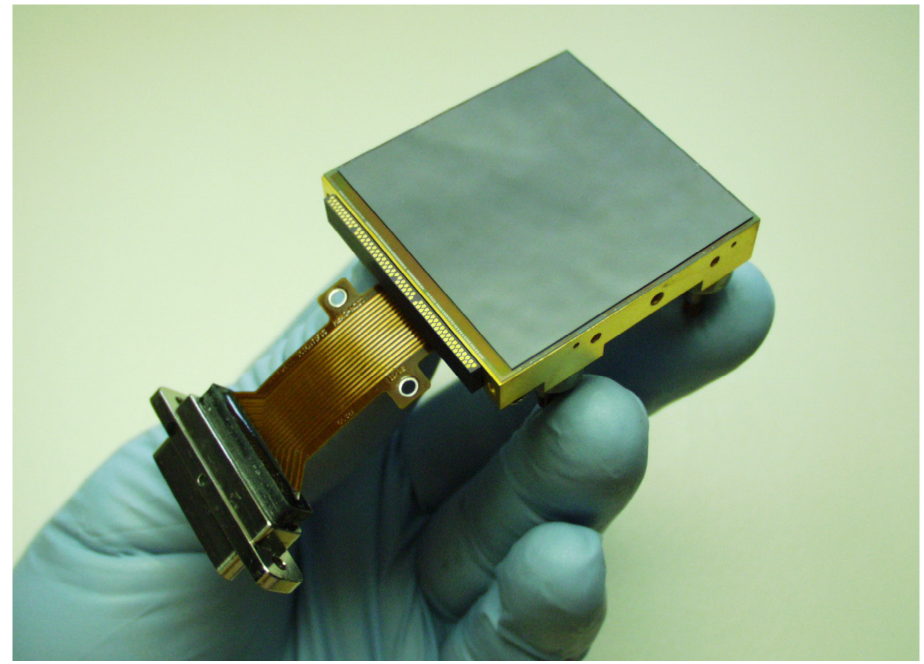


Detector Array

Near-IR Detectors

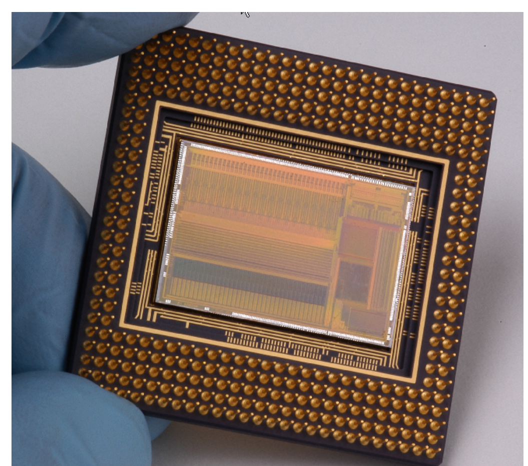
HgCdTe Arrays:

Format: 2k x 2k
QE: >70%
Total Noise:
<7e in 1000s
10 (NIRCam)
2 (NIRSpec)
4 (FGS/TF)
16 in total

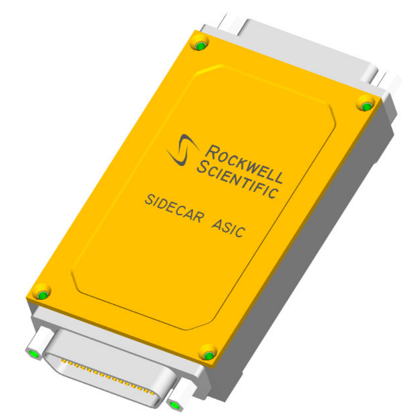


Cryogenic ASIC:

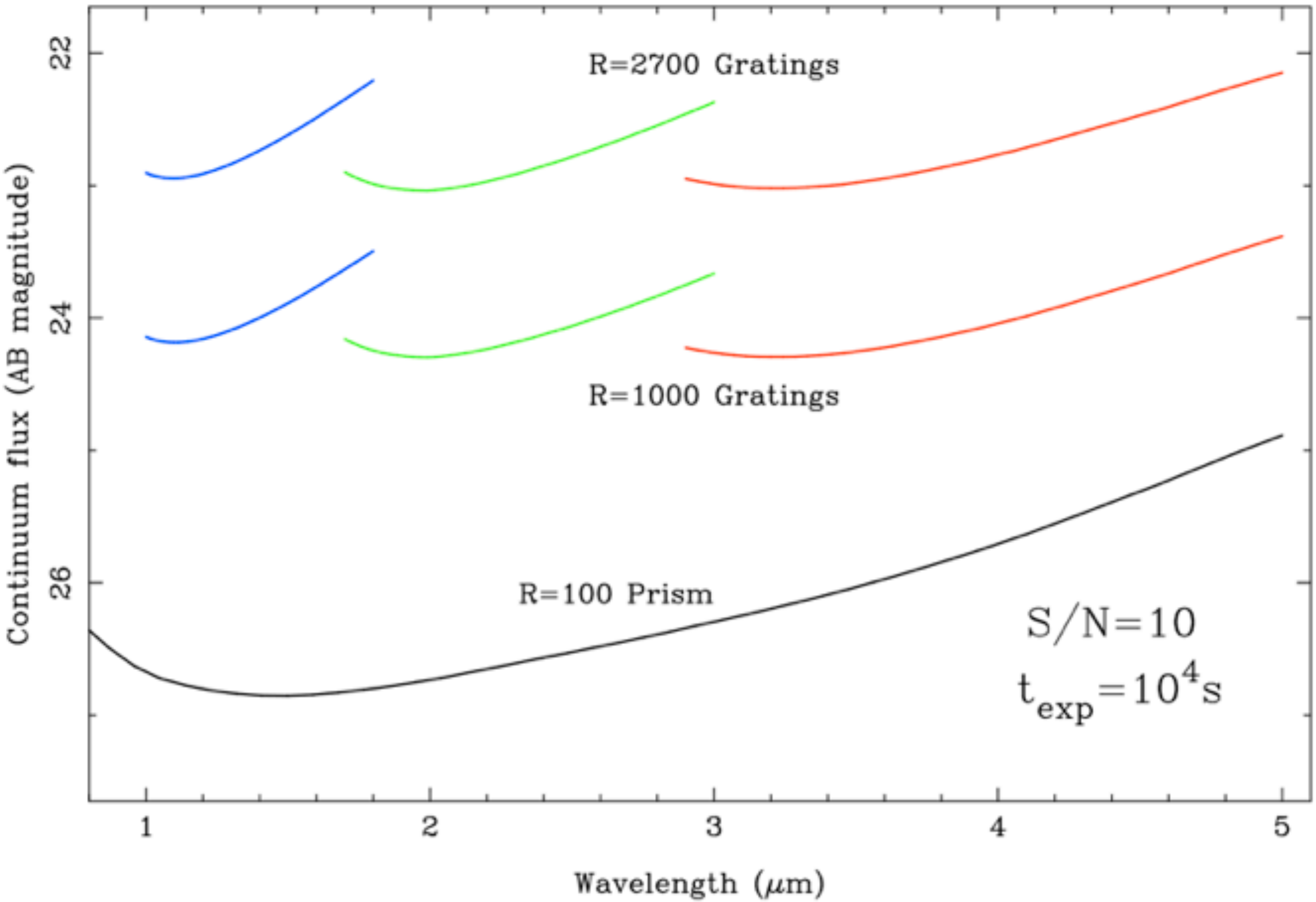
Controls Array
Power & commands in - digital signal out



TELEDYNE TECHNOLOGIES INCORPORATED

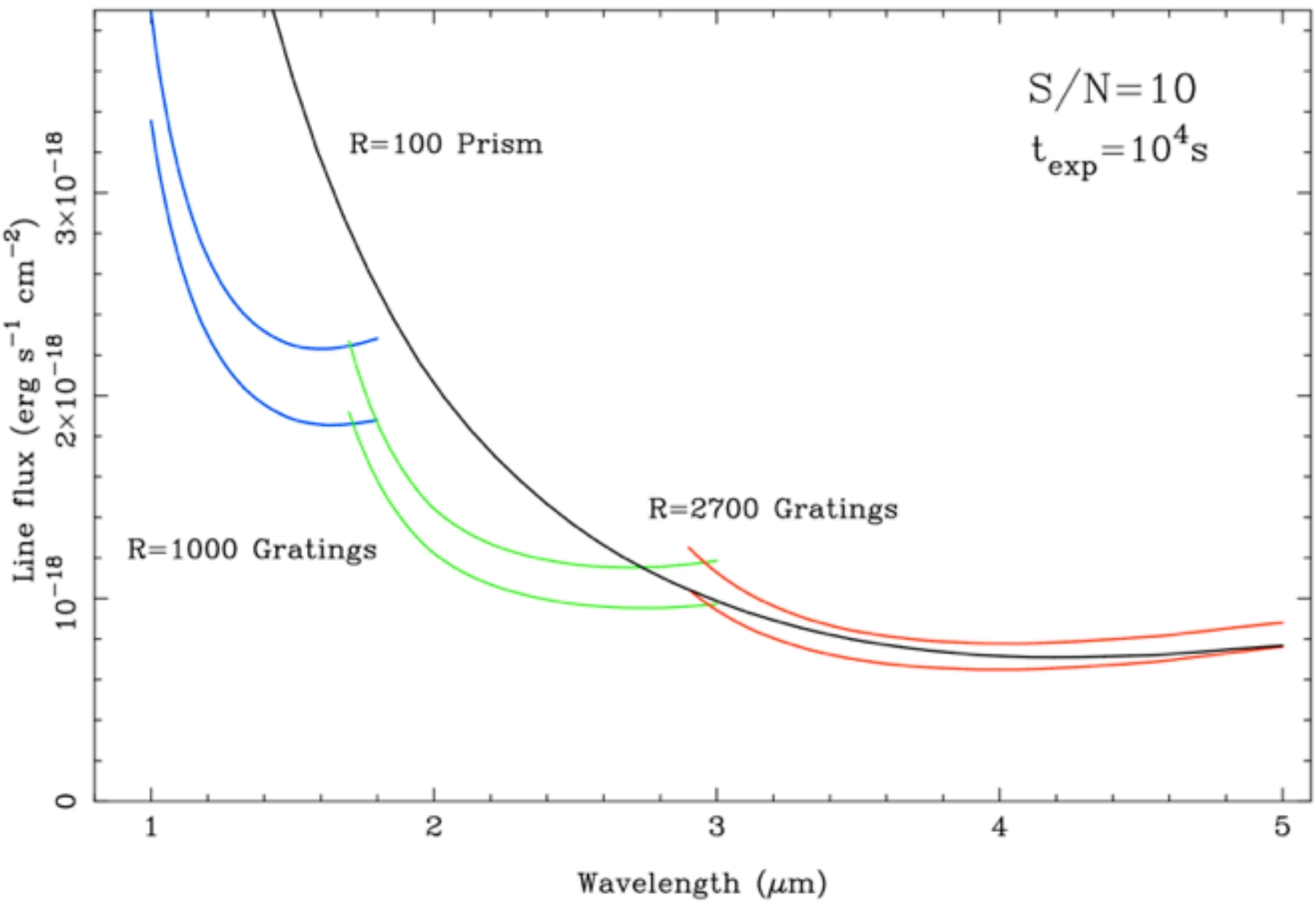


Continuum Flux Sensitivities



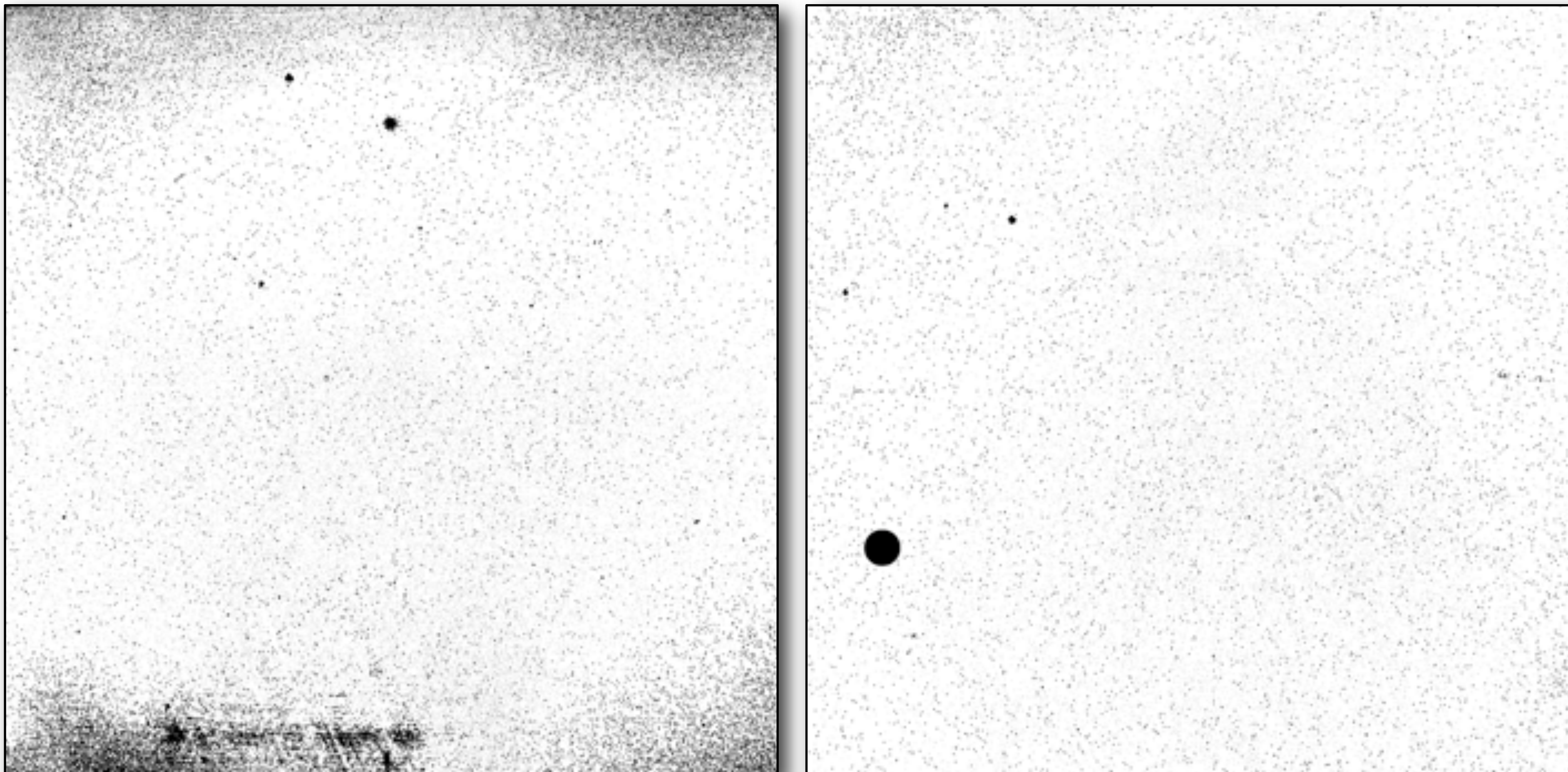
James Webb Space Telescope

Emission Line Sensitivities

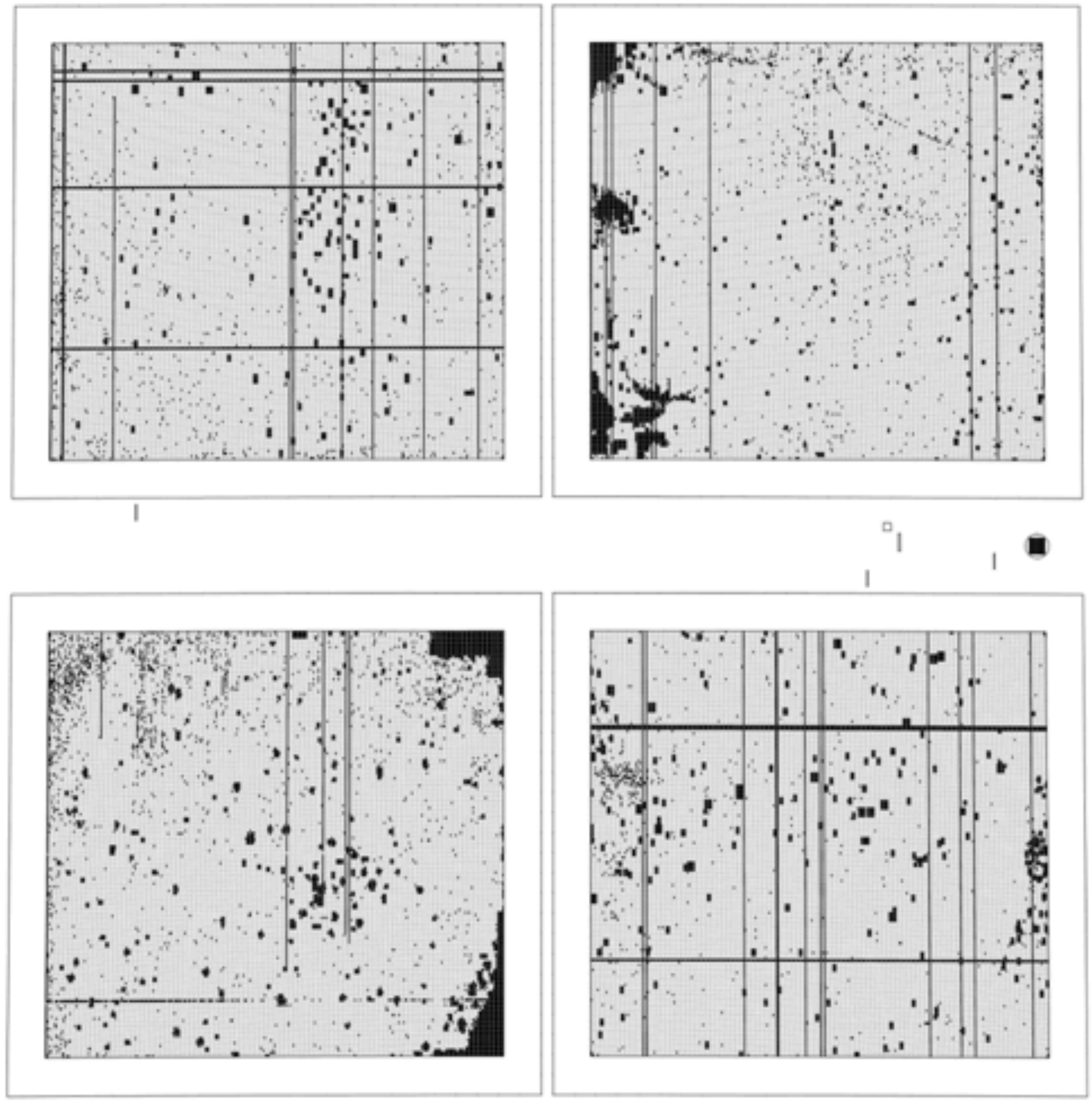


Enough with the sales pitch - now a few of the ugly bits..

Bad Pixel Map Flight Detectors

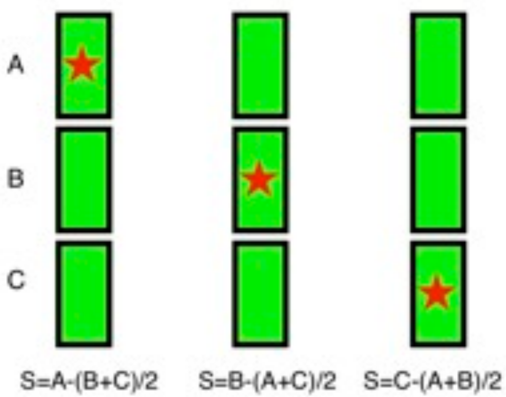


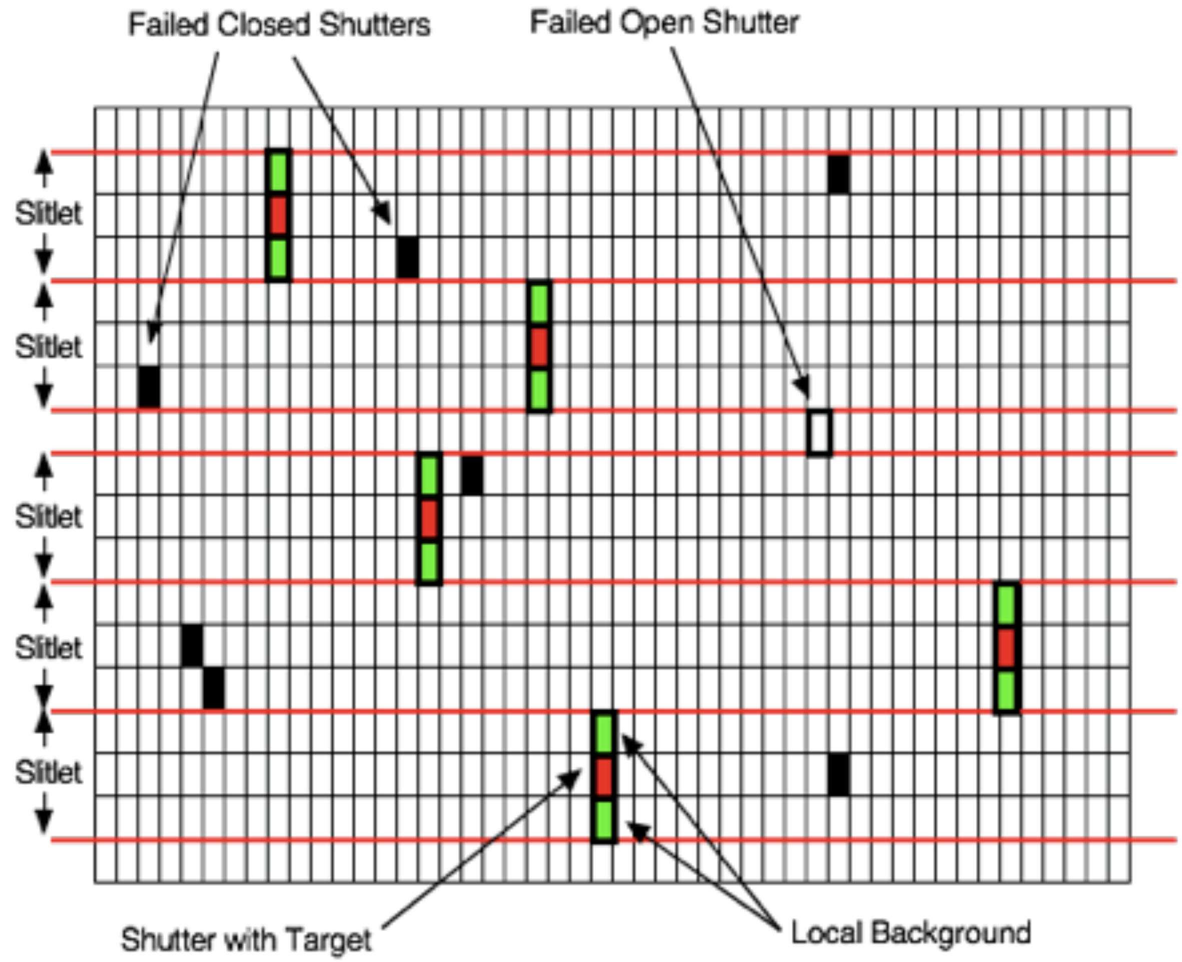
Bad Shutter Map Flight MSA



Living with Bad Shutters and Pixels

‘Slitlet’ dithering scheme

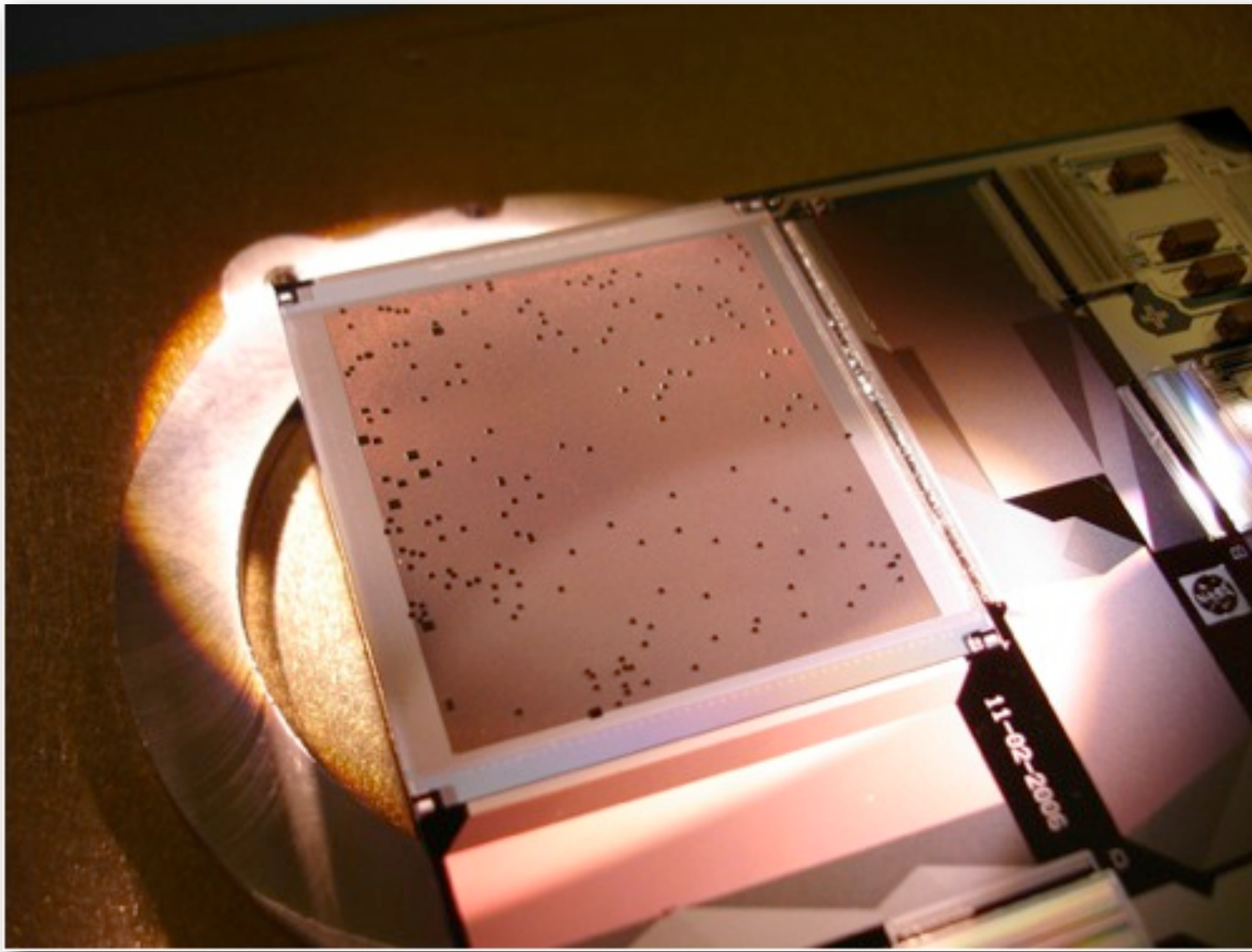




- Failed Open shutters affect multiplexing much more severely than do Failed Closed shutters

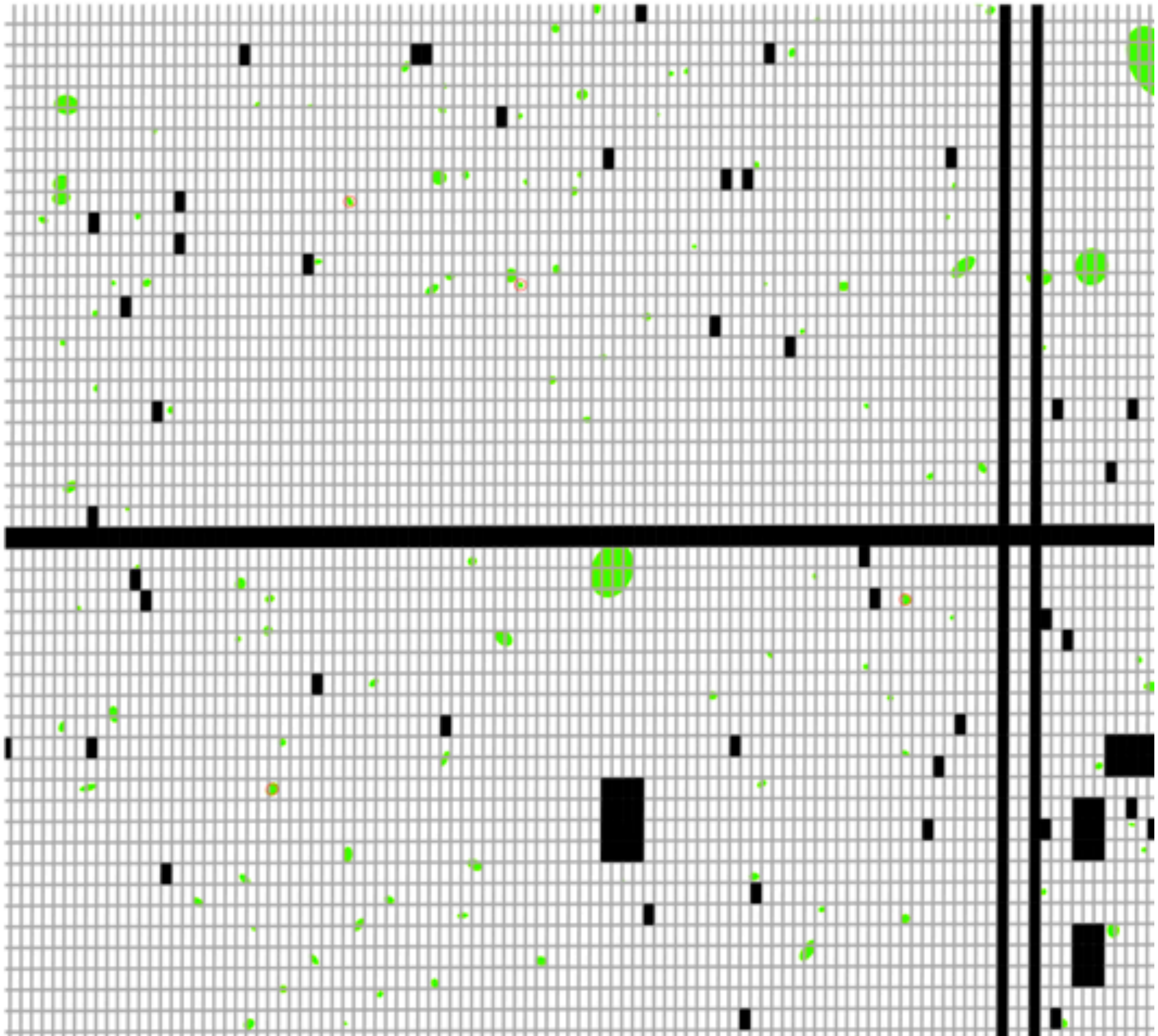
Micro-Shutter Array (MSA)

The Process of Plugging

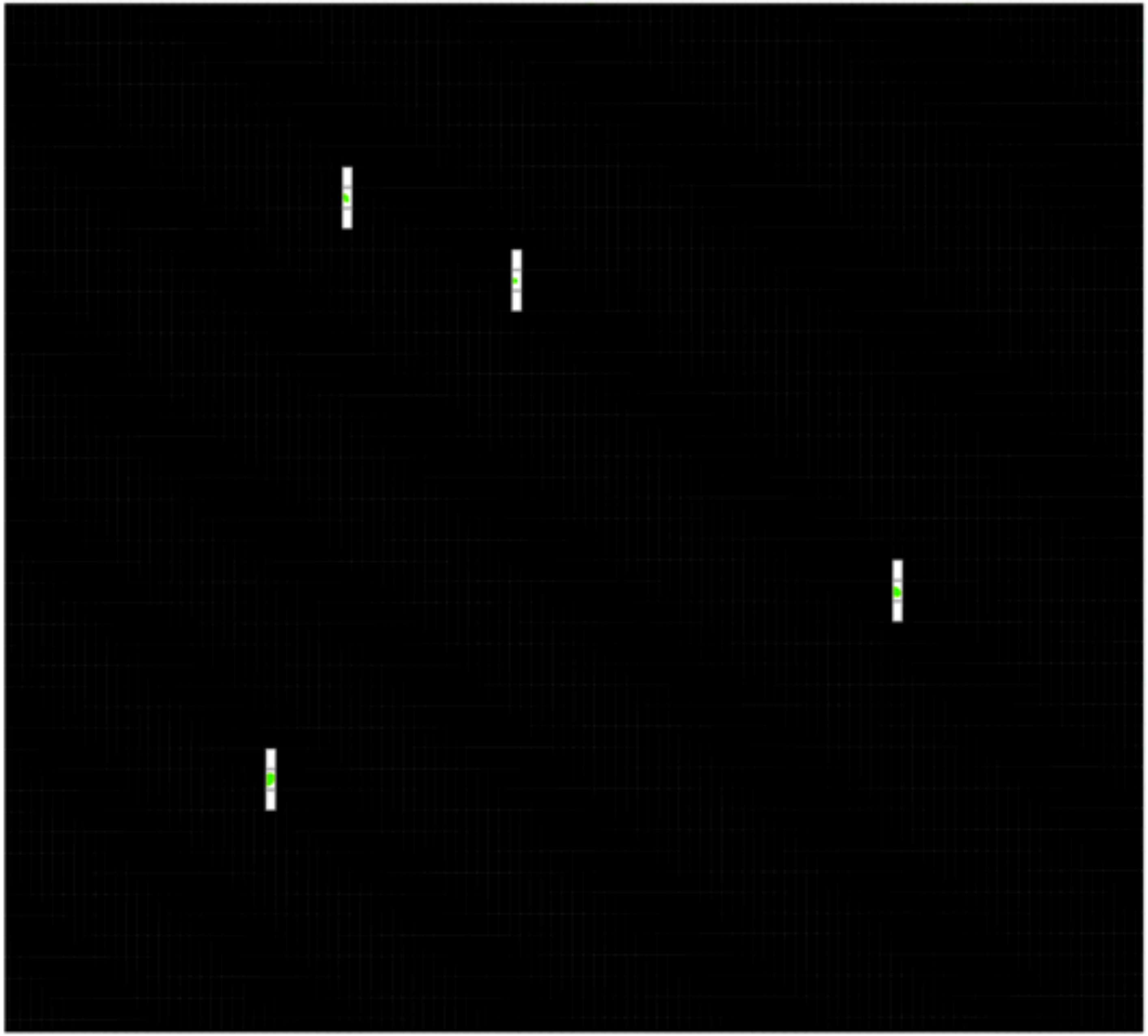


Trade each failed open shutter for 3x3 patch of failed closed ones

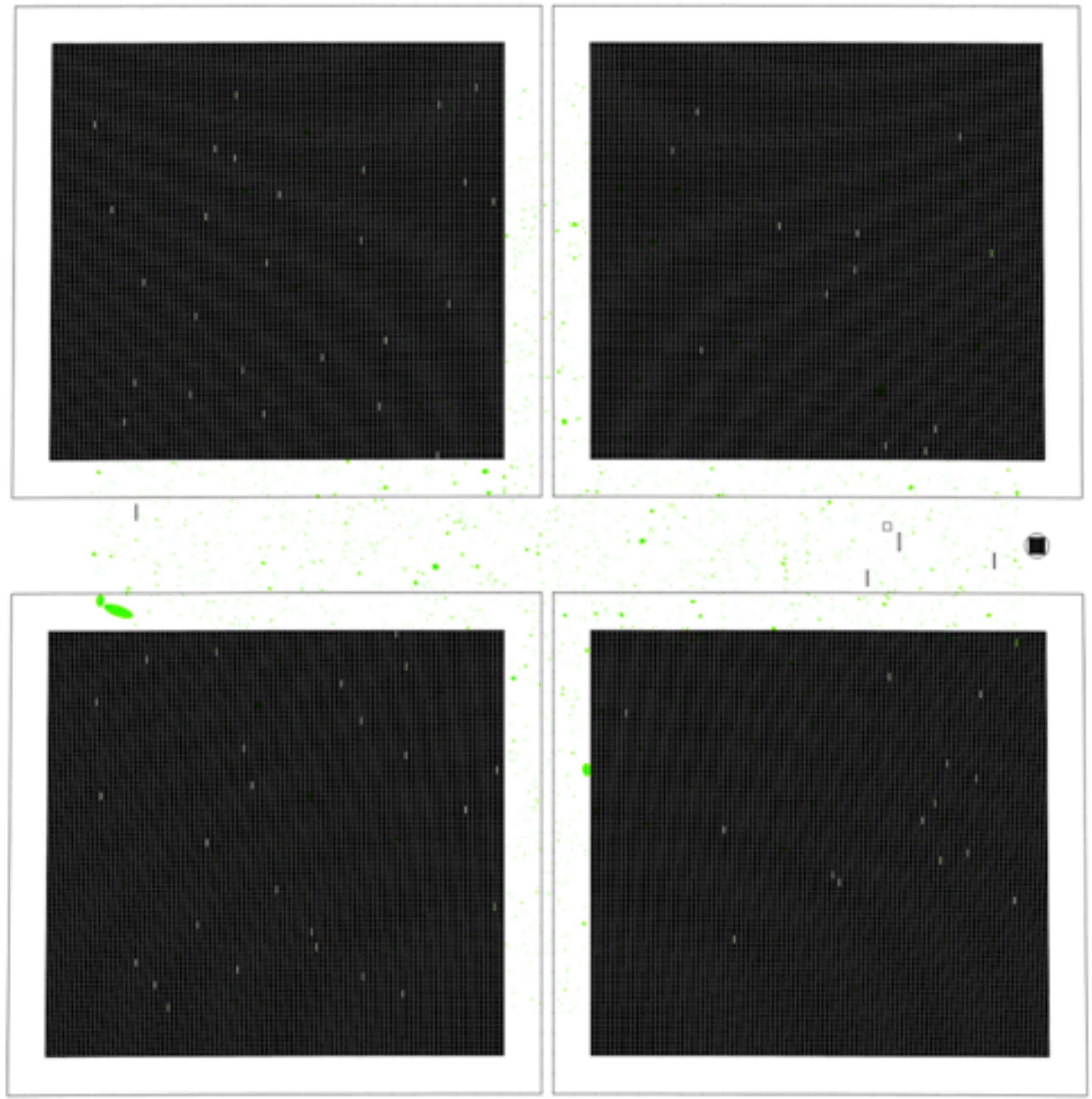
Close-up of MSA



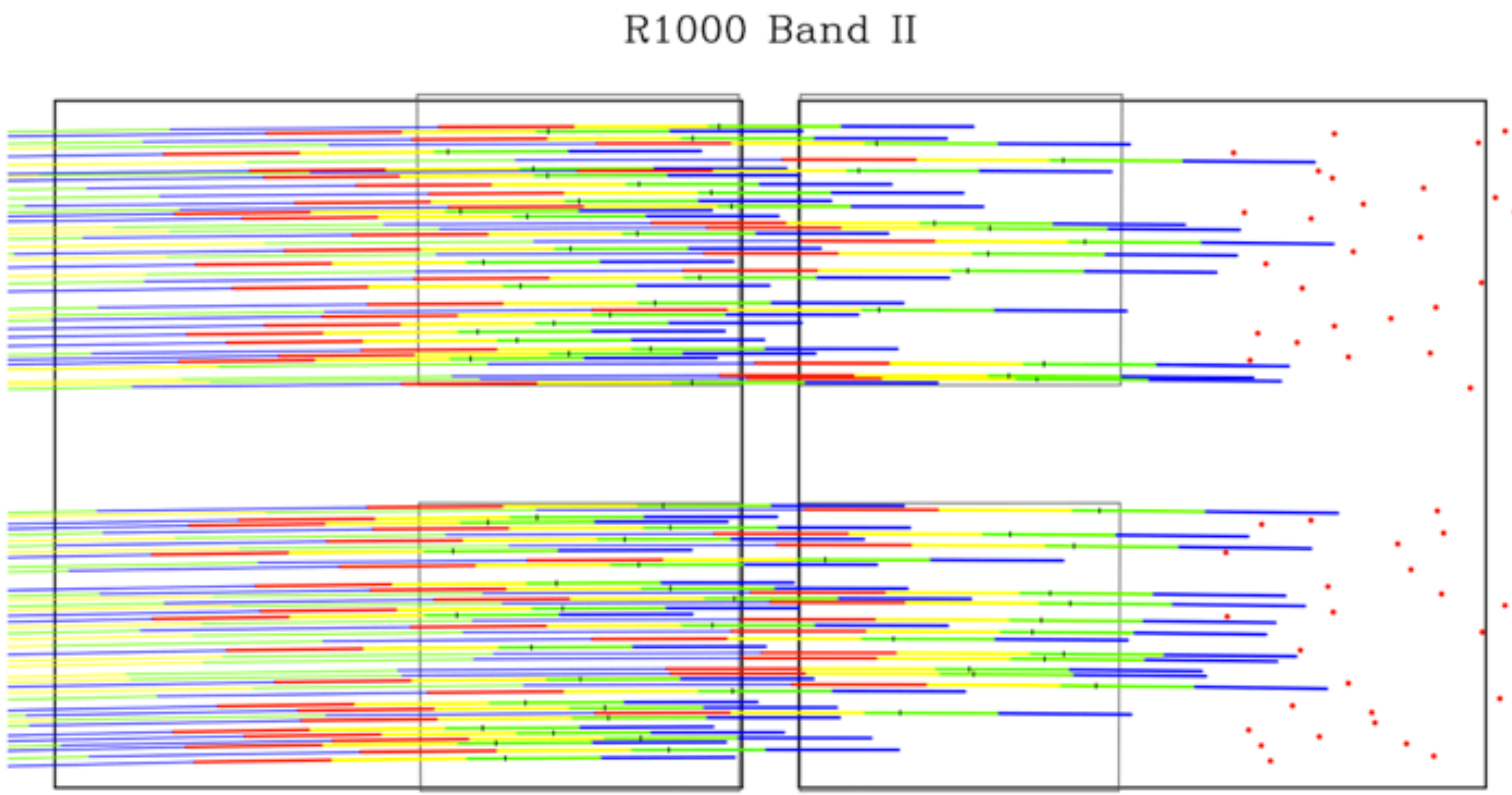
Close-up of MSA



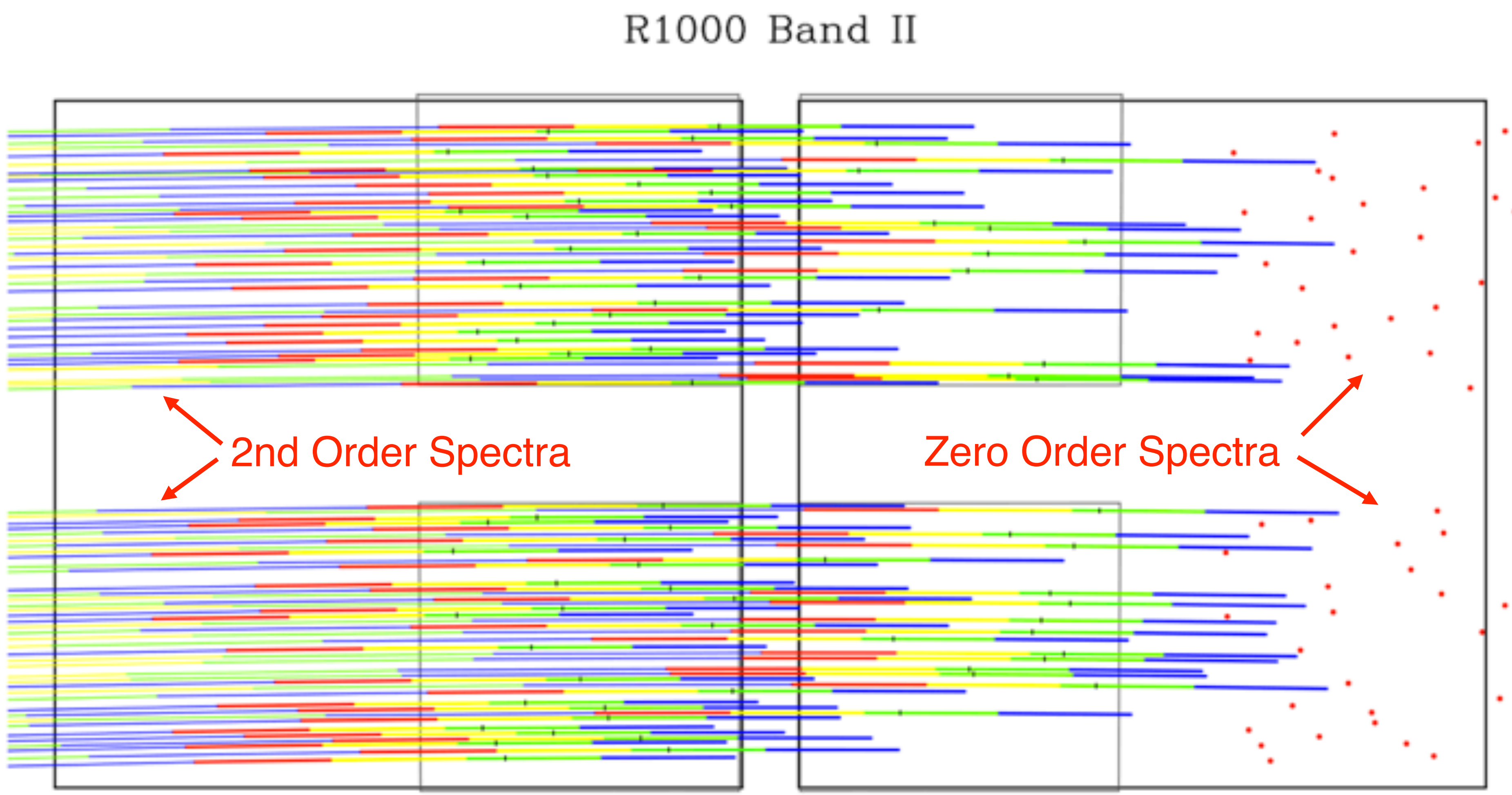
MSA Operational Configuration



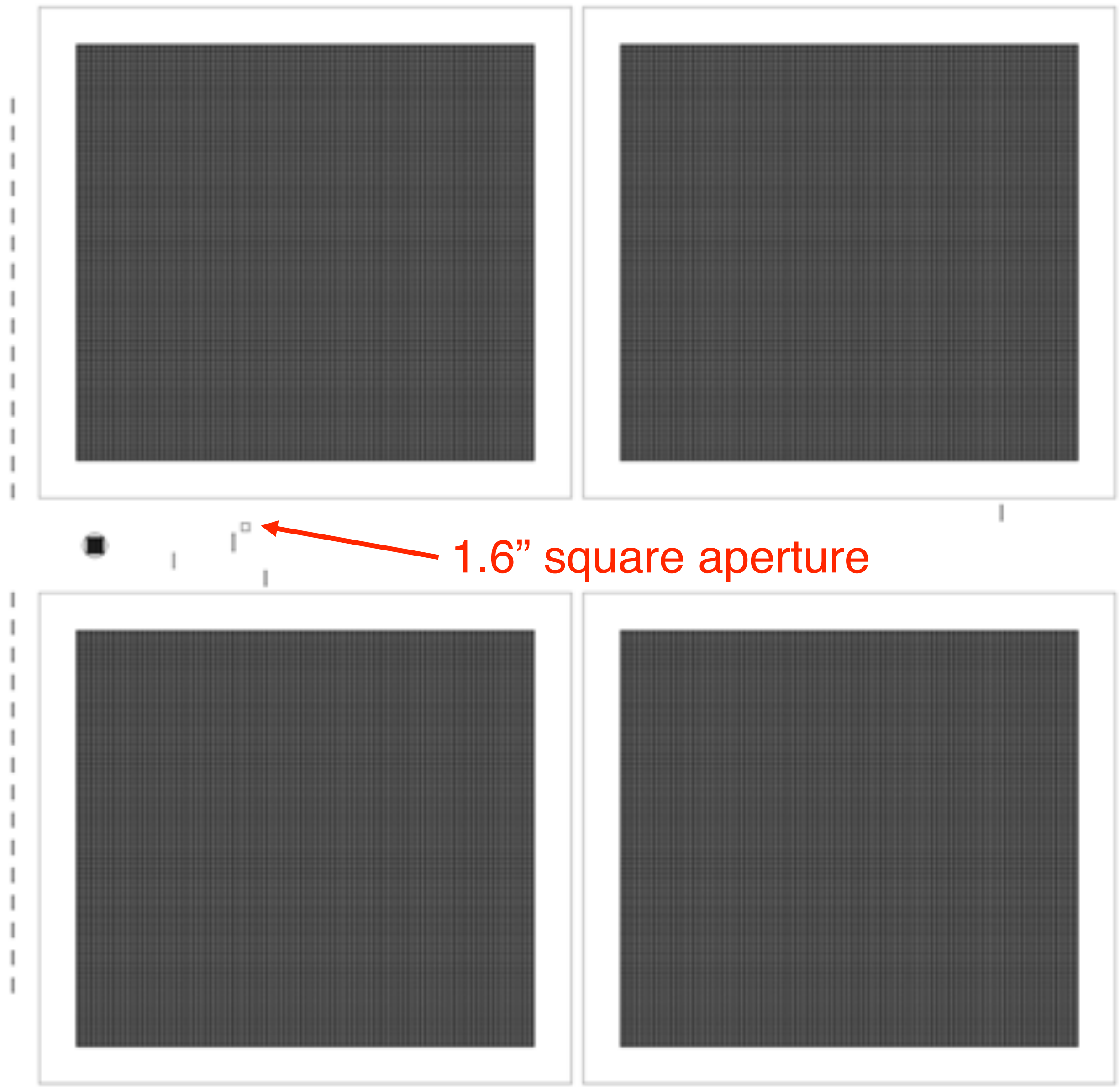
Resulting Spectra on Detector



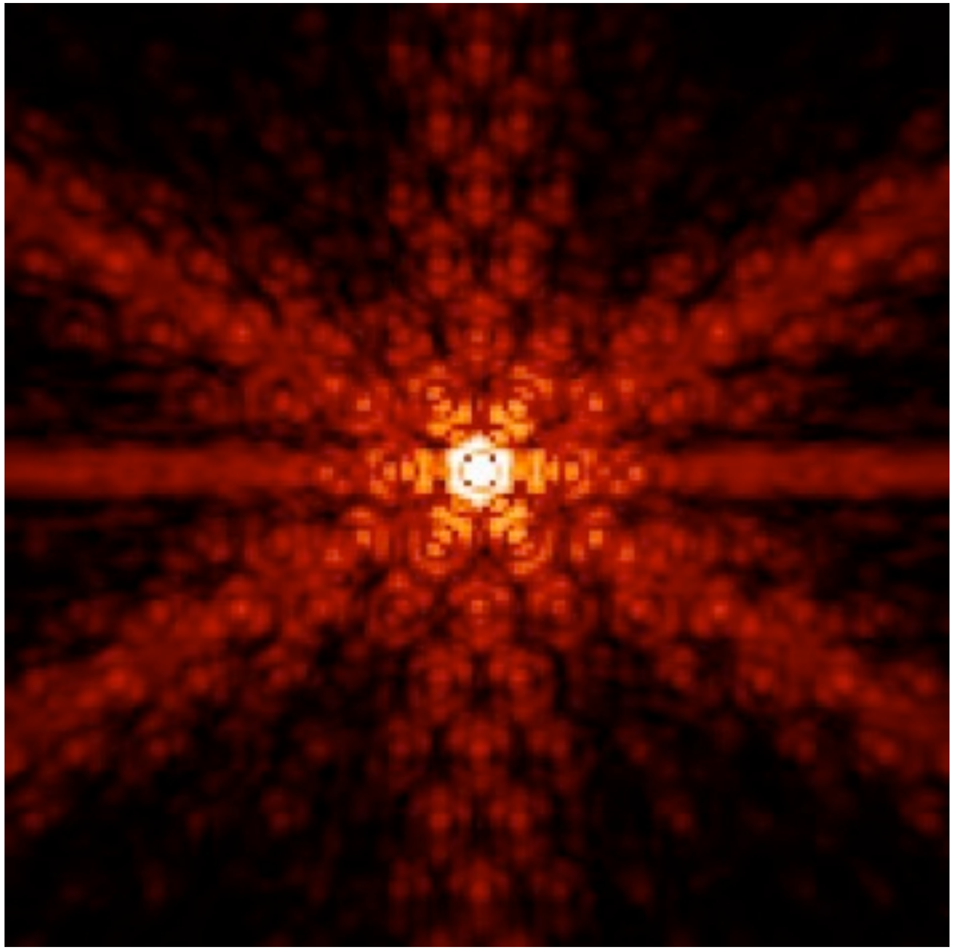
Resulting Spectra on Detector



One More Thing..



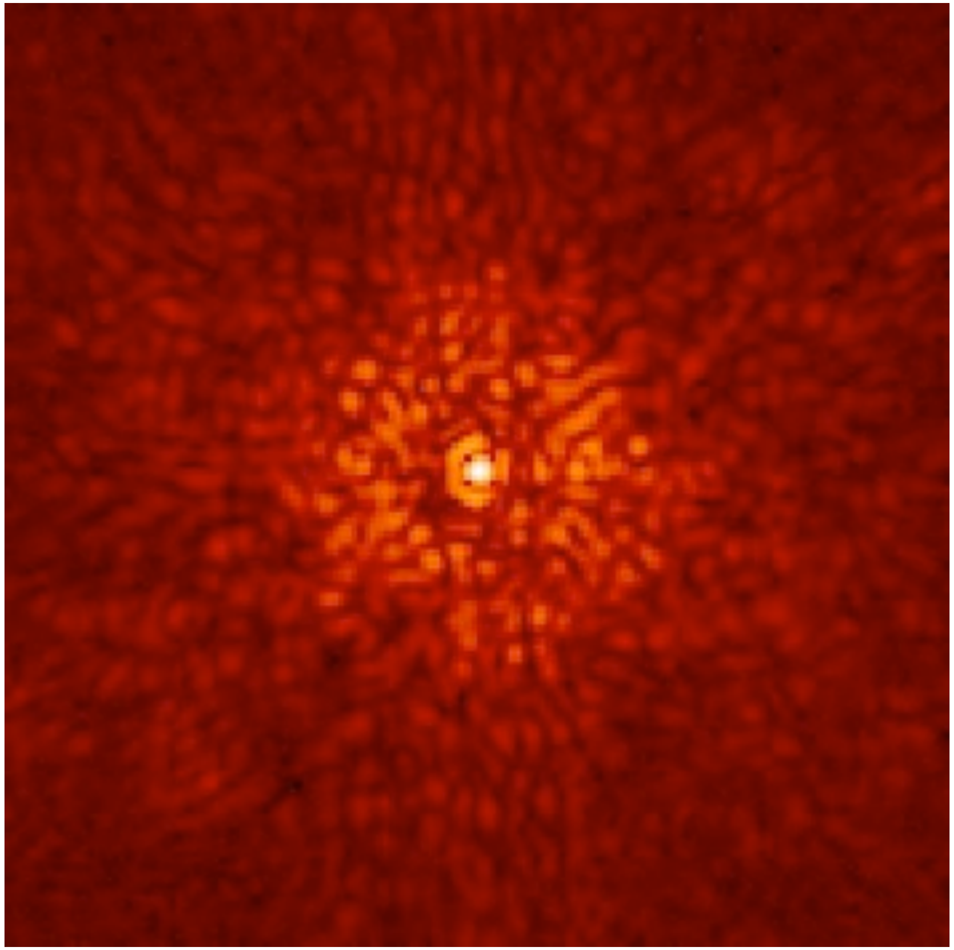
Exoplanets



TF Simulation

NIRCam, FGS/TF & MIRI *all* carry coronographs

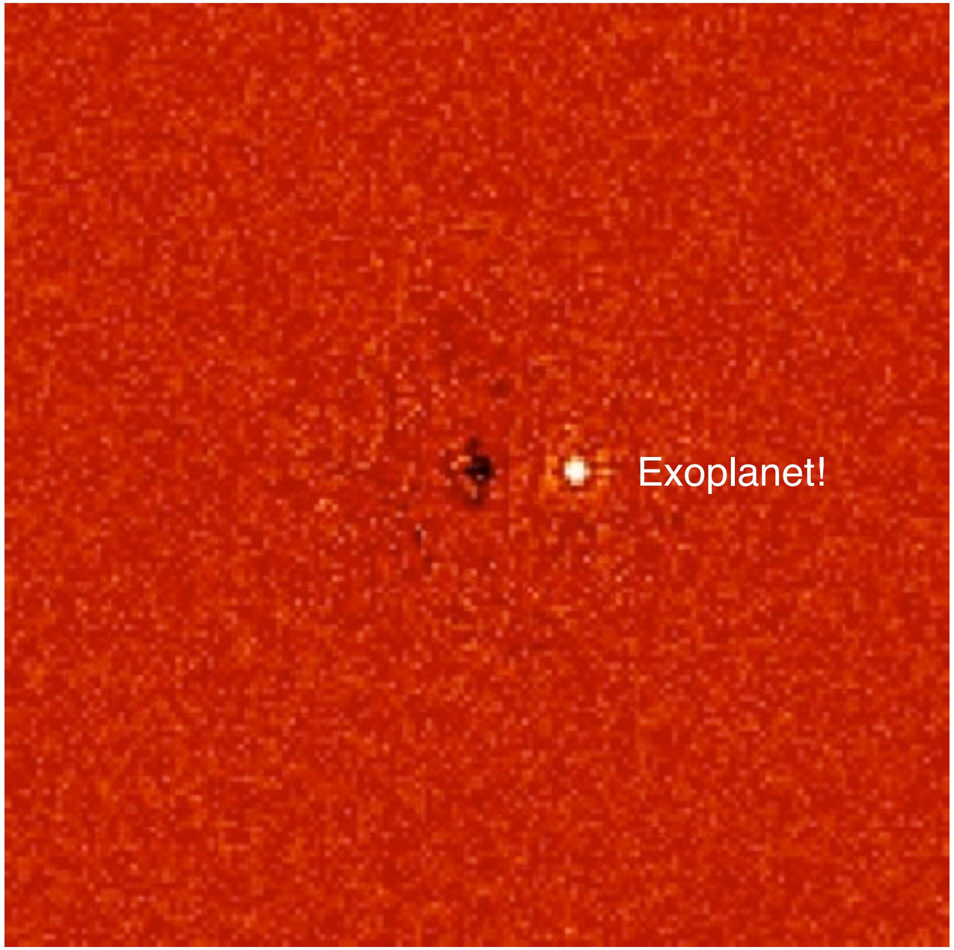
Exoplanets



TF Simulation

NIRCam, FGS/TF & MIRI *all* carry coronographs

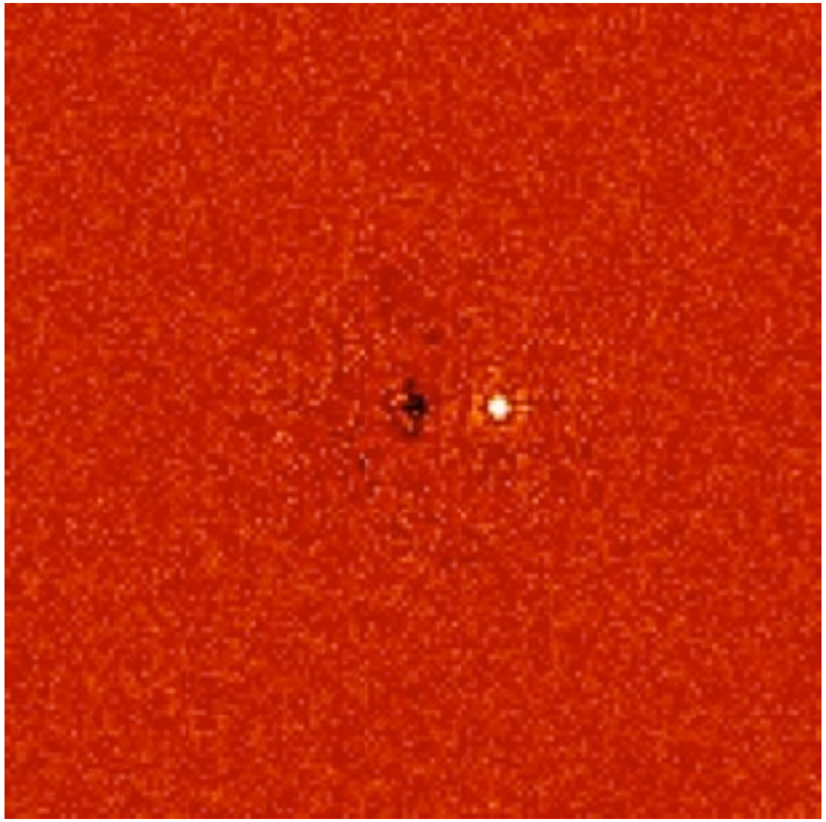
Exoplanets



TF Simulation

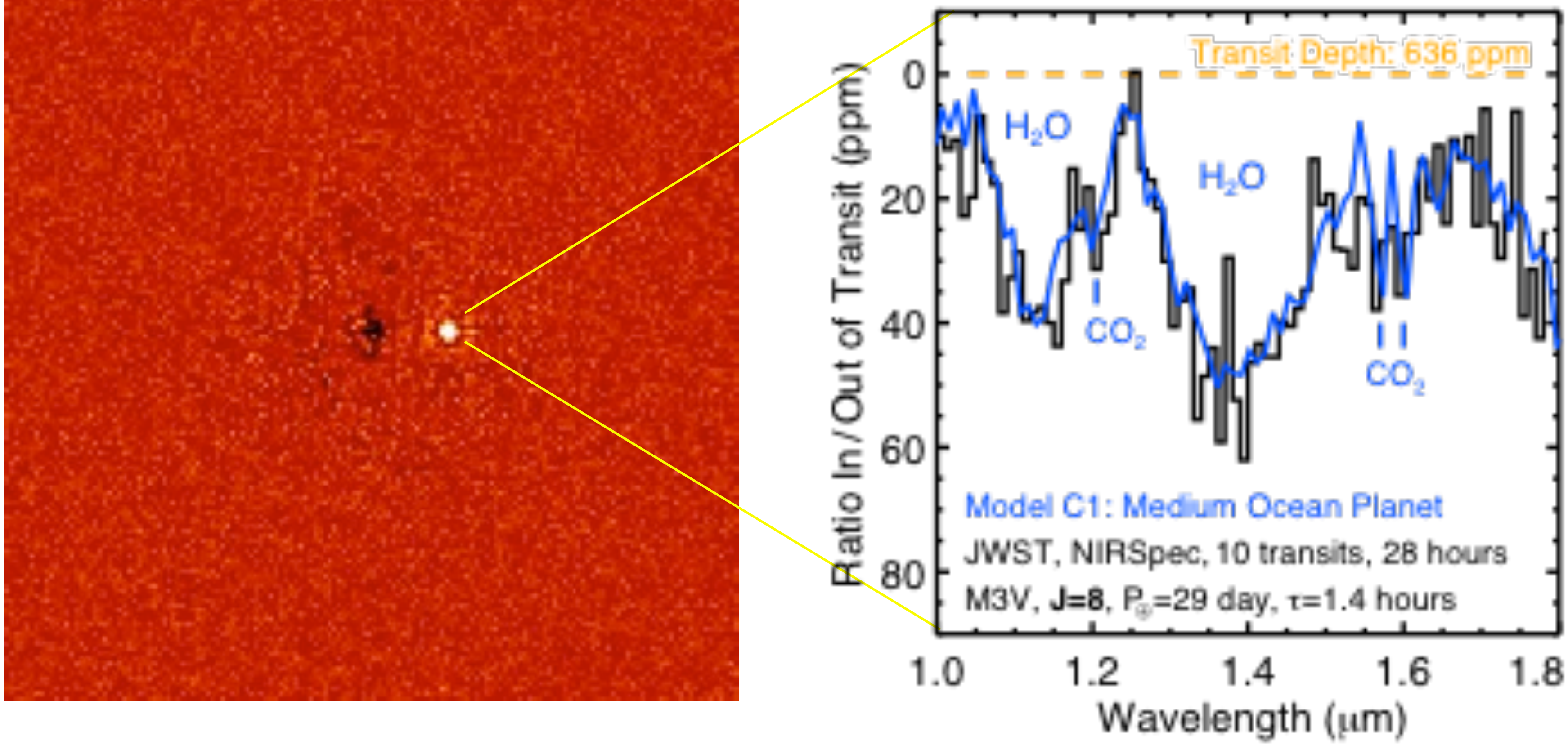
NIRCam, FGS/TF & MIRI *all* carry coronographs

A Pretty Picture Is (Still) Not Enough



A Pretty Picture Is (Still) Not Enough

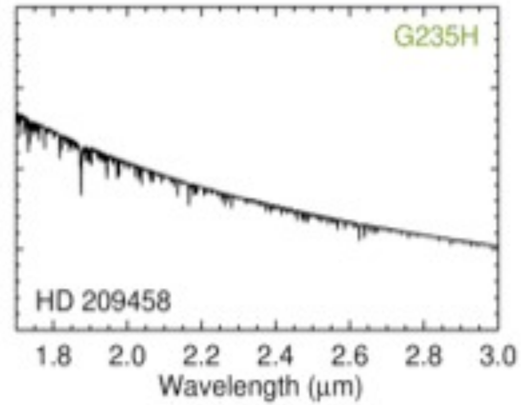
Enter NIRSpec



Imaging is Astronomy - Spectroscopy is **Astrophysics**

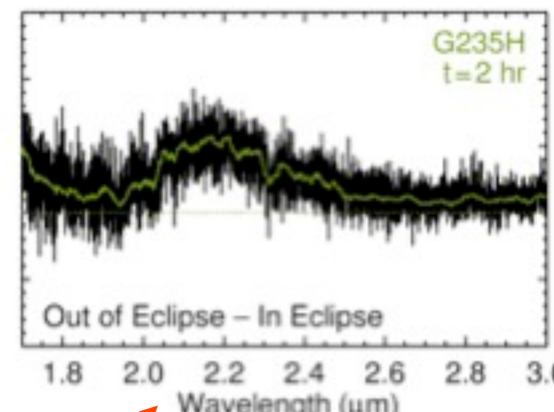
Nature's Coronograph

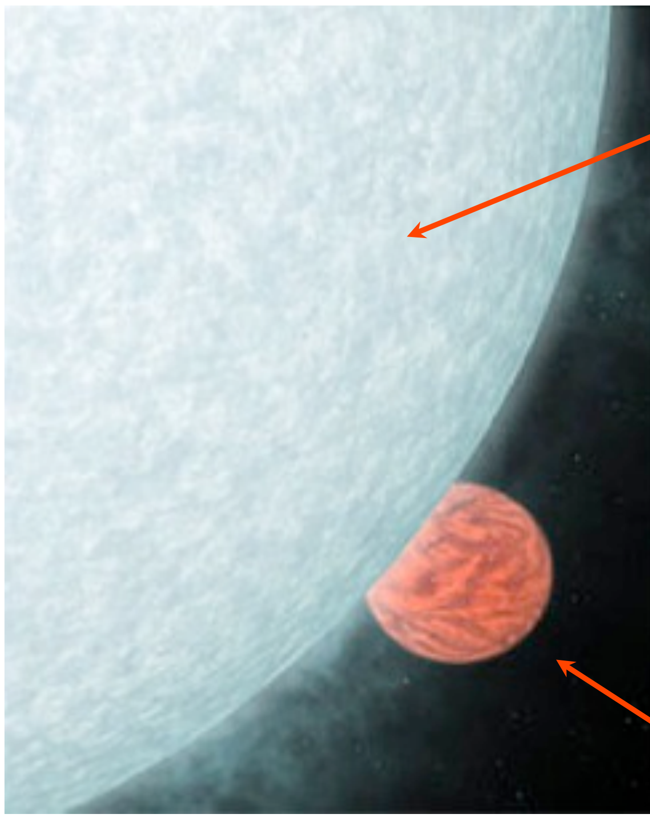
Spectrum of Star



NIRSpec Simulation

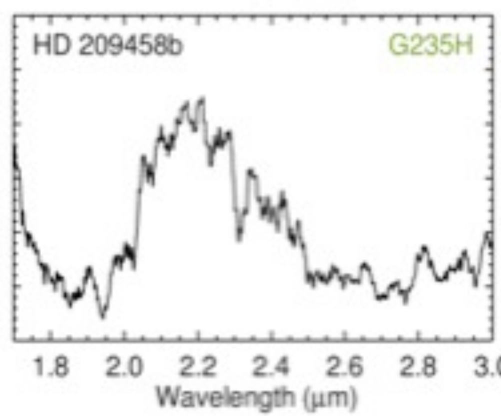
Difference Signal





Transiting Exoplanet (Corot, Kepler, ..)

Spectrum of Planet



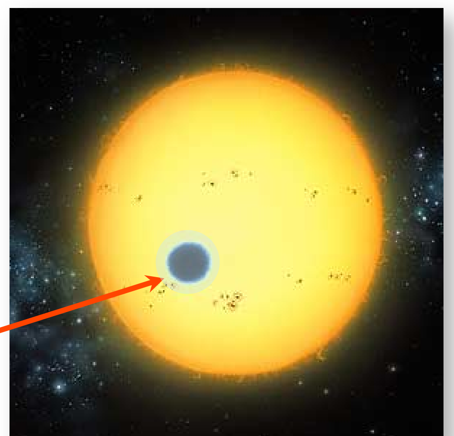
~10^{-3} - 10^{-6} Level Problem

Successfully done with Spitzer.....

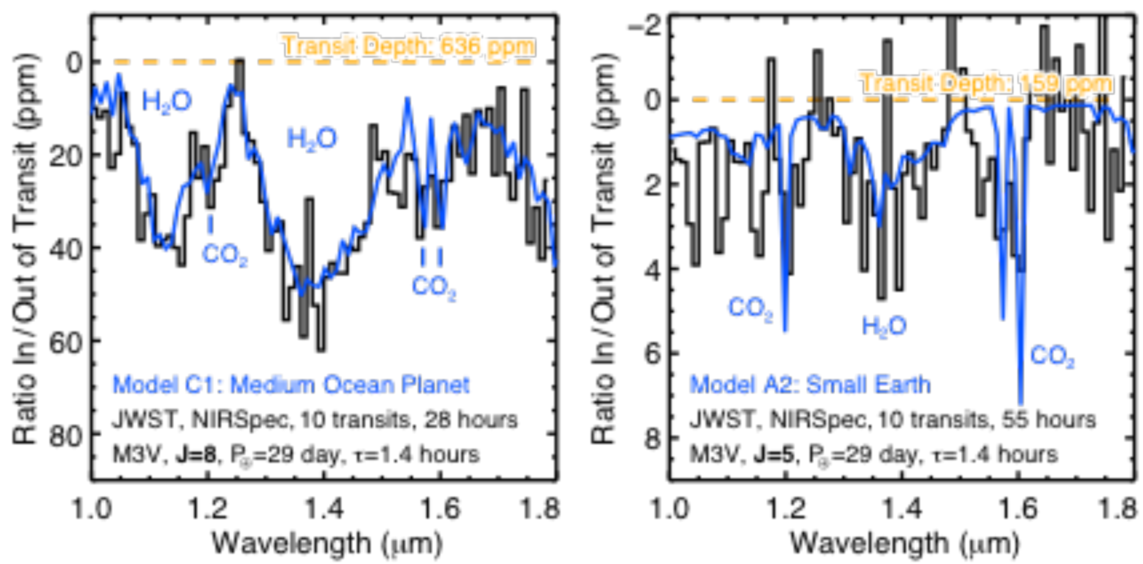
Exoplanet Transmission Spectra

- Search for “habitability” spectral signatures from planet atmosphere during transit

Extended Planetary Atmosphere



Transiting Exoplanet



NIRSpec Simulation

Successfully done with HST.....

~10^{-4} - 10^{-7}
Level Problem