MIRI
The Mid-Infrared Instrument for the JWST

Gillian Wright, MIRI European PI

Summary

- Science in the mid-Infrared on JWST
- MIRI design overview, status and “vital statistics”.
- Sensitivity, saturation and sub-arrays, operations/ dithering

Astronomy at thermal/mid-infrared wavelengths

Is good for studying

- ***Redshifted objects:*** $\lambda_{obs} = \lambda_{rest} \times (1 + z)$.
- ***Objects that are very dusty:*** $\tau_{vis} \sim 15 \times \tau_{MIR}$ **(e.g., newly forming stars and centers of galaxies)**
- ***Objects that are cool:*** **T ~ 300 K (e.g., brown dwarfs, planets, molecular clouds)**
- **re-radiated light ("warm dust") from very massive stars or active galactic nuclei**
- ***Objects rich in unique spectral features*** **(atomic fine-structure and hydrogen lines, isotopes, H_2 pure-rotational transitions, PAHs, crystalline and amorphous silicates, features of H_2O, CO, CH_4, CH_3OH, NH_3, OCN–, H_3+, C_2H_2, HCN, OH, ...)**

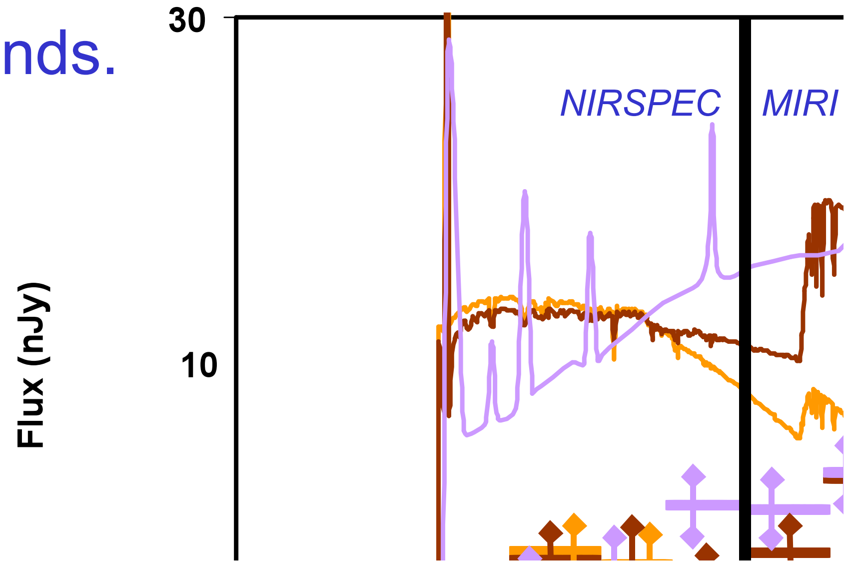
‘First light’ objects

Identified by low signal in MIRI imager filter bands.

First light:
low metallicity hot massive stars

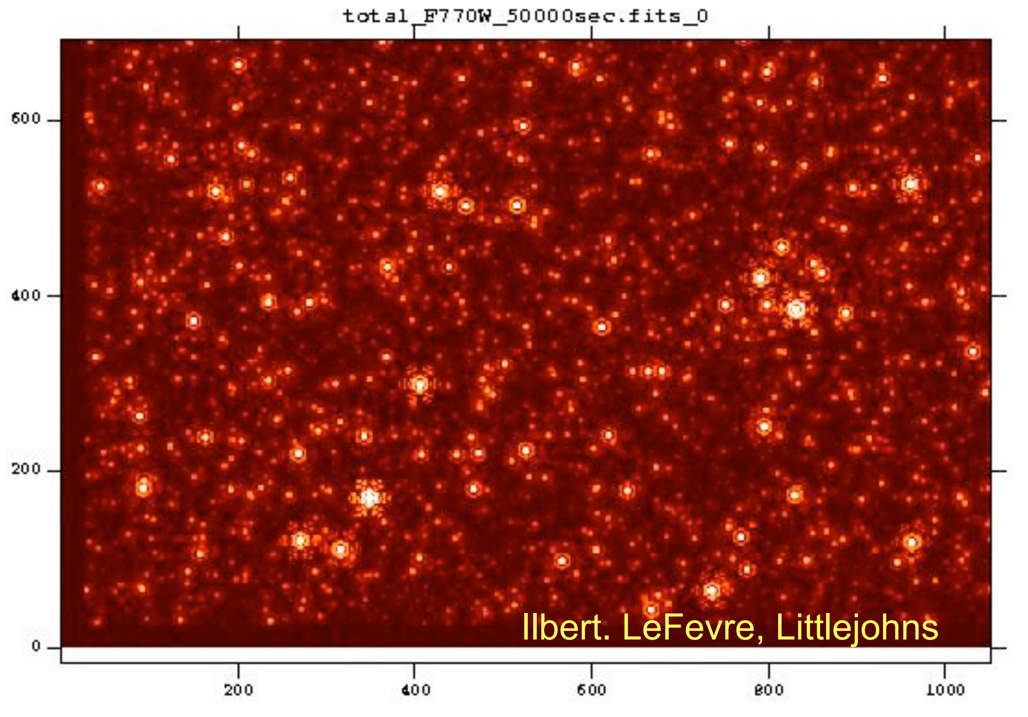
Older galaxy:
dusty, cooler.

Bright for NIRCAM, too faint for MIRI = 1st light object.

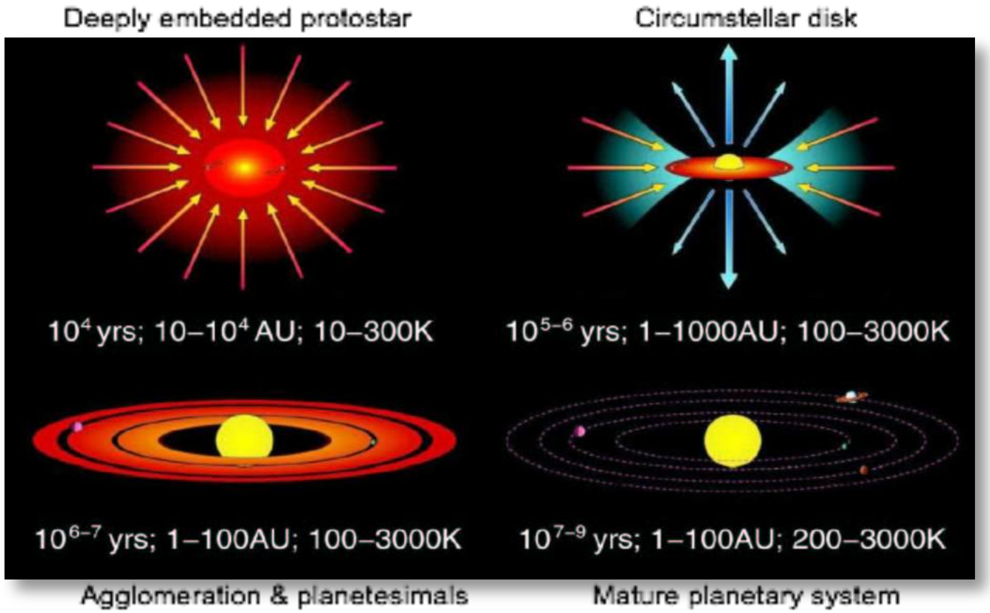


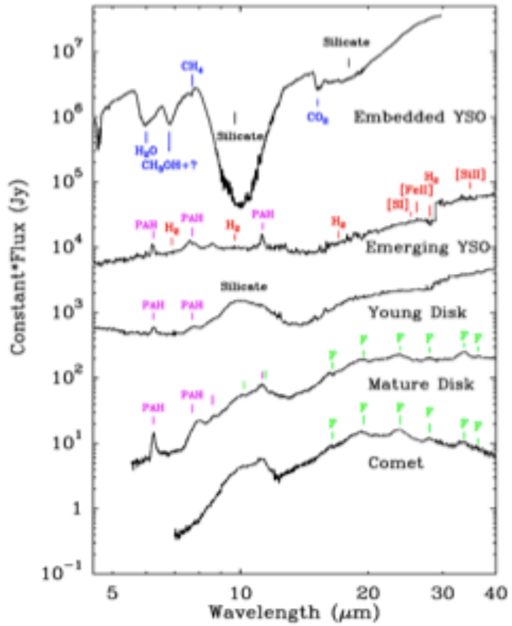
Galaxy Evolution with MIRI

- **Mass assembly of galaxies out to z ~ 6**
  - Deep images in 6-8um range provides direct measurement of rest frame red/near-IR light – mass and morphology of the older stellar population
    - For z = 10 – 6: MIRI(λ = 5μm) <-> restframe λ: 0.5 – 0.7 μm
  - High redshift QSOs : New information about the central engine, correlations e.g. between bolometric luminosity, black – hole mass, accretion properties, element enrichment (as found for low z samples)

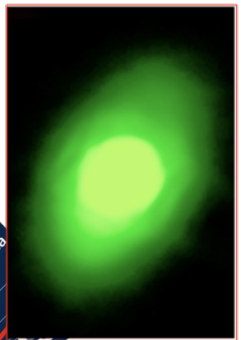


Formation and evolution of disks

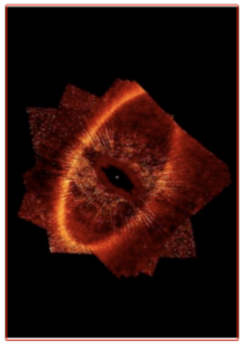




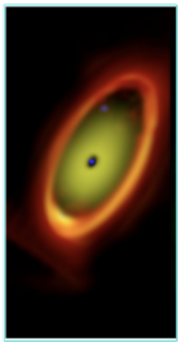
Spitzer (24 μm)



ACS (Visible)



JWST (20 μm)

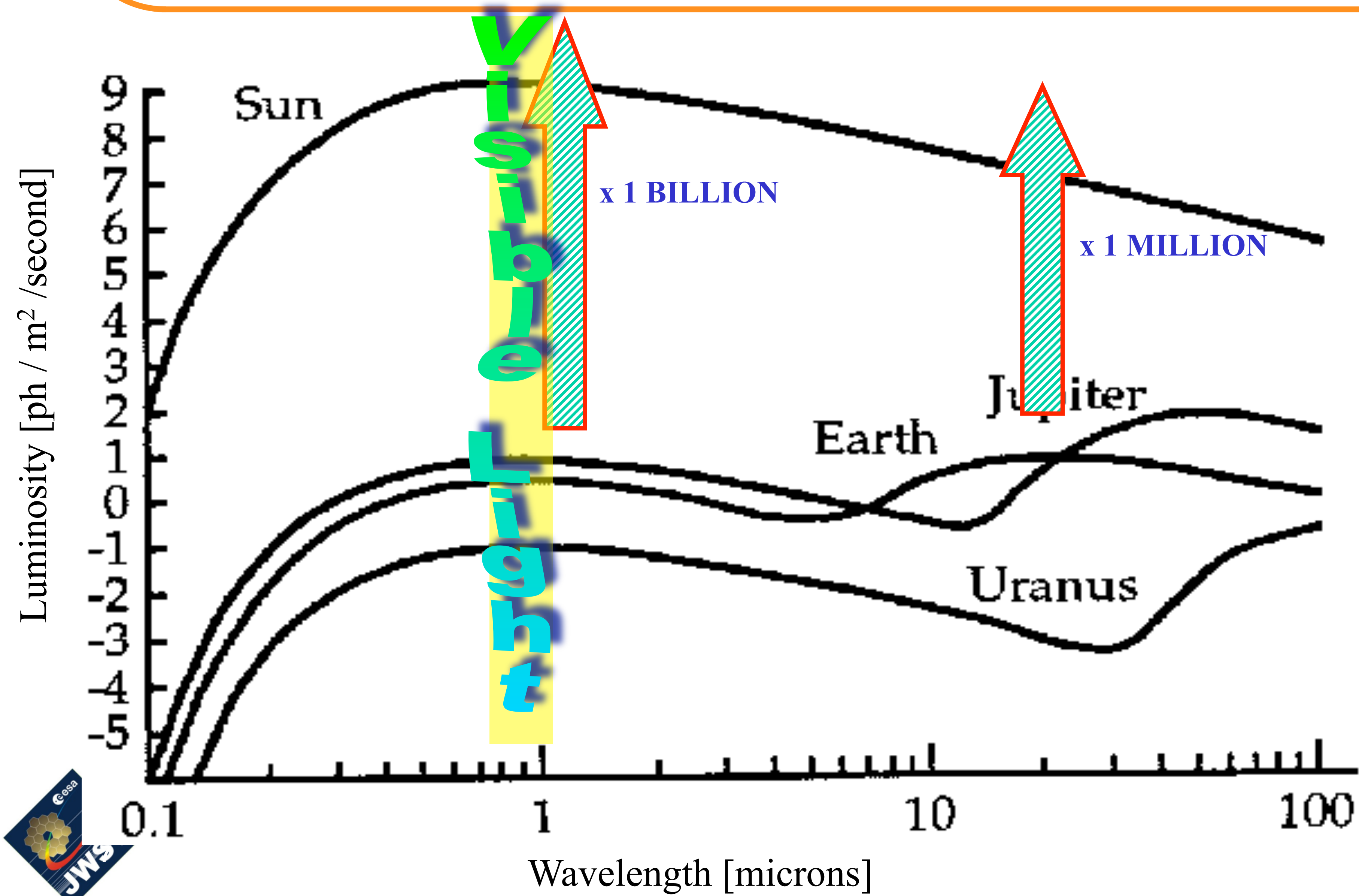


- Probe transition and debris disks in scattered light and thermal emission to resolve zodiacal and kuiper belt dust structures

- Indirect evidence of exoplanets e.g. Kalas et al. (2008), Stark and Kuchner (2008)

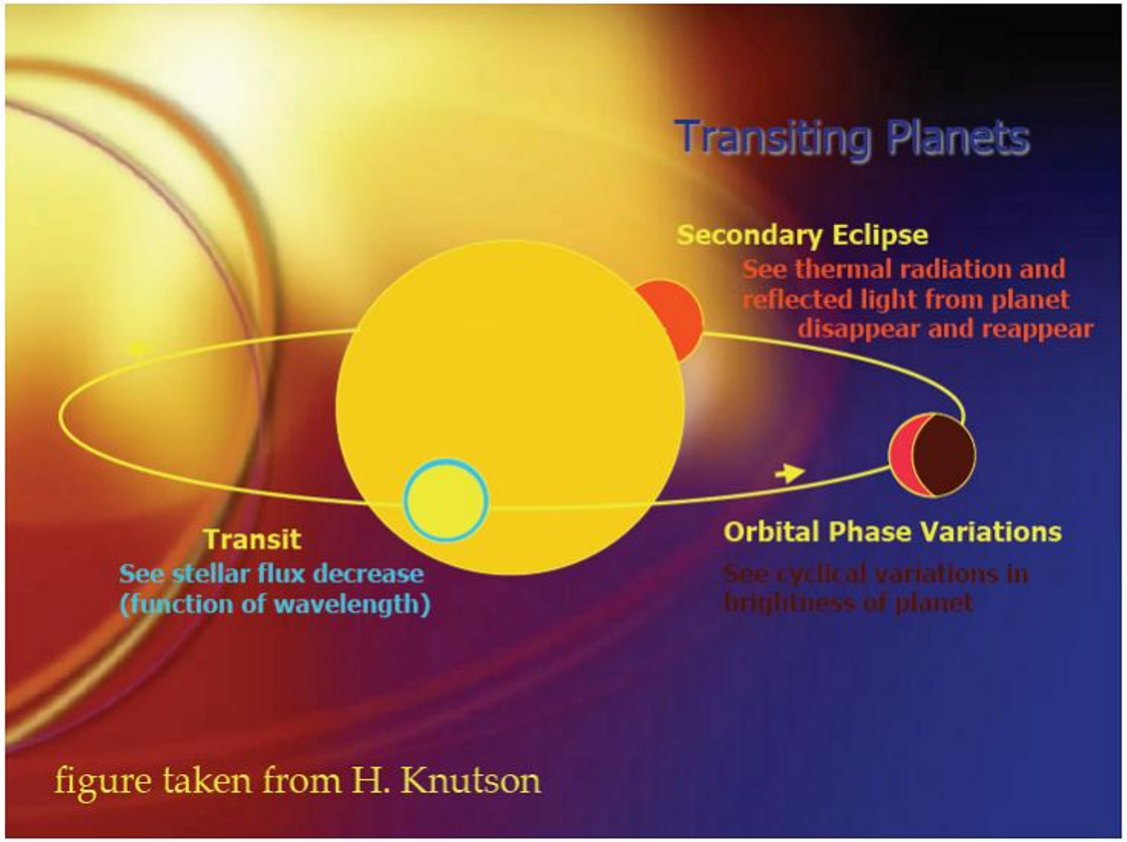
- **Spatially resolved spectroscopy**
  - **Disk mineralogy**

Planets in the Thermal IR



Exoplanets

- **In general MIRI strengths are planet characterisation, not planet hunting – transit spectroscopy**
- **MIRI “niche” - saturn-mass planets around young M dwarfs located in nearby moving groups and associations, a class of extrasolar planets that can only be accessed with JWST.**



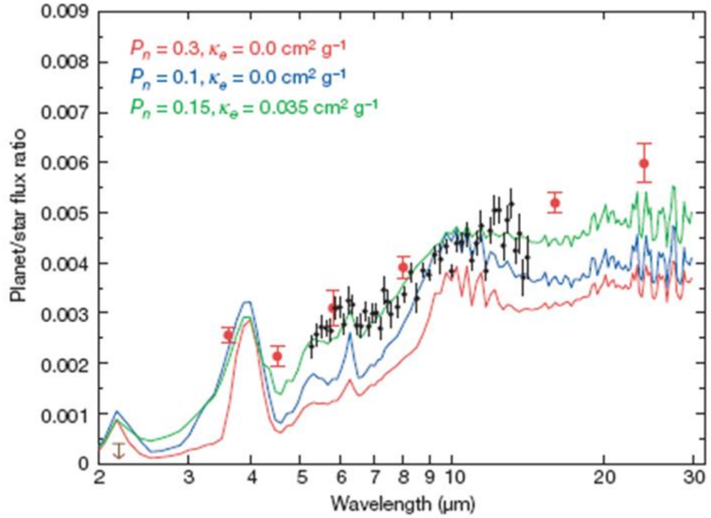
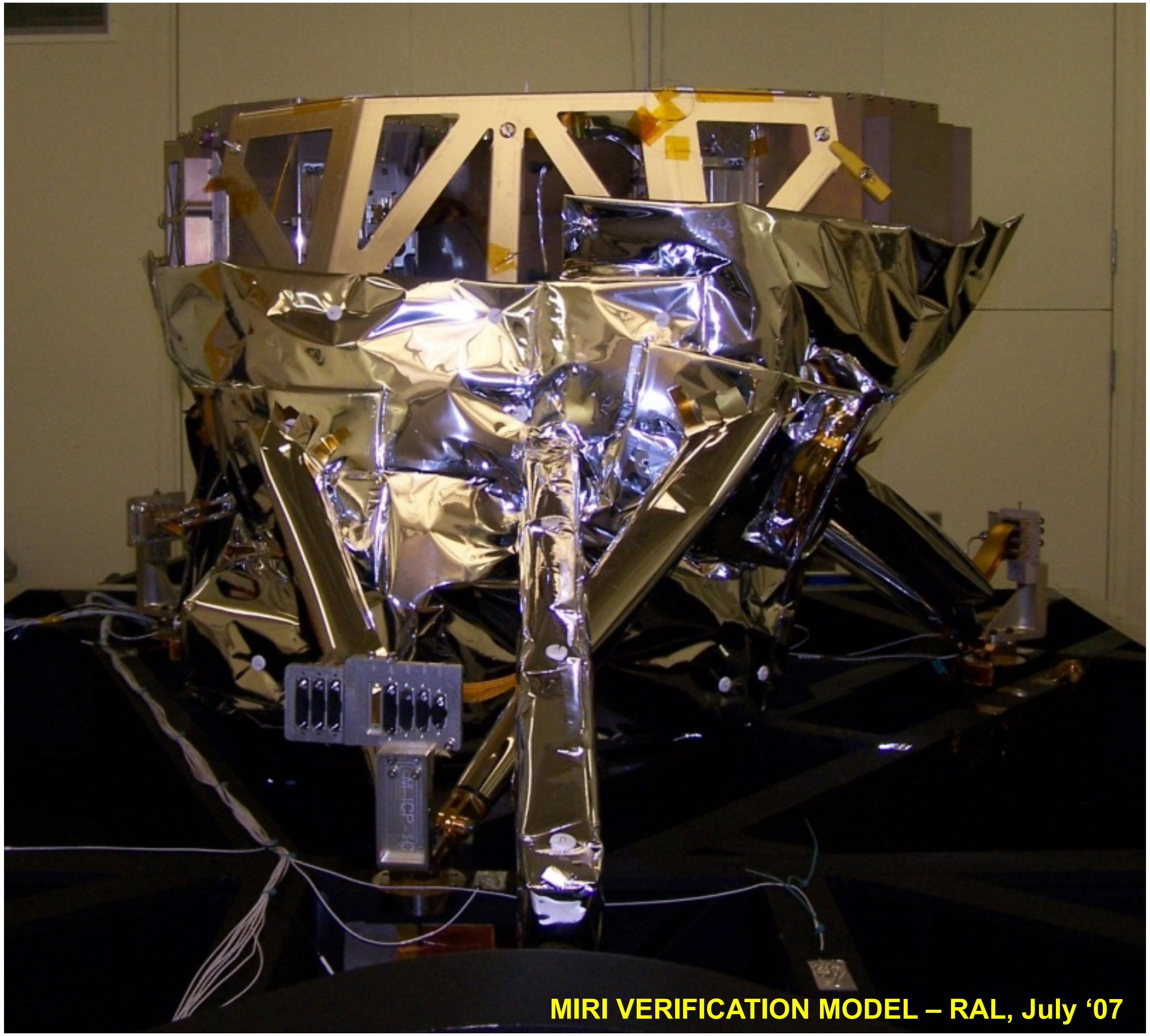


Figure 3 **Comparison of spectral observations with broadband photometry and theoretical models of the dayside atmosphere of HD 189733b.** The black points show the mean planet/star flux ratios for six second-order spectra (5–8 μm) and four first-order spectra (7.5–14 μm). The data have been binned by a factor of four after light-curve fitting (corresponding to two IRS resolution elements), and the plotted uncertainties reflect the standard error in the mean in each wavelength bin. The filled red circles show broadband measurements from ref. 5 at 3.6, 4.5, 5.8, 8.0, 16 and 24 μm (error bars on this data, s.e.). The upper limit at 2.2 μm is derived from Keck spectroscopy[16]. The red, blue and green traces are atmospheric model predictions for three values of a dayside–nightside heat redistribution parameter, P_n, and two values of the extra upper-atmosphere opacity, κ_e. The model predictions have not been scaled in any way.

From Grillmair et al., Nature 2008.

MIRI

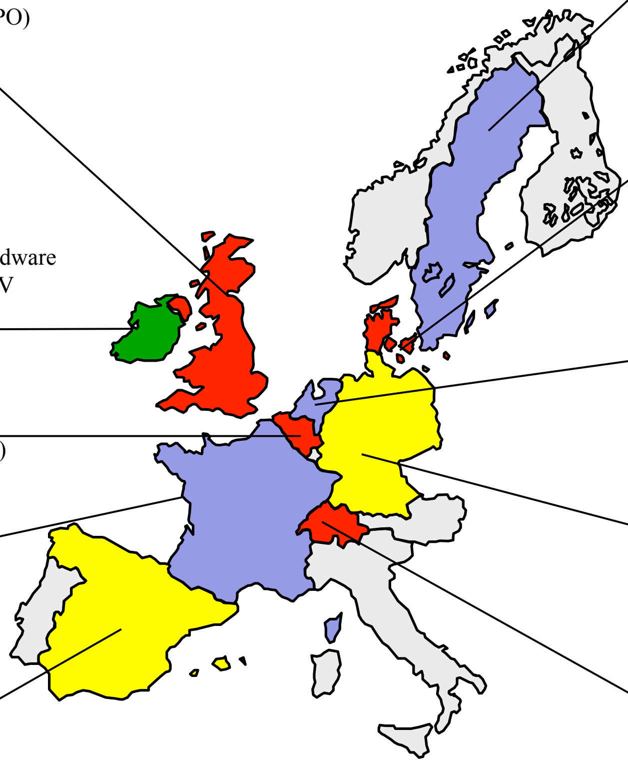
- **A 5 to 28 μm imager and spectrometer**
- **Flight model systems now being integrated at the Rutherford Appleton Lab**
- **Built by a nationally funded consortium of European Institutes and JPL**
- **Unlike the other JWST instruments MIRI has to be cooled to ca 7K**
  - Dedicated cryocooler
  - MIRI hardware is distributed across all regions of the spacecraft.



MIRI VERIFICATION MODEL – RAL, July '07

The MIRI European Consortium

UK-ATC	Principal Investigator Optical Engineering Spectrometer Pre-Optics (SPO) Calibration Sources
Astrium Ltd.	Consortium Management PA Coordination System Engineering
U. of Leicester	Mechanical Engineering Primary Structure MGSE
RAL	Thermal Engineering & Hardware Optical Bench Assembly AIV
DIAS	Filters
CSL	Input, Optics & Calibration (IOC) Instrument Control Electronics (ICE) Imager Mirrors
U. of Leuven	EGSE Software Support
CEA	Imager
LESIA/LAM	Coronagraph
INTA	MIRI Telescope Simulator (MTS)



U. of Stockholm	Filters and Dichroics
DSRI	Hexapod
NOVA-ASTRON	Spectrometer Main Optics (SMO)
U. Leiden	Spectroscopy Analysis
MPIA Heidelberg	Electrical Engineering Cryo Mechanisms
U. of Köln	Low Resolution Spectrometer Double Prism
PSI	Contamination Control Cover Cryo Harness

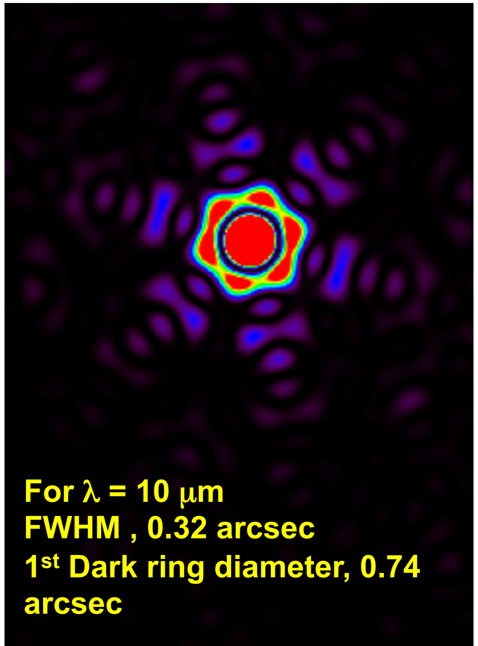
NASA/GSFC	JWST Project Office Spacecraft Integrated Science Instrument Module (ISIM)
JPL	**Detector System** **Flight Software** **Cryo-Cooler**
Univ Arizona	**Quick-look pipeline**

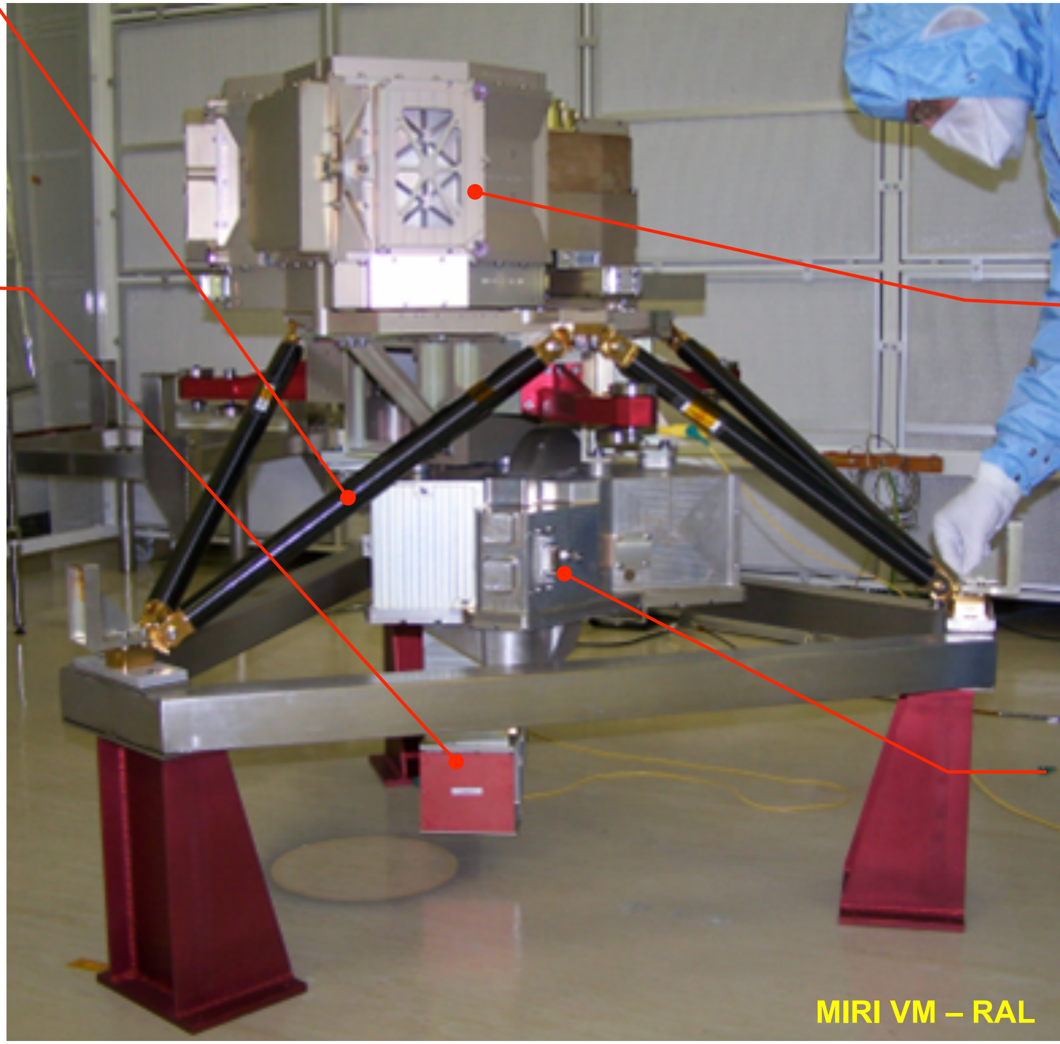
ESA/ESTEC	JWST Project Office Prodex Office

MIRI Optical System

A carbon fibre truss isolates 7 K MIRI optics from the 40 K telescope

Light enters from the JWST telescope

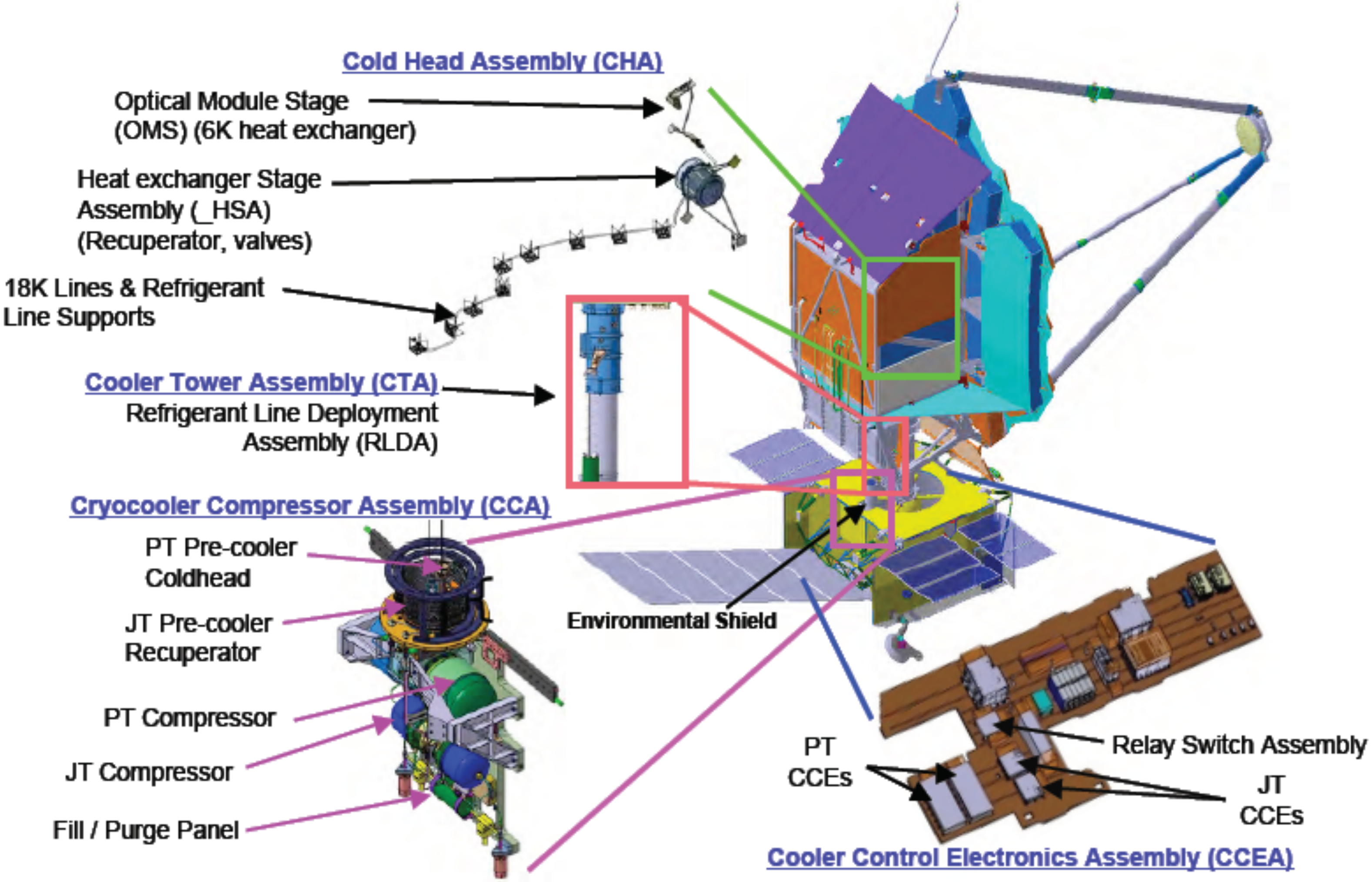




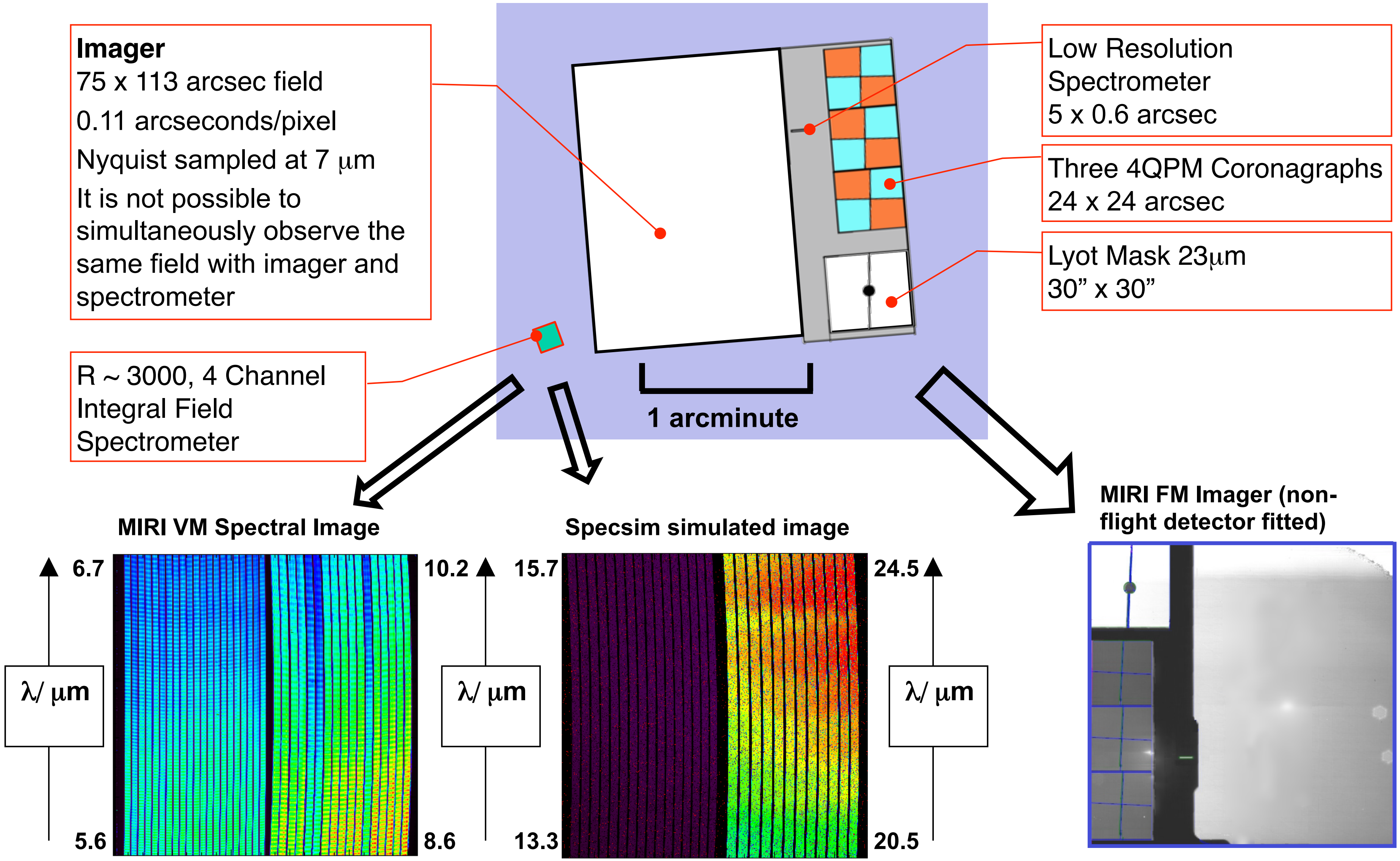
A 10 x 10 arcsec field passes through the deck into the R ~ 3000,
4 channel integral field spectrometer
2 detectors
2 channels per detector

A 115 x 115 arcsec region of the focal plane is directed into the imager
10 bandpass filters
4 coronagraphs
R ~ 100 slit spectrometer.

MIRI Cooler System



The MIRI Focal Planes (Entrance + Detector)



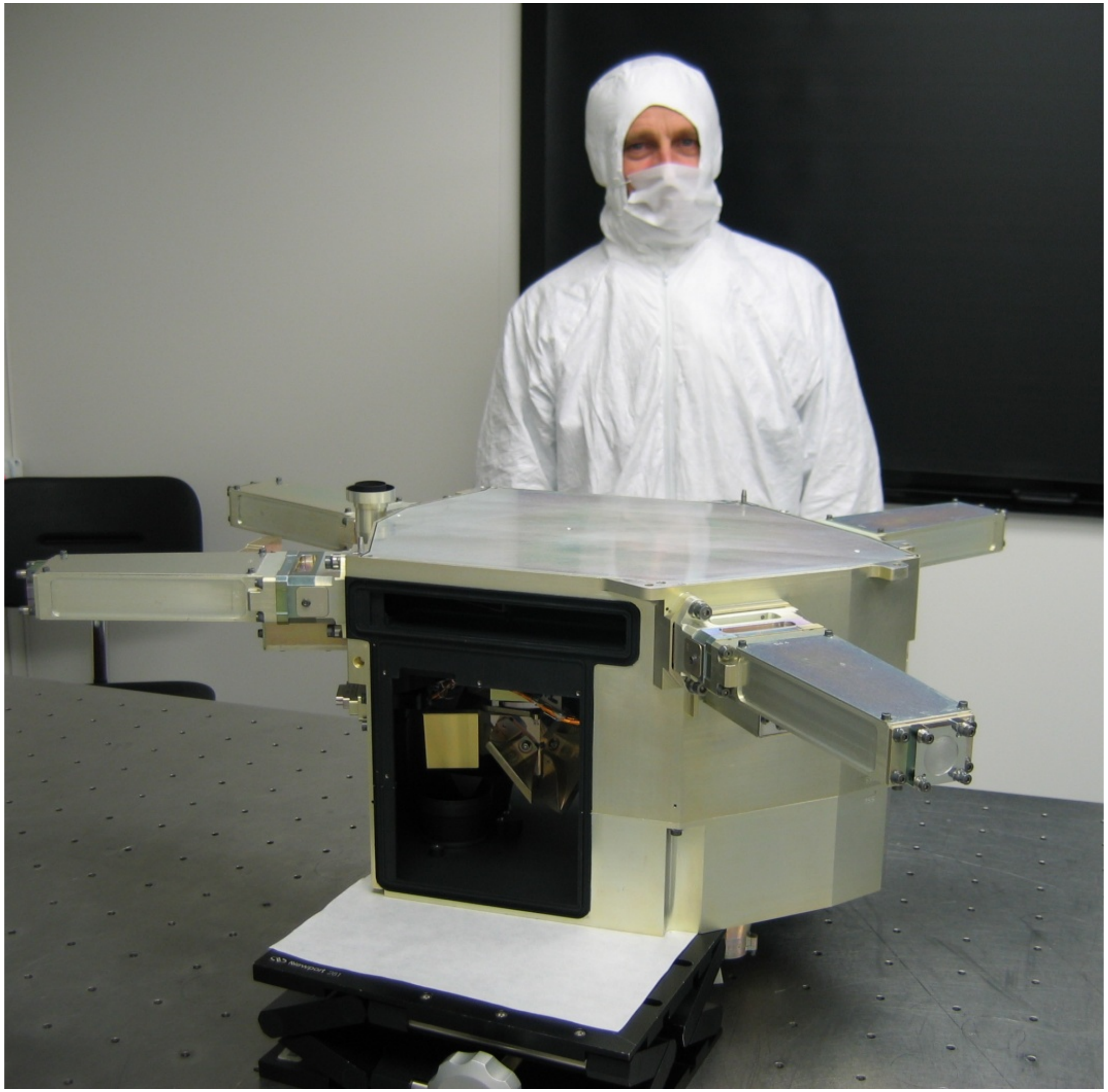
MIRI Imager Filters

CEA + MPIA + DIAS
+ CSL+ U.Stockholm

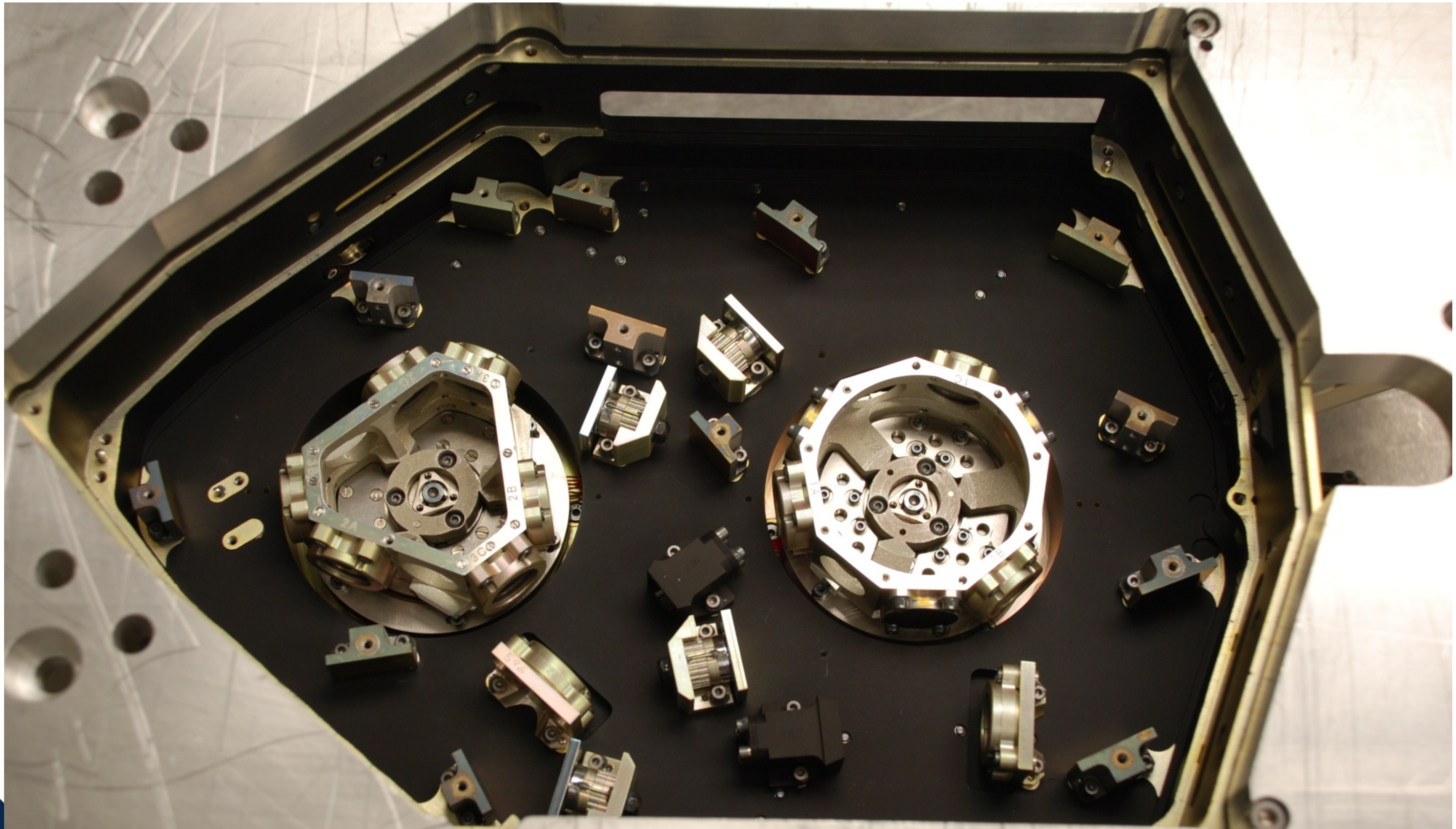
Filter name (and wavelength)	Pass band Δλ (μm)	Function
F560W	1.2	Imaging
F770W	2.2	
F1000W	2.0	
F1130W	0.7	
F1280W	2.4	
F1500W	3.0	
F1800W	3.0	
F2100W	5.0	
F2550W	4.0	
F2550WR	4.0	
P750L	5	R ~ 100 Spectroscopy
F1065C	0.53	Coronagraphy
F1140C	0.57	
F1550C	0.78	
F2300C	4.6	
FND	10	Target Acquisition
FLENS	N/A	Alignment
BLANK	N/A	Calibration

MIRI MRS – The SPO

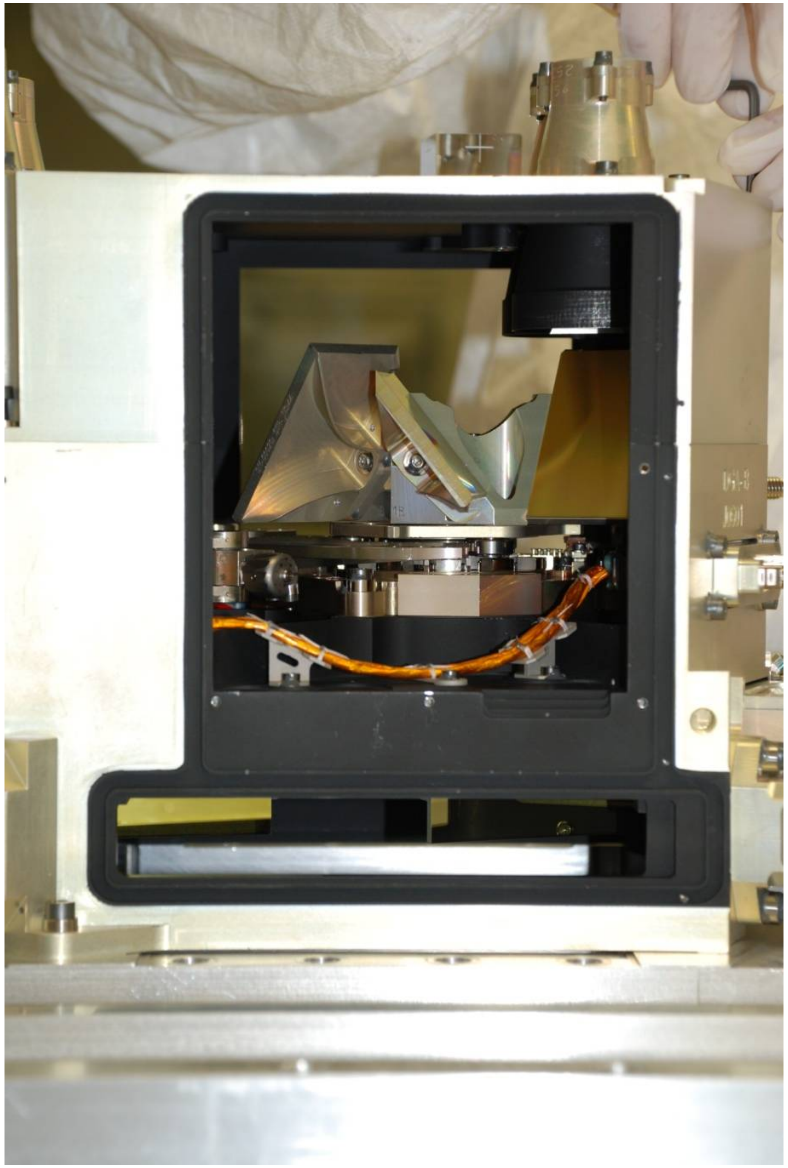
- Spectrometer Pre-Optics
- Separates the 4 spectral channels x 3 sub-spectra using 9 dichroics mounted in 2 mechanisms.
- 4 IFUs image slice the fields and present them to the spectrometer cameras.
- Spectra dispersed using 12 diffraction gratings.
- Pupil and field filtering provided throughout for straylight control.

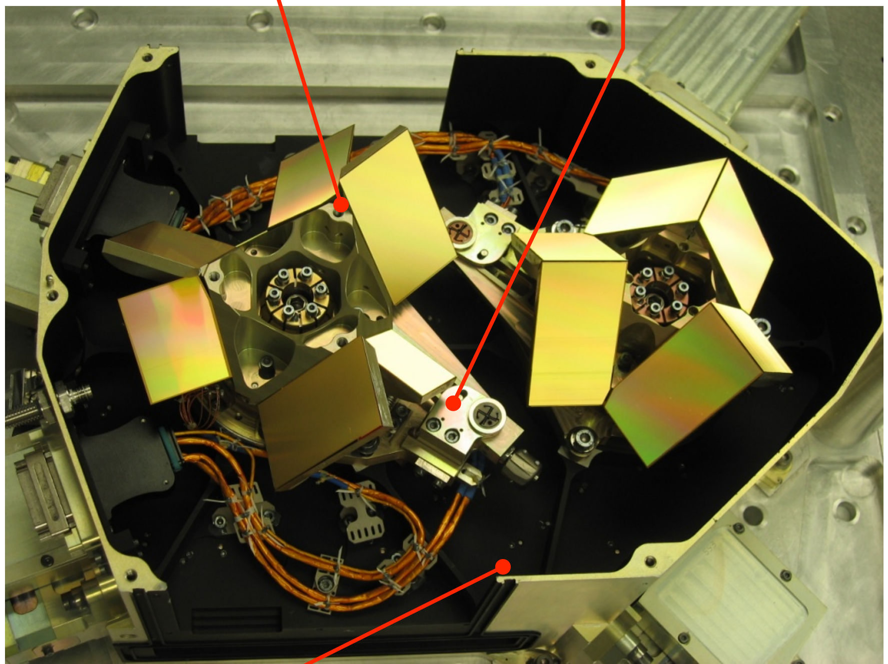


Spectral Filtering by Dichroic Chain

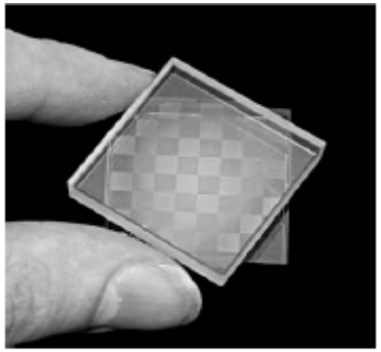


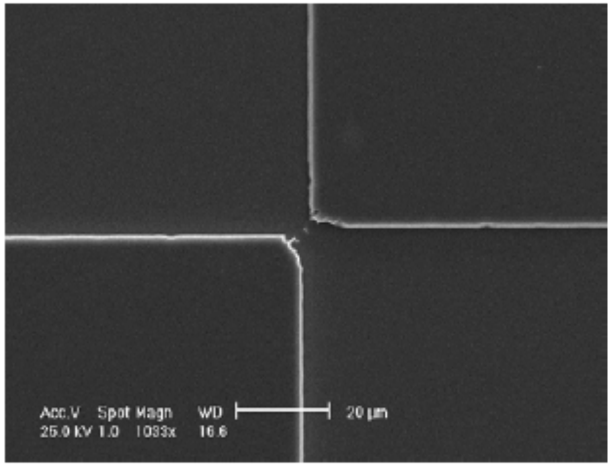
Grating Wheels

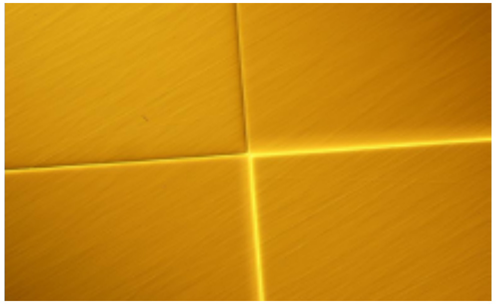




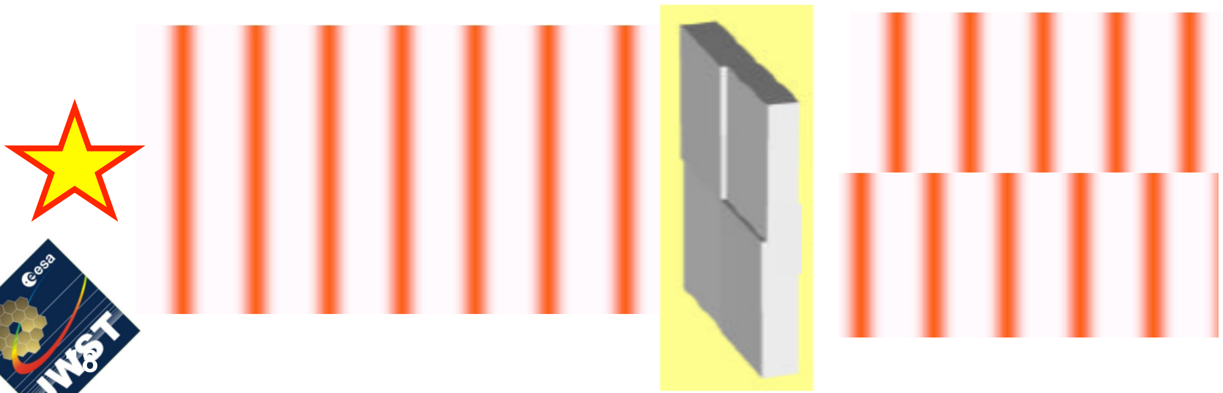
The MIRI 4Quadrant Phase Mask Coronagraph

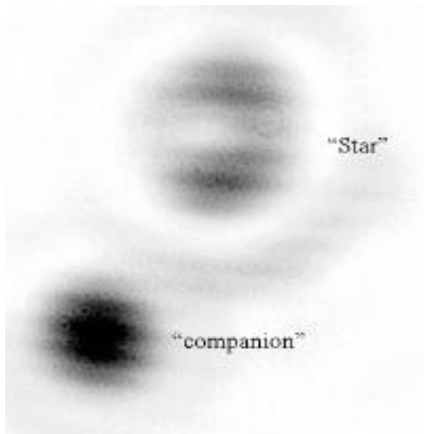




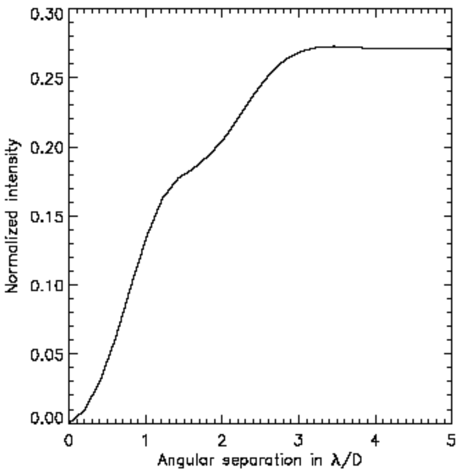


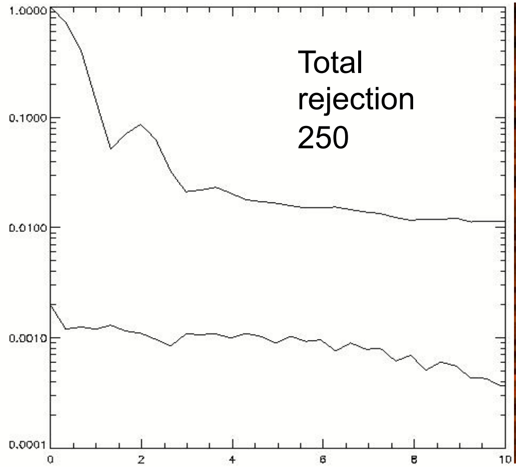
- **A flat ‘window’ with 4 panes (quadrants)**
- **If the star is centred on the cross at the centre of a 4QPM, half of its light is retarded by half a wavelength.**

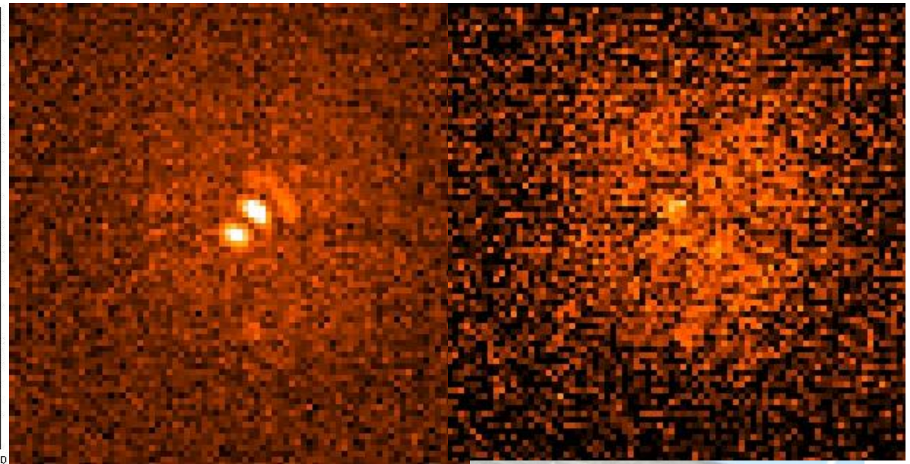


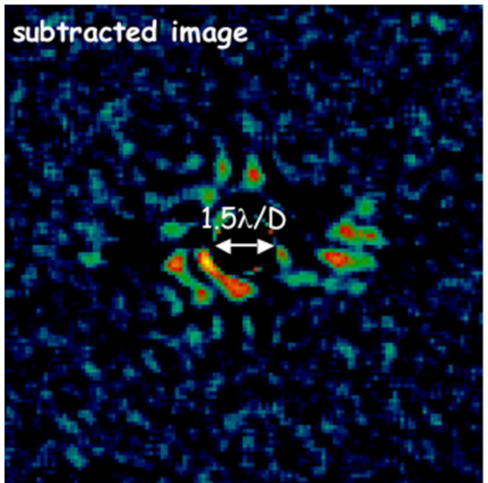


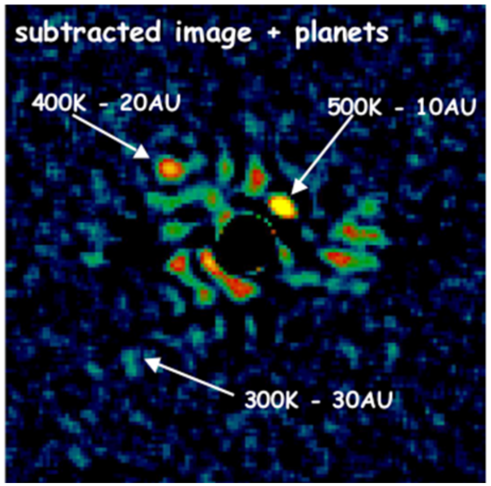
Coronagraph 4QPMs





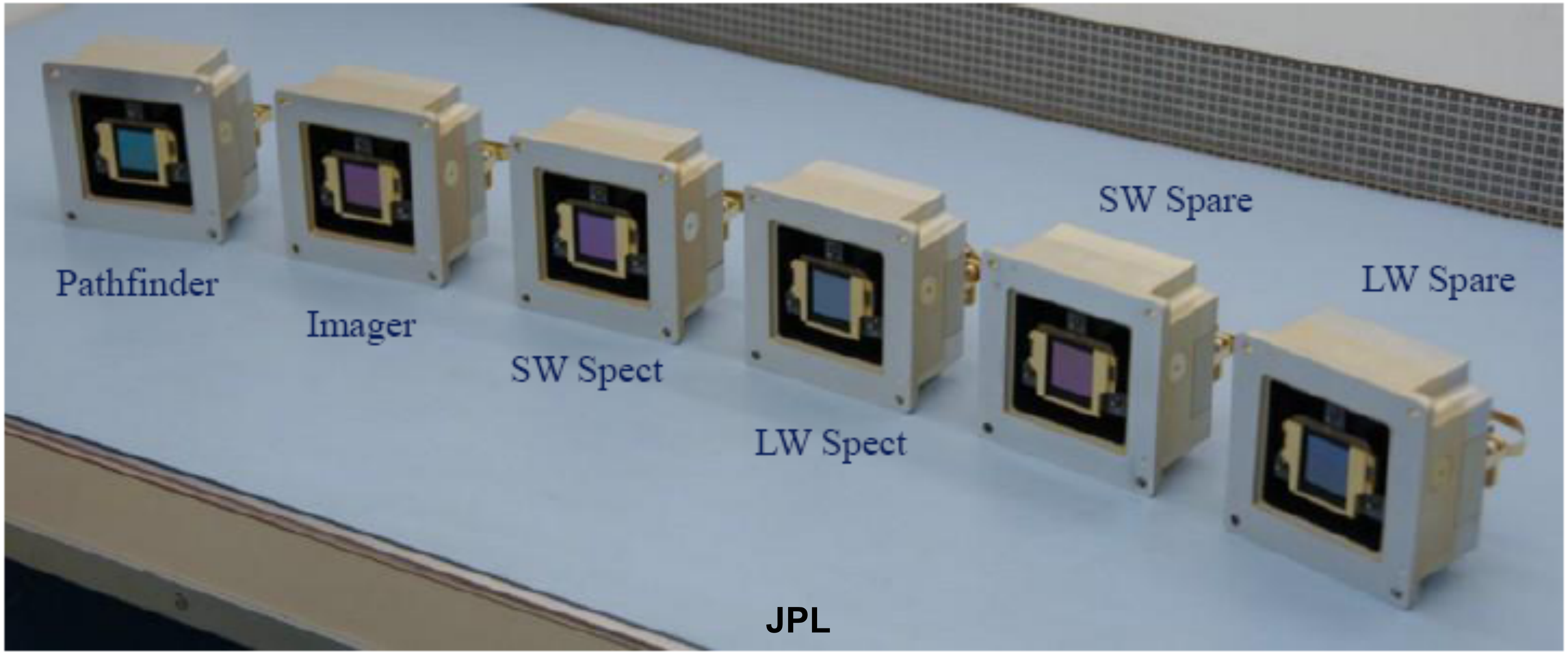






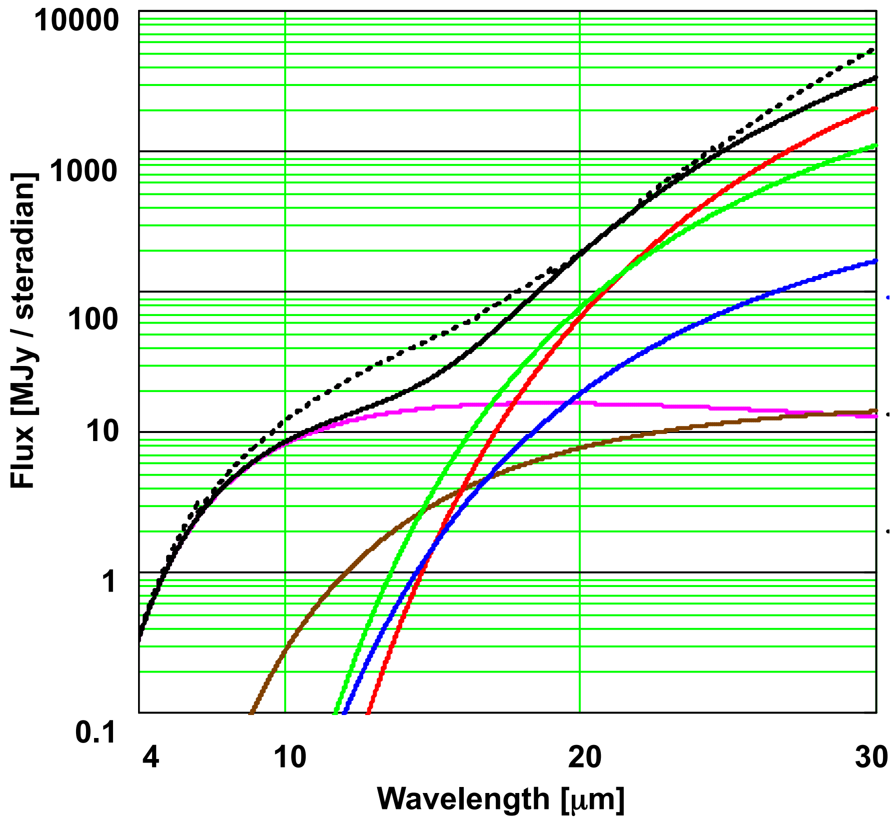
MIRI focal plane system

- **Three 1024 x 1024 Si As arrays**
  - Dedicated anti-reflection coatings
  - Very good cosmetics and noise characteristics



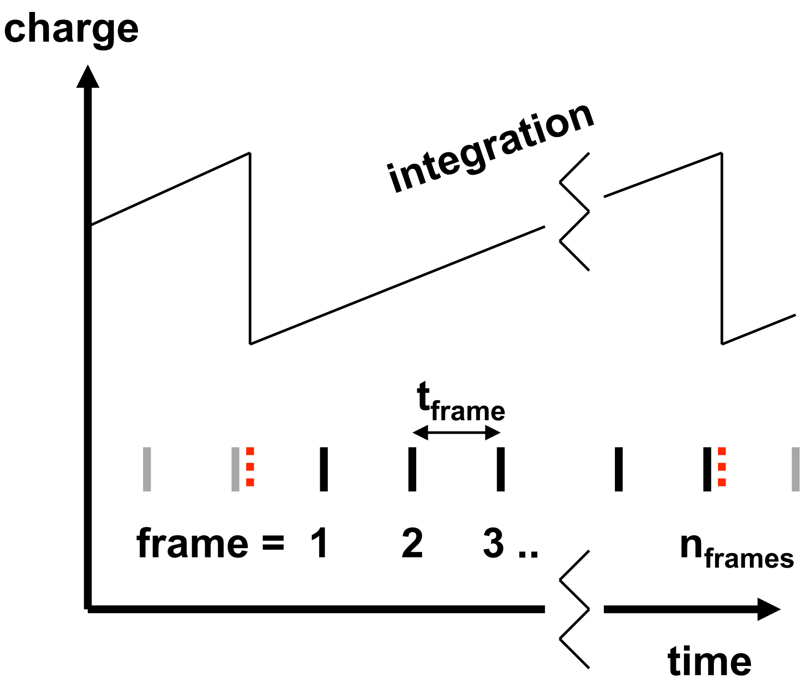
The JWST Mid-Infrared Background

- **Photon background increases by > x1000 from short to long wavelengths.**
  - Zodiacal dust
  - Straylight from Sun/Earth/etc.
  - Telescope thermal emission
  - **Cosmic ray flux expected to disturb > 50 % of pixels every 1000 seconds**



- **Aim to achieve shot noise limited sensitivity at all wavelengths and SRPs**
- **Need to make optimum use of detector**

Detector Readout Patterns

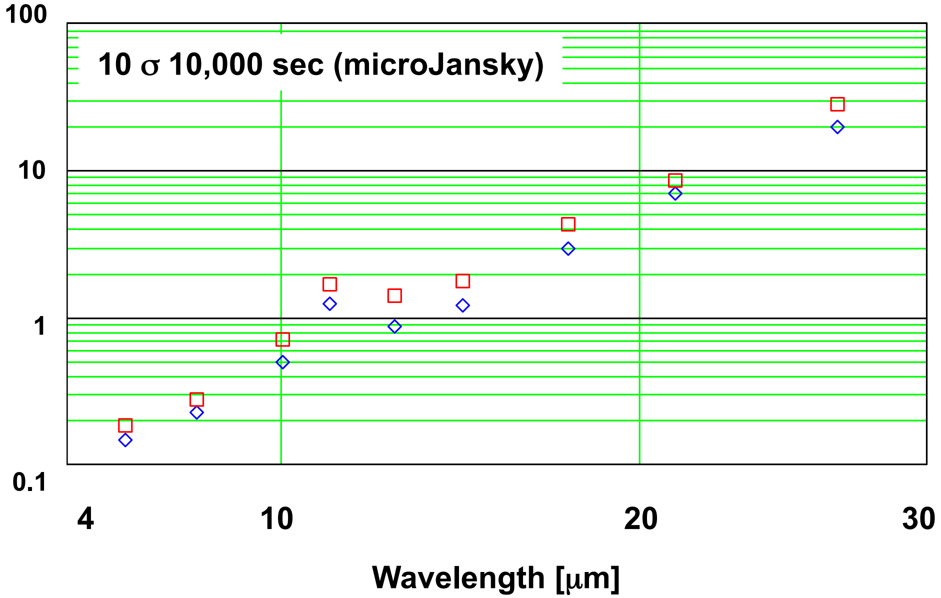


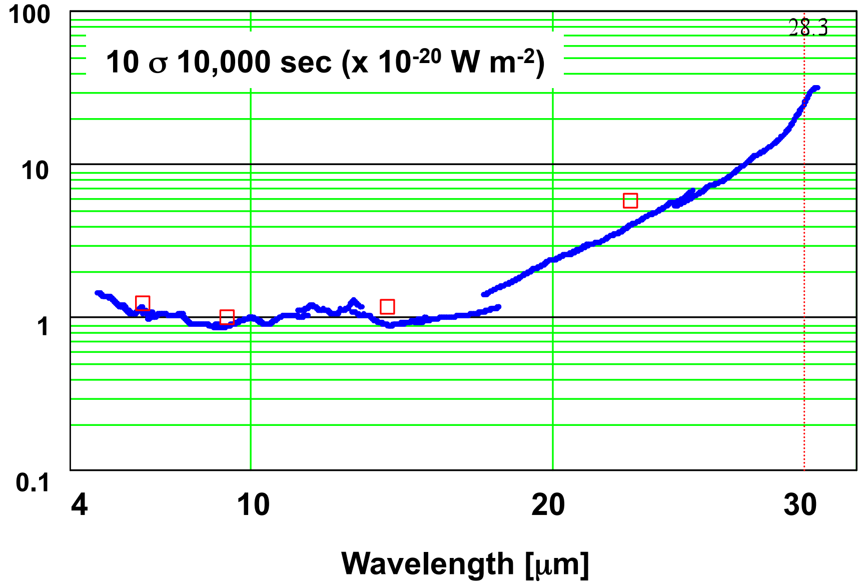
	t_{frame} [secs]	n_{frames}
FAST – Bright and extended objects (plus sub-arrays), Long wavelength imaging)	2.7	1 to 40
SLOW – Faint Objects, Deep Imaging, MRS Spectroscopy	27.6	1 to 40

- **Aim to fill the pixel capacitance**
  - measure plenty of frames to beat down the effective read noise.
- **SLOW mode averages 8 samples per frame to reduce the read noise**
  - t_{frame} is the minimum integration time. (No true dark)
- **Can estimate the sensitivity for these basic readout patterns…**

Sensitivity estimate

- Sample photocurrent with model detector (+ photometric aperture, FM estimated PCE, read noise, and FULL frame readout pattern).
- S/N = 10 in 10,000 second exposure for a faint point source

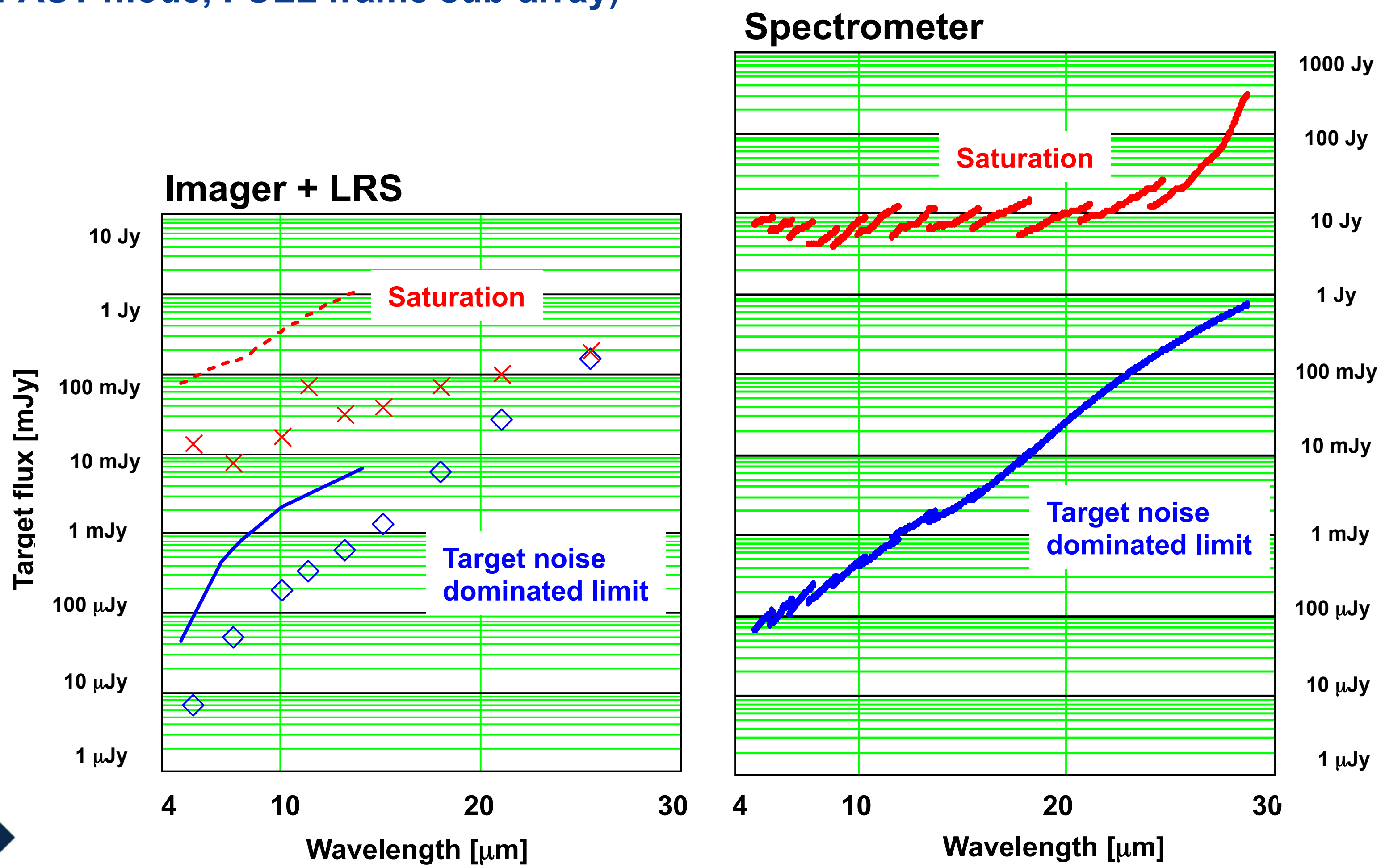




- Very sensitive, but finite detector dynamic range means that MIRI will saturate on targets which are faint on 8 m ground-based telescopes.

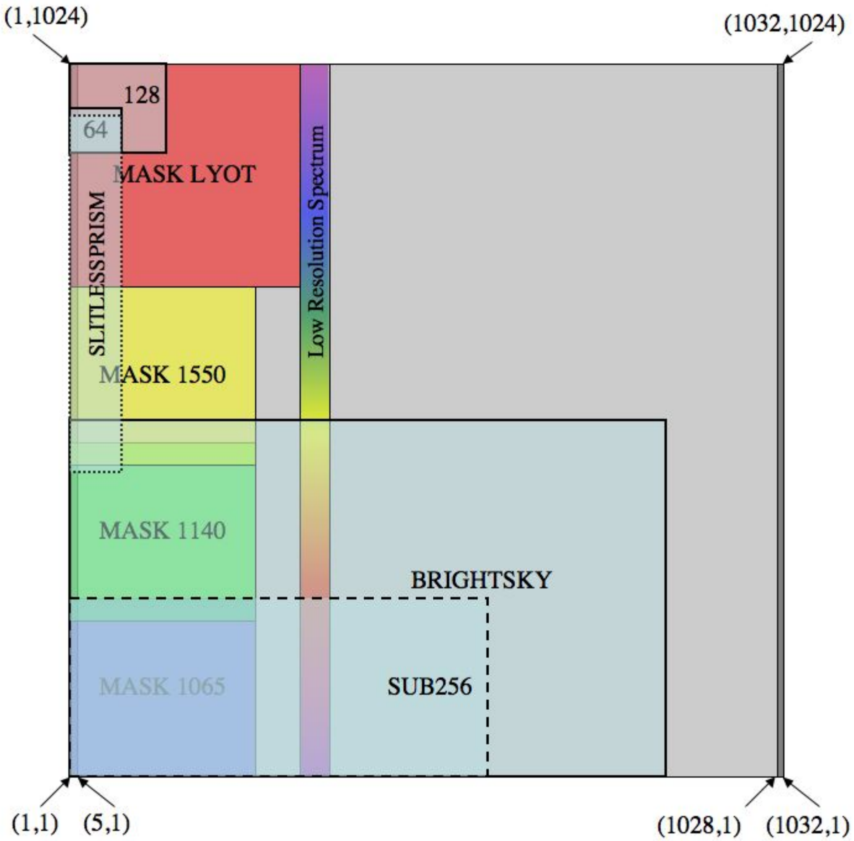
Target flux sensitivity limits

- **Target noise dominates for target photocurrent > background + dark**
- **Saturation (1/8th of flux in brightest pixel at 8 microns, 80,000 el (1/3rd full well), FAST mode, FULL frame sub-array)**



Imager Readout Patterns

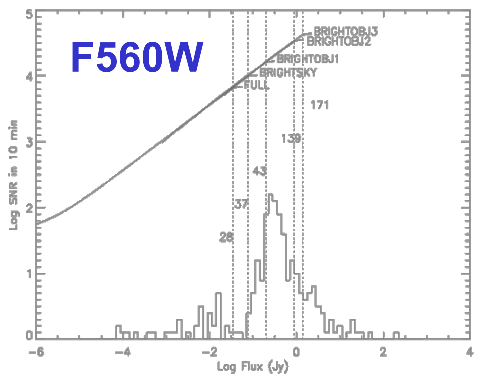
- **Extend the saturation limit using sub-arrays to trade field of view for faster frame rates.**
  - For example, a 0.5 Jy source will not saturate the F1000W filter using the SUB128 sub-array with its 14 x 14 arcsecond field.
  - Note the SLITLESSPRISM sub-array's specific capability for transit spectroscopy.

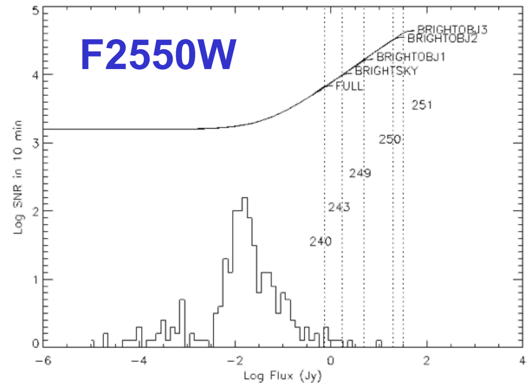


SUB-ARRAY	FAST frame time	SLOW mode frame time	Purpose
	sec	sec	
FULL	2.775	27.105	Full frame imaging + nominal LRS spectroscopy
BRIGHTSKY	1.183	11.274	Imaging at 2.3 x FULL frame saturation limit
SUB256	0.453	4.024	6.1 x FULL frame saturation
SUB128	0.100	0.515	28 x FULL frame saturation
SUB64	0.065	0.180	40 x FULL frame saturation
MASK1065	0.228	1.772	Coronagraphy
MASK1140	0.228	1.772	
MASK1550	0.228	1.772	
MASKLYOT	0.228	1.772	
SLITLESSPRISM	0.164	1.430	Slitless LRS spectroscopy

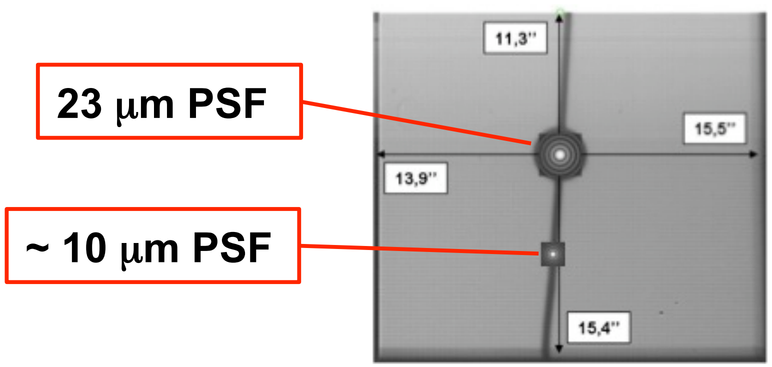
Sub-arrays and exoplanet imaging

- **Modelling sub-array impact on S/N for exoplanet parent star imaging. (Christine Chen, STSci)**



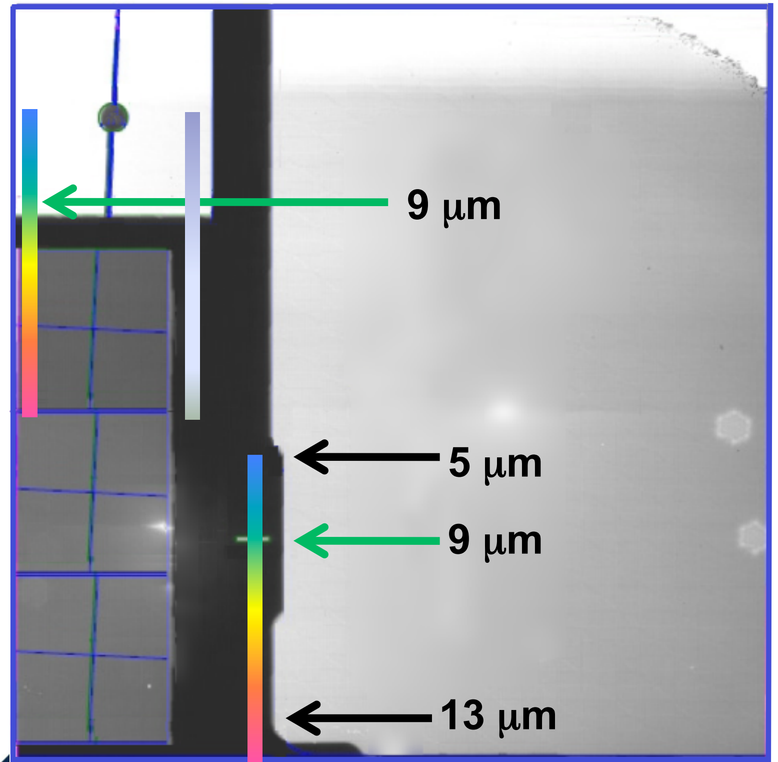


- **Proposal (Anthony Boccaletti, Meudon) to use Lyot bar for > 10^5 contrast using short wavelength filters.**



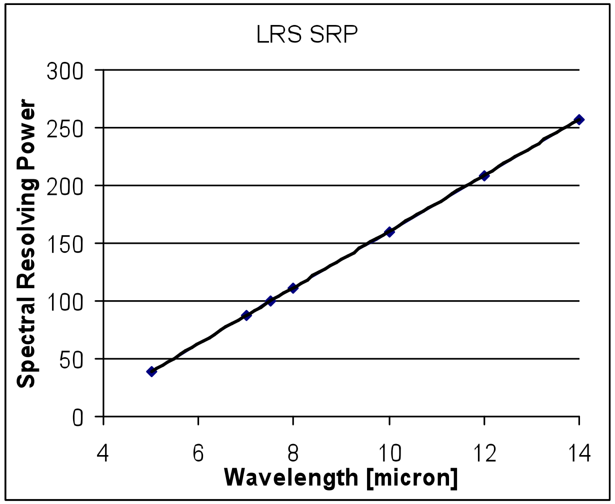
Low Resolution Spectrometer

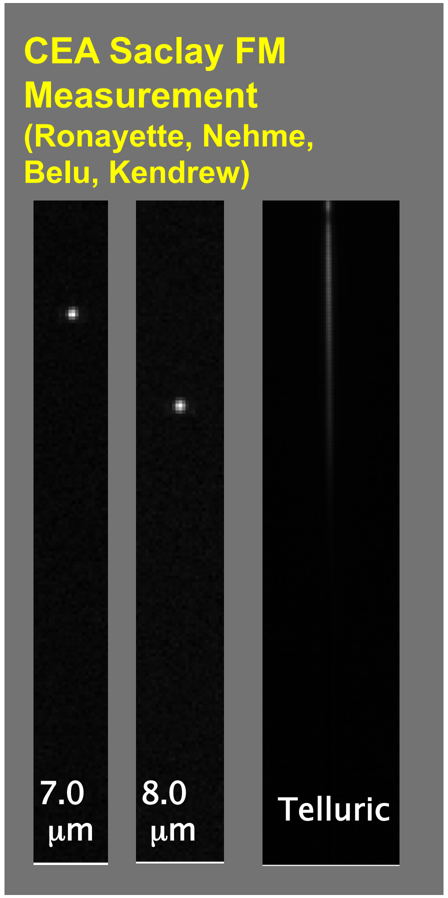
- **Slit and slitless locations**
  - Cusp at 5 μm in slitless spectra
  - Possible alternate slitless location (currently unsupported)



- **Continuum sensitivity**
  - ~3 microJansky 10 σ 10000 sec at 7.5 μm

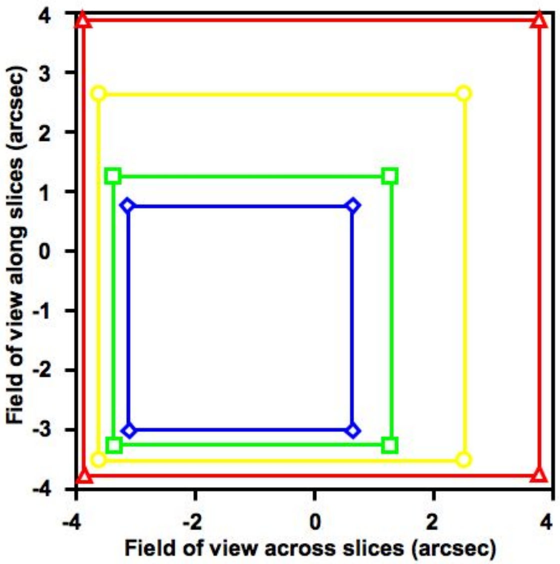
- **Spectral Resolving Power**





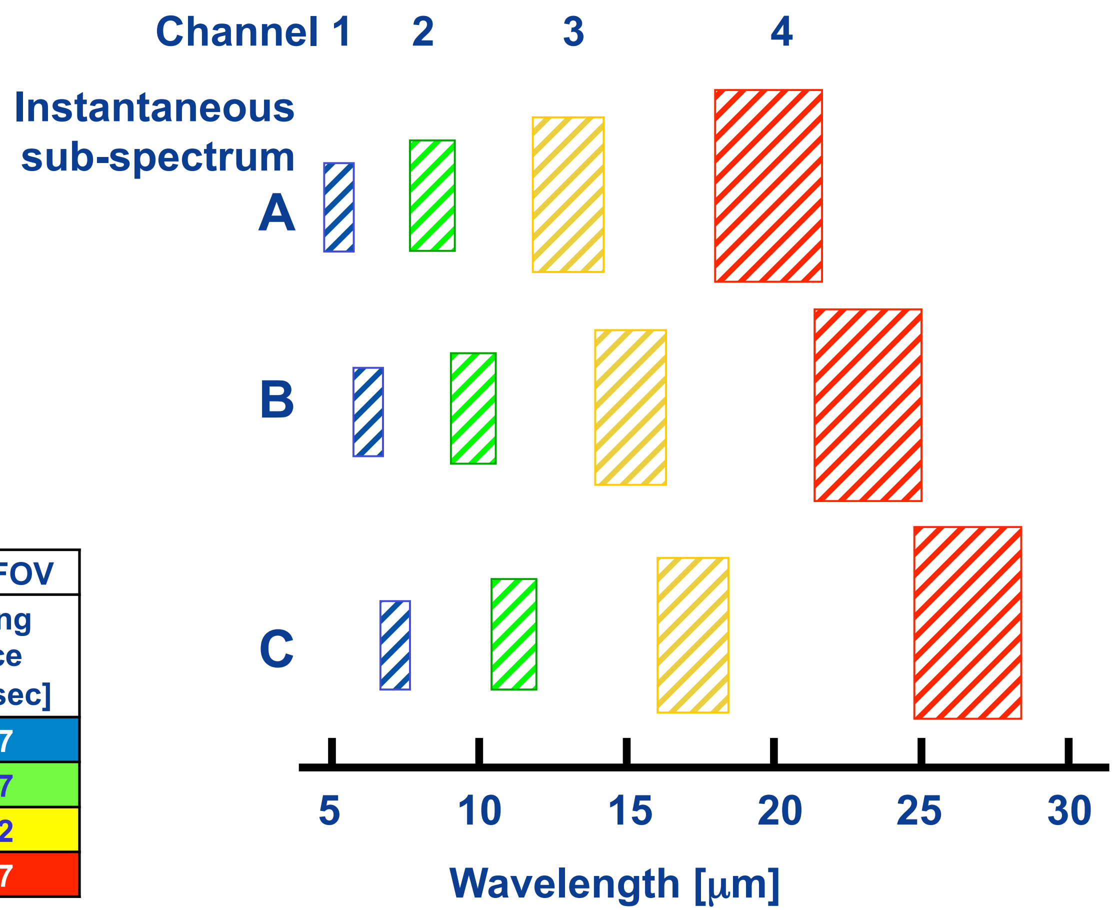
MIRI Medium Resolution Spectrometer

- 4 Spectral Channels with concentric fields of view



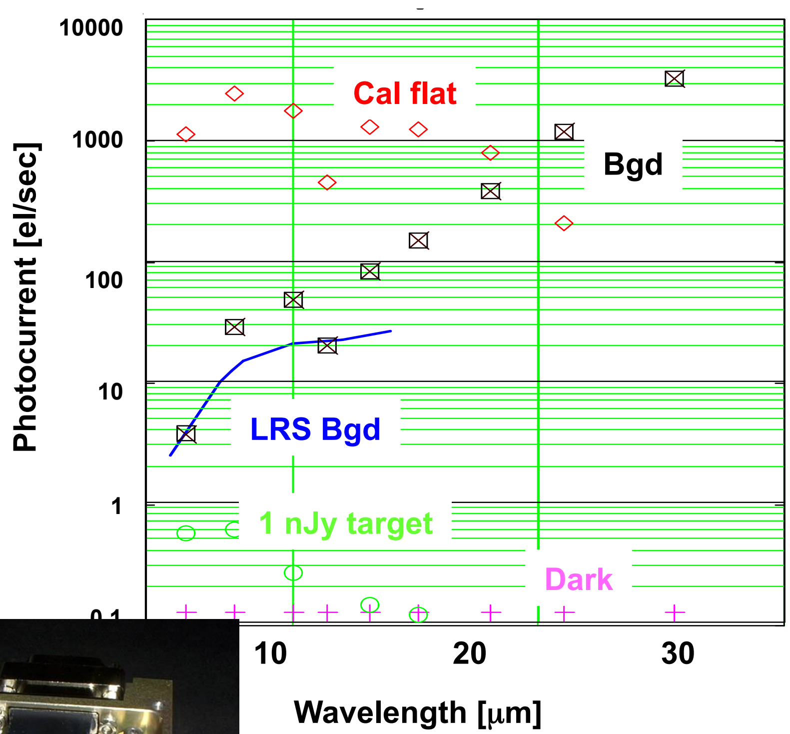
Channel Name	Spatial sample dimensions		Instantaneous FOV	
	Across slice (Slice width) [arcsec]	Along slice (Pixel) [arcsec]	Across slice [arcsec]	Along slice [arcsec]
1	0.18	0.20	3.7 (21)	3.7
2	0.28	0.20	4.5 (17)	4.7
3	0.39	0.25	6.1 (16)	6.2
4	0.64	0.27	7.9 (12)	7.7

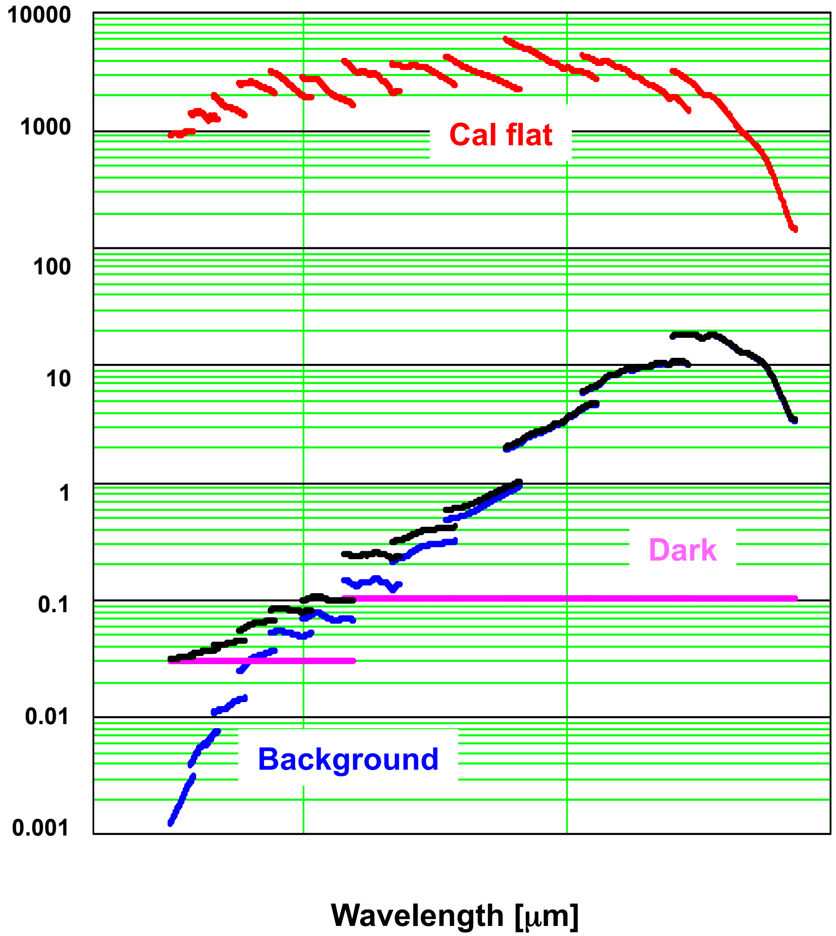
- 3 mechanism selected sub-spectra per channel with dedicated dichroic and gratings



Calibration Sources

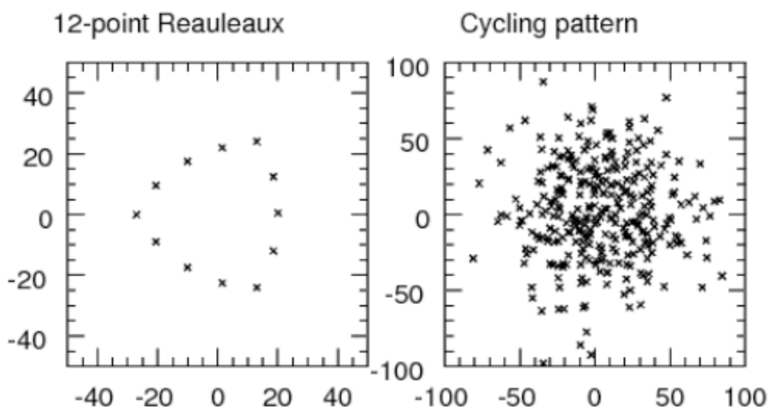
- Background variation – zodi to telescope – background not suitable calibration in many cases
- Wavelength calibration in flight will use astronomical sources





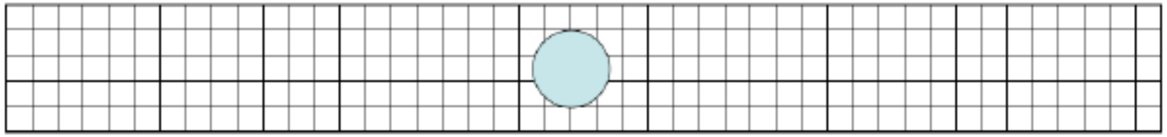
Imager - Dithering

- **Purpose. Bad pixel removal, full spatial sampling (F560W), background subtraction.**
- **FGS/FSM (2.3 x 2.3') acquires target, telescope moves – thermal path unchanged.**
- **Proposed imager dither patterns (all include 0.5 pixel sampling offsets)**
  - 4 point box pattern. (2.5 x 2.5 pixel).
  - 12 point Reauleaux . Move around circumference of triangle, (15, 30 and 60 pixel scale sizes)
  - Cycling Gaussian. 311 points (10, 120 and 160 pixel sizes).

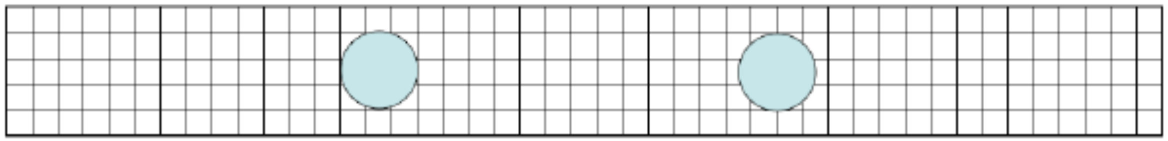


Low Resolution Spectrometer - Dithering

- **Extended source/mapping**
  - Target acquired at centre of slit.
  - User defined offsets (within FGS 2.3’ x 2.3’) for mapping extended sources.



- **Point source/staring**
  - Target dithered along slit (15.5 pixel throw = 1.7 arcseconds)



Medium Resolution Spectrometer Dithering

- The MRS spatial sample element is set by the detector pixel in the along slice direction and the slice width in the across slice direction.

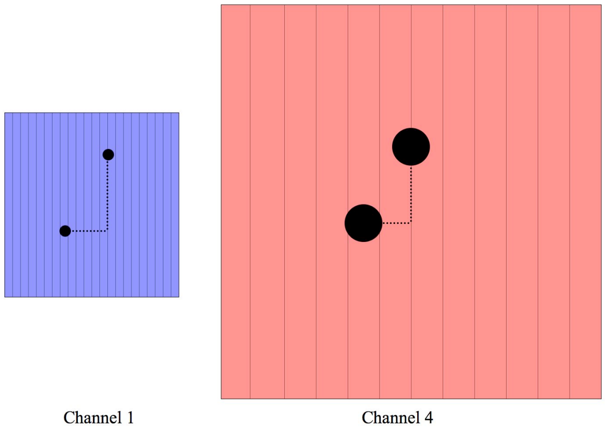
- Medium Resolution Spectrometer

Channel Name	Spatial sample dimensions		FOV in a single integration	
	Across slice (Slice width) [arcsec]	Along slice (Pixel) [arcsec]	Across slice [arcsec]	Along slice [arcsec]
1	0.18	0.20	3.7	3.7
2	0.28	0.20	4.5	4.7
3	0.39	0.25	6.1	6.2
4	0.64	0.27	7.9	7.7

- Neither dimension is well sampled in a single exposure.

MRS Dithering

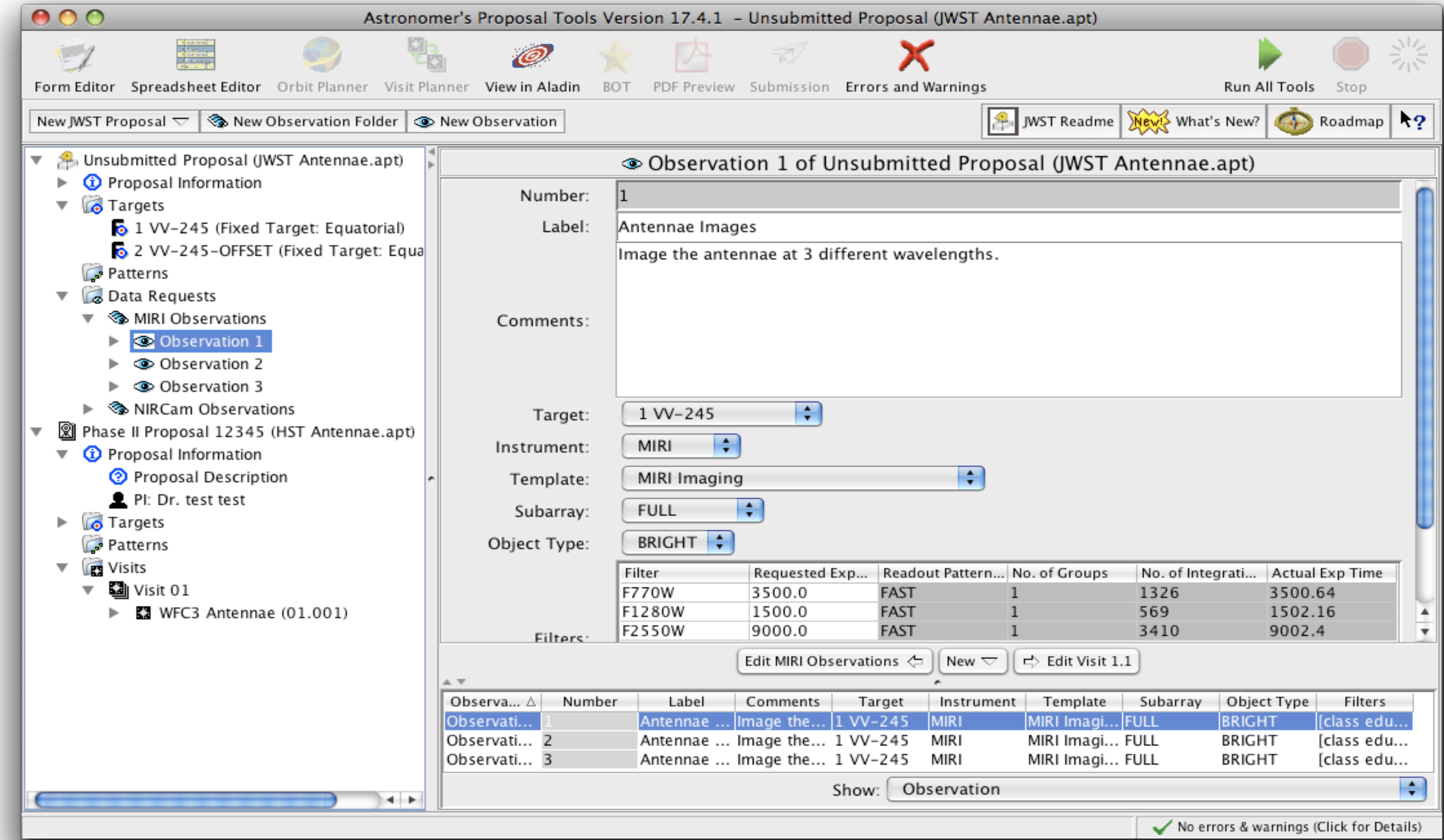
- The slice width is fine tuned so that a single telescope offset (of 0.97”) moves the image by n + ½ slices, where n = 1, 2, 3 and 5 (for Channel 1,2,3 and 4).
- A 2.05” along-slice offset will fully sample Channels 1, 2 and 4.



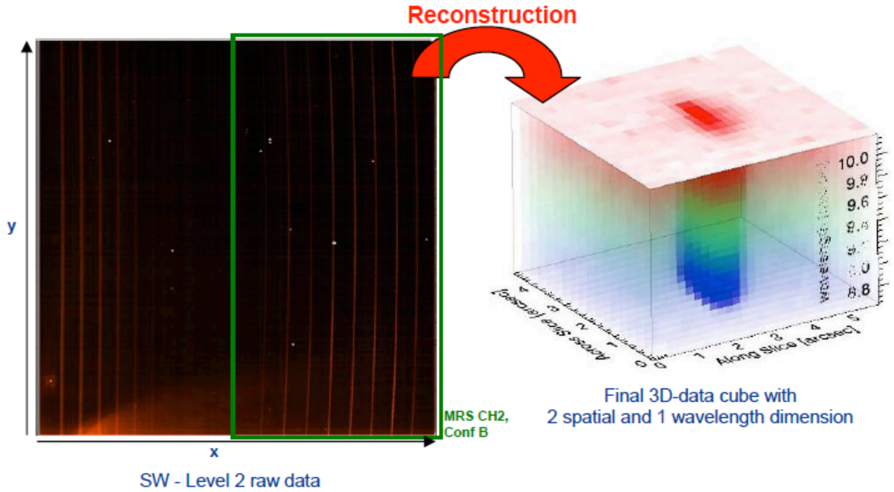
- For Channel 4 only, a 2.26” x 4.78” two point dither is proposed.

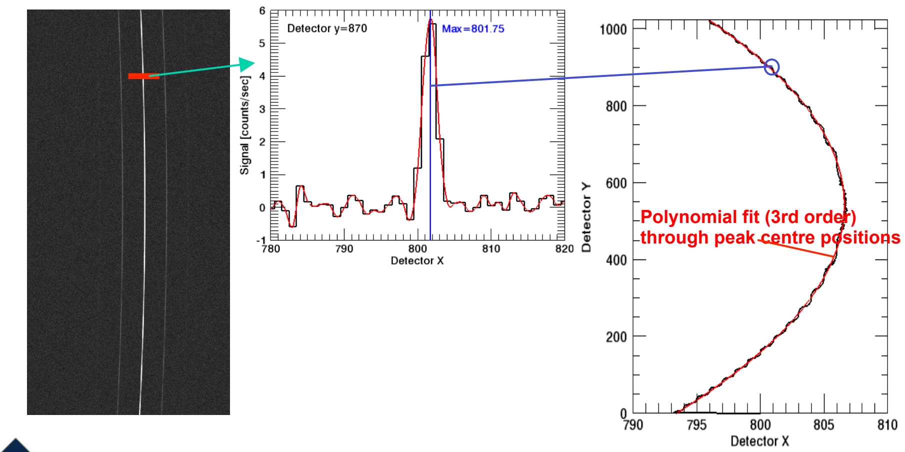
Example MIRI Observation Template

- **Cycle 18 release of APT includes preliminary templates for MIRI**

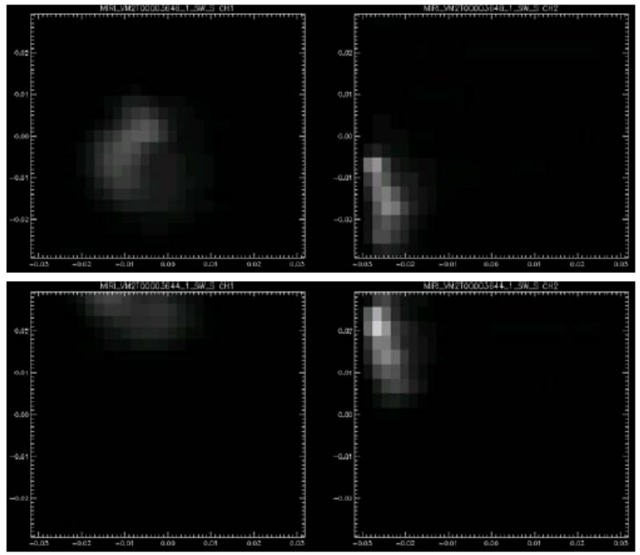


MRS Image Reconstruction





1B and 2B reconstructed images



(Adrian Glauser)

- **Cube_build tool is mature and ready to support FM test analysis.**

Acknowledgements

- The material presented here is the work of many people in the MIRI team !

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