The Mid-Infrared Instrument (MIRI) for the JWST

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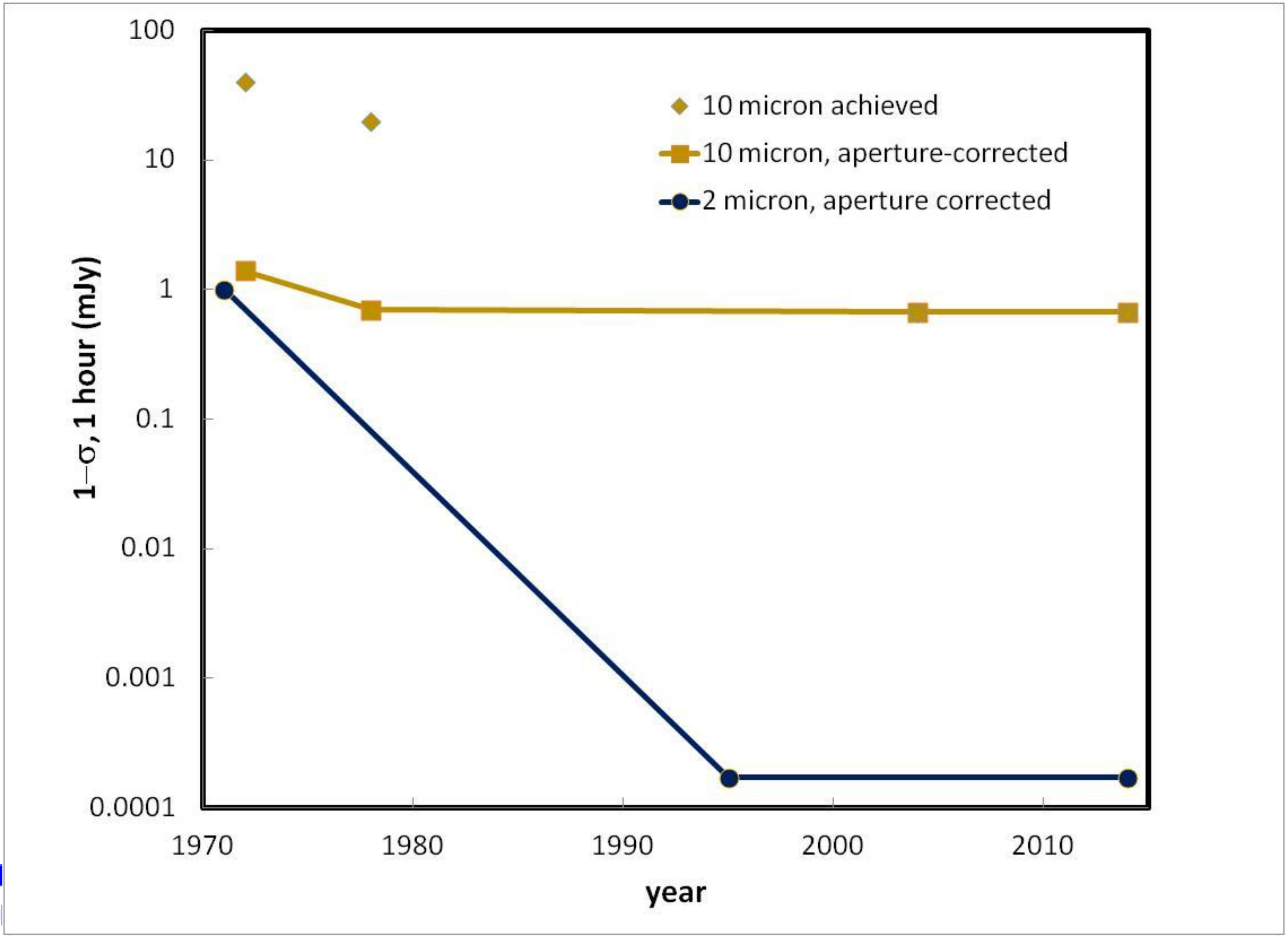
for the MIRI Instrument Team
at

Science Enabled by Novel Infrared Instrumentation

in honor of Jim Houck

MIRI European Consortium

Although progress in the near infrared has been phenomenal, 10μm is another story. Cold telescopes in space are required.



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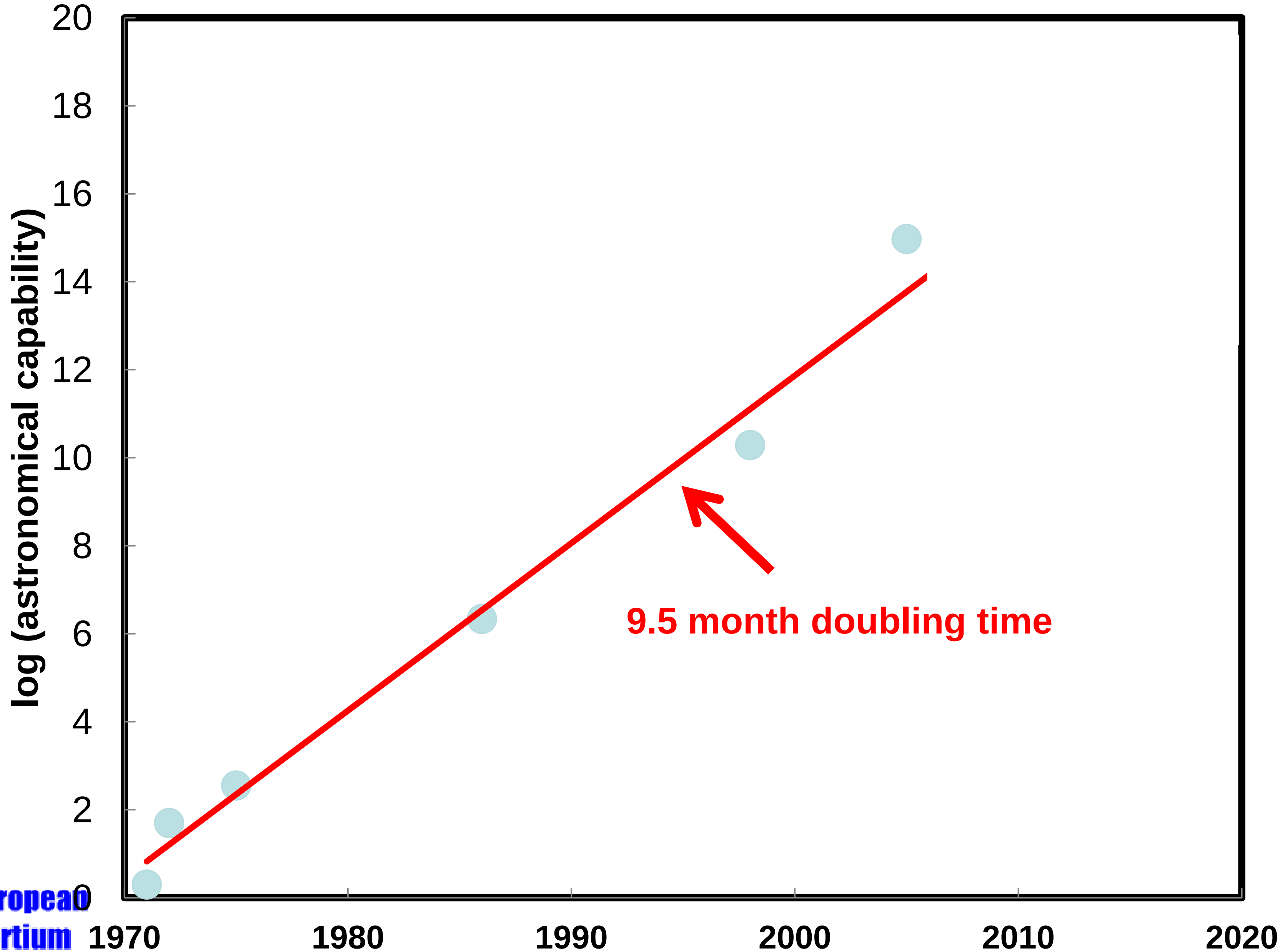
IRAS, ISO, and Spitzer have brought phenomenal growth in 10μm capability. First 3 points are ground, then IRAS, ISO, and Spitzer.



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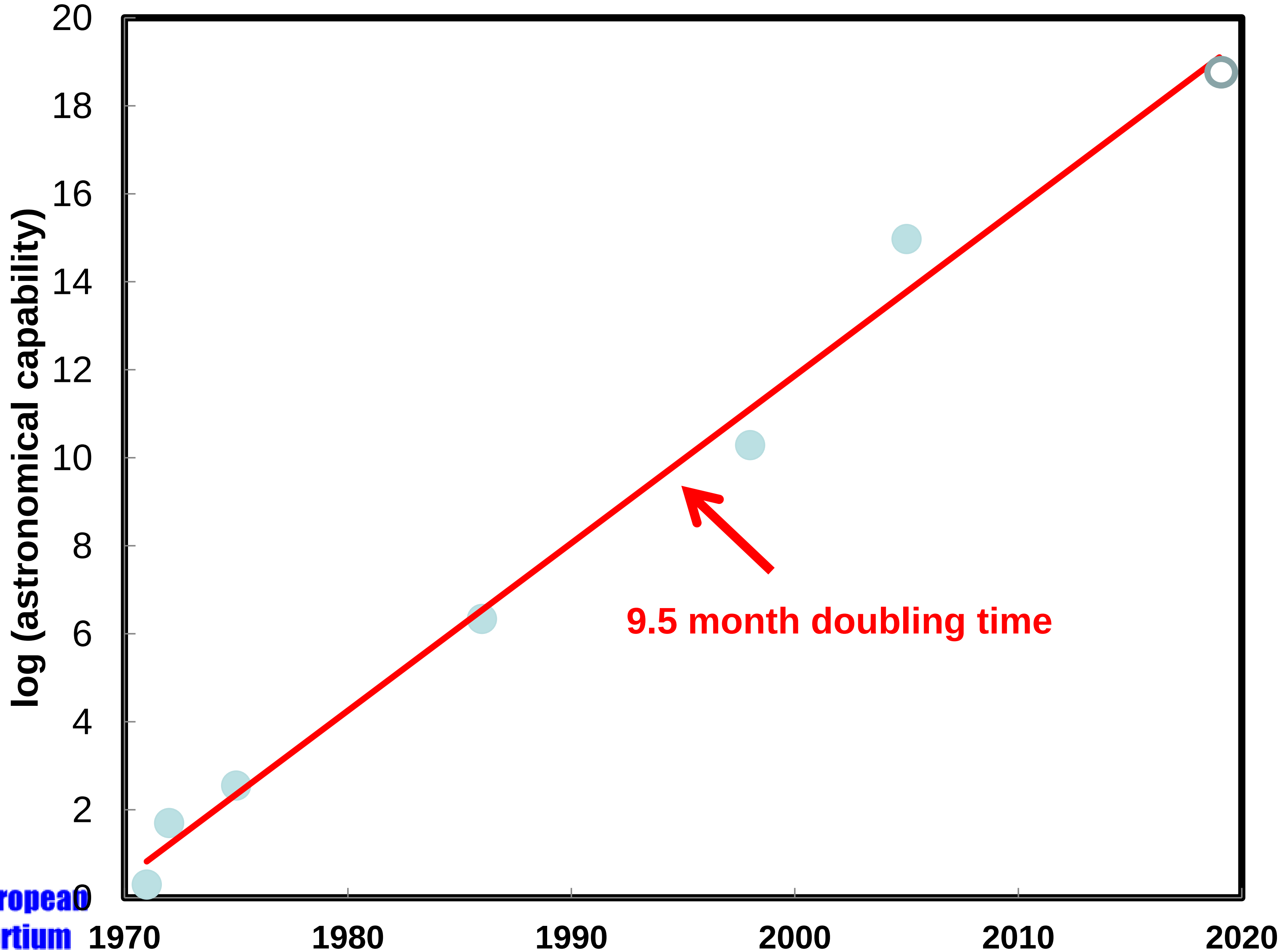
JWST with its Mid-IR Instrument (MIRI) continues the steep Moore's-Law-like growth in capability.



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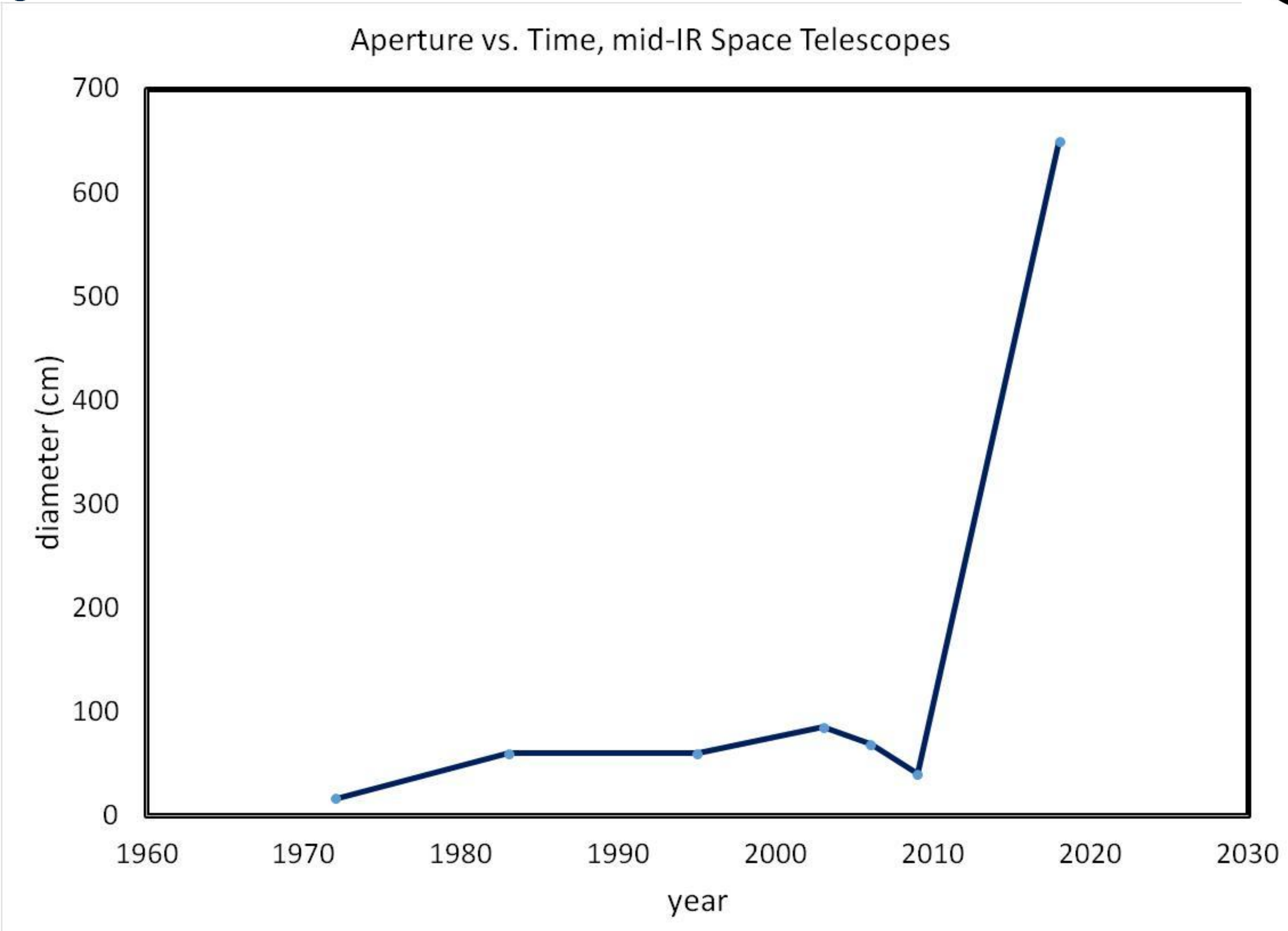
JWST uses the warm launch concept to provide a much bigger telescope. It will be the first LARGE cold infrared telescope in space.



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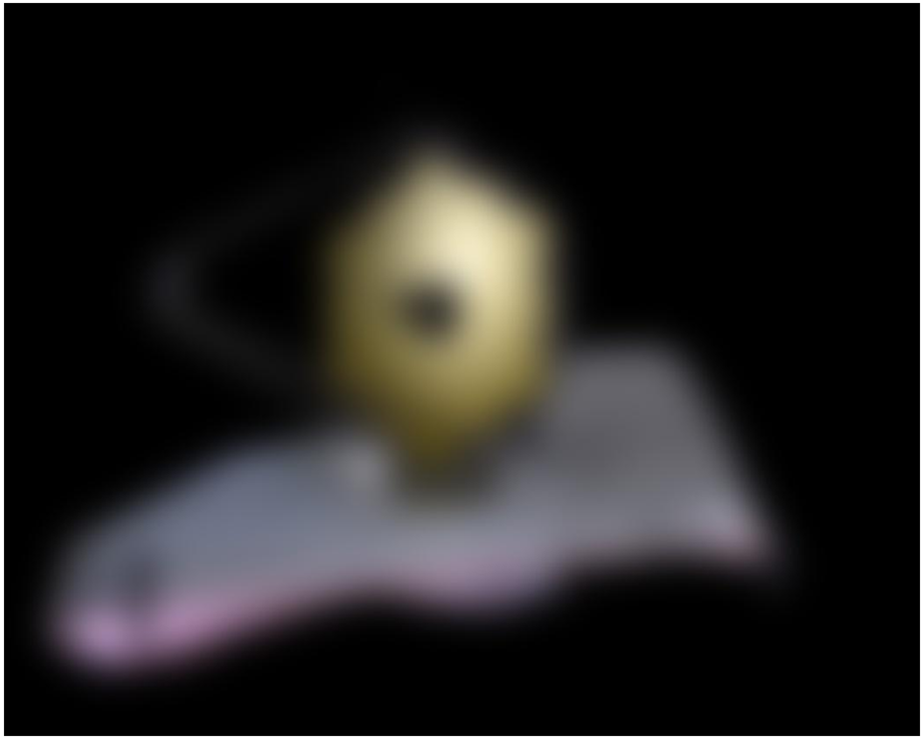
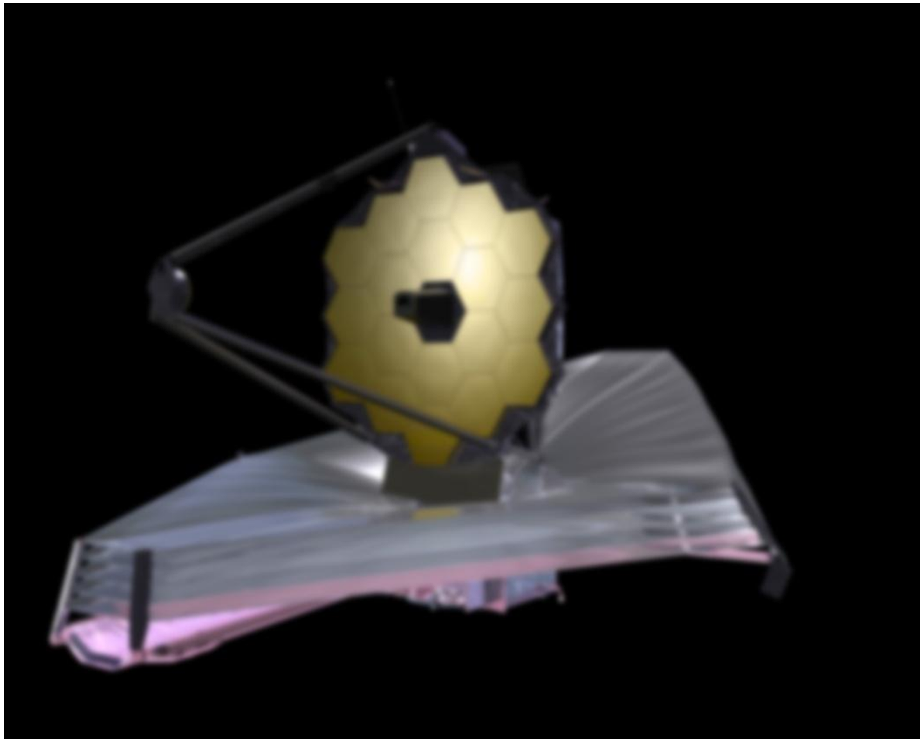
Resolution is Important!!!

Spitzer, with a 0.85-meter aperture, was limited by resolution more than sensitivity. At 24μm, its beam was 6 arcsec FWHM, and it reached the confusion limit in a few hours of integration.



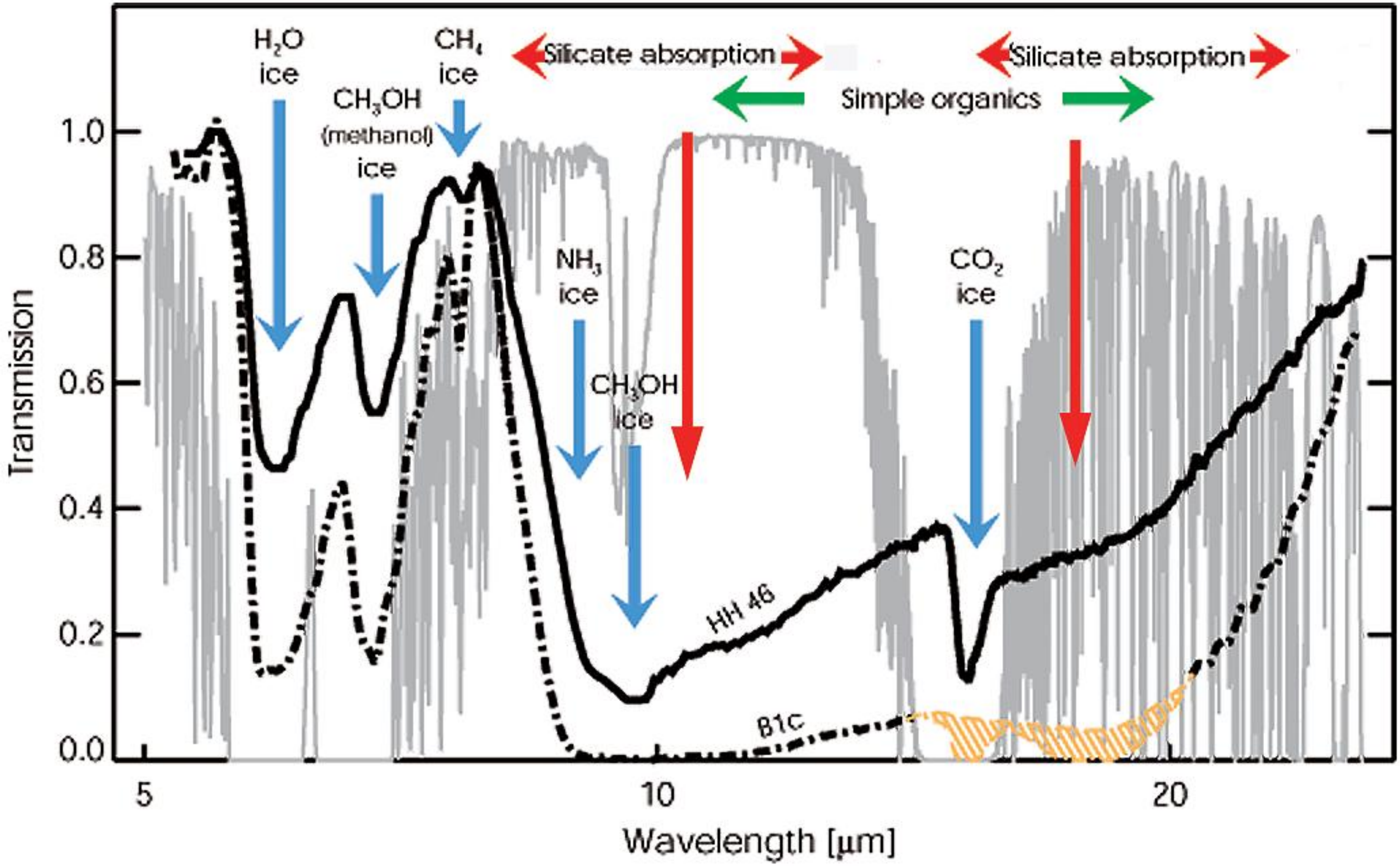
Resolution is Important!!!

MIRI on the 6-meter JWST provides far higher resolution. It also has highly versatile capabilities.



And (of course!) JWST is in Space!

Atmospheric absorptions block the infrared interstellar windows! This is a serious obstacle for studies of young stars, for example.



Something Else Has Changed:

"Jim Houck had been working with Ball Aerospace to demonstrate that his IRS could be manufactured cheaply. The Ball fabricators could maintain tolerances so well that the instrument could be assembled in alignment without a sequence of measurements and adjustments. He had termed this approach 'bolt and go.' Ball was building a demonstration spectrograph … and Houck had brought its housing to the meeting [at NASA HQ] to show us. Toward the end of the meeting, Houck and NASA Astrophysics head Ed Weiler took it upstairs to show Goldin, to demonstrate a faster better, cheaper approach to building SIRTF."

From "The Last of the Great Observatories," G. Rieke

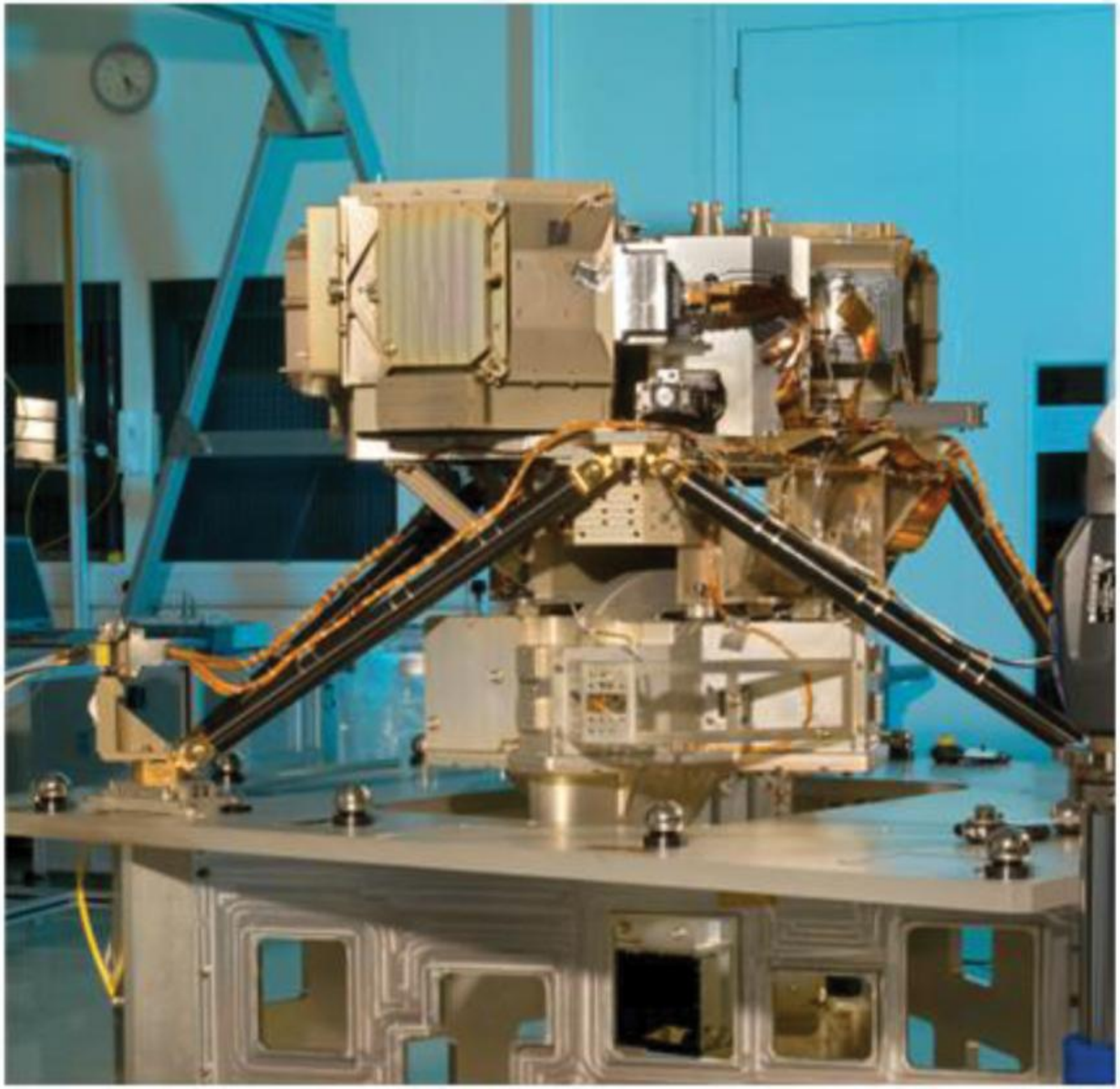
The pendulum has swung on instrument complexity!

MIRI: Designed and *built* as if by committee*! And all done ve[r]
and successfully.

*MIRI would give committees a good name!

Contributions from:
26 research organizations
2 space agencies
11 countries
GSFC, JPL, & STScI
Northrop Grumman,
EADS – Astrium,
& Raytheon

Led by Gillian Wright and George Rieke (and Alistair Glasse and Mike Ressler)



Here we are!

UK-ATC — European PI; Instrument Science; Optical Engineering; Spectrometer Pre-Optics & Calibration Sources
Astrium Ltd — Project Office & Consortium Management; PA Coordination; System Engineering
U. of Leicester — Mechanical Engineering; Primary Structure; MGSE
RAL — Thermal Engineering & Hardware Integration; AIV Facility & Instrument Testing
Cardiff — Cal Filament Units

DIAS — Filters

CSL — Input, Optics & Calibration; Instrument Control Electronics; Imager Mirrors
U. of Leuven — EGSE Software Support

CEA — Imager; Coronagraph Analysis
LESIA/LAM — Coronograph

INTA — MIRI Telescope Simulator (MTS)

U. of Stockholm — Filters and Gratings

DSRI — Hexapod

ESA/ESTEC — JWST Project Office; Prodex Office

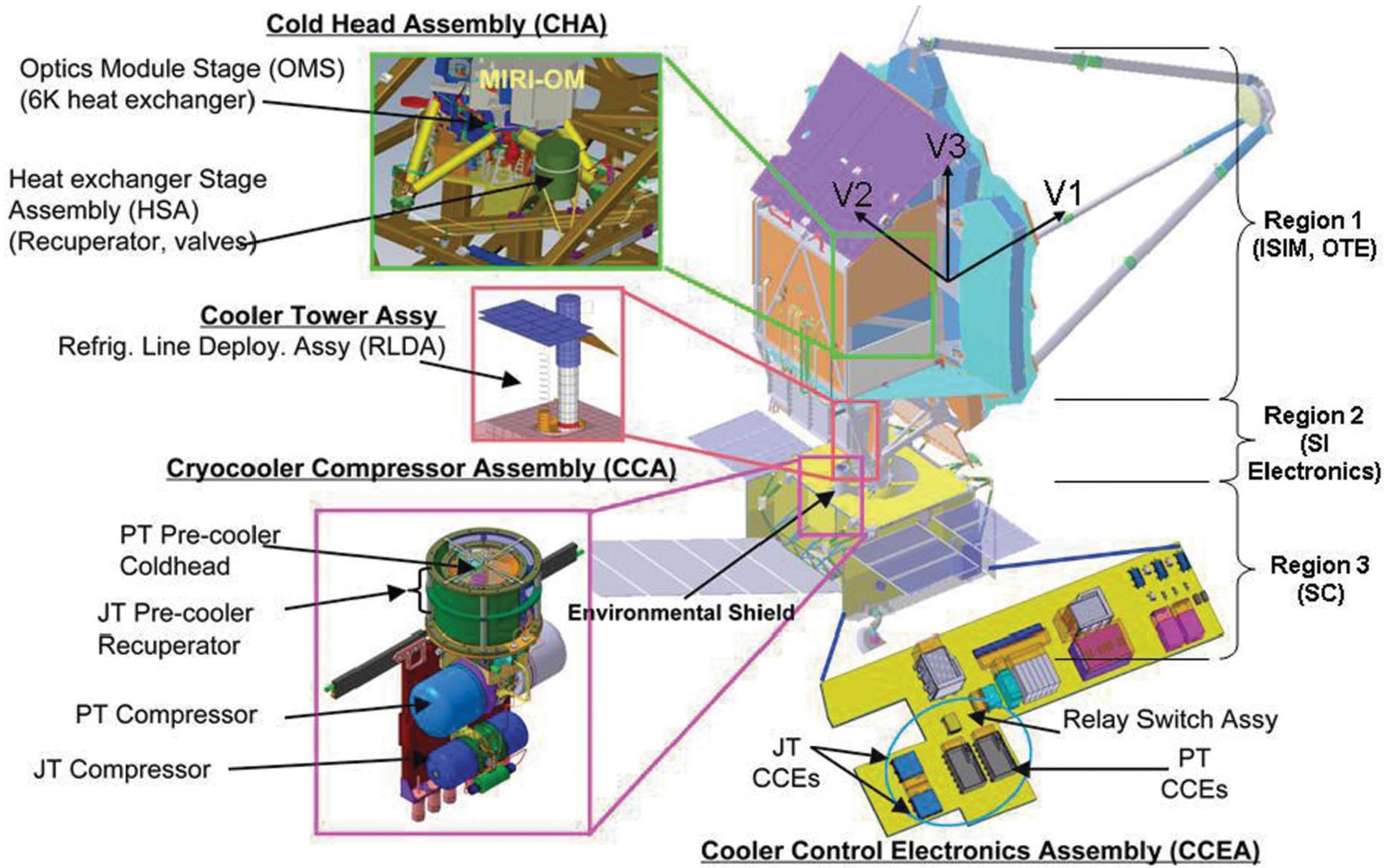
NOVA — Spectrometer Main Optics
U. Leiden — Spectroscopy Analysis

MPIA Heidelberg — Electrical Engineering; Cryo Mechanisms
U. of Köln — Low Resolution Spectrometer; Double Prism

PSI — Contamination Control
Cover — Cryo Harness

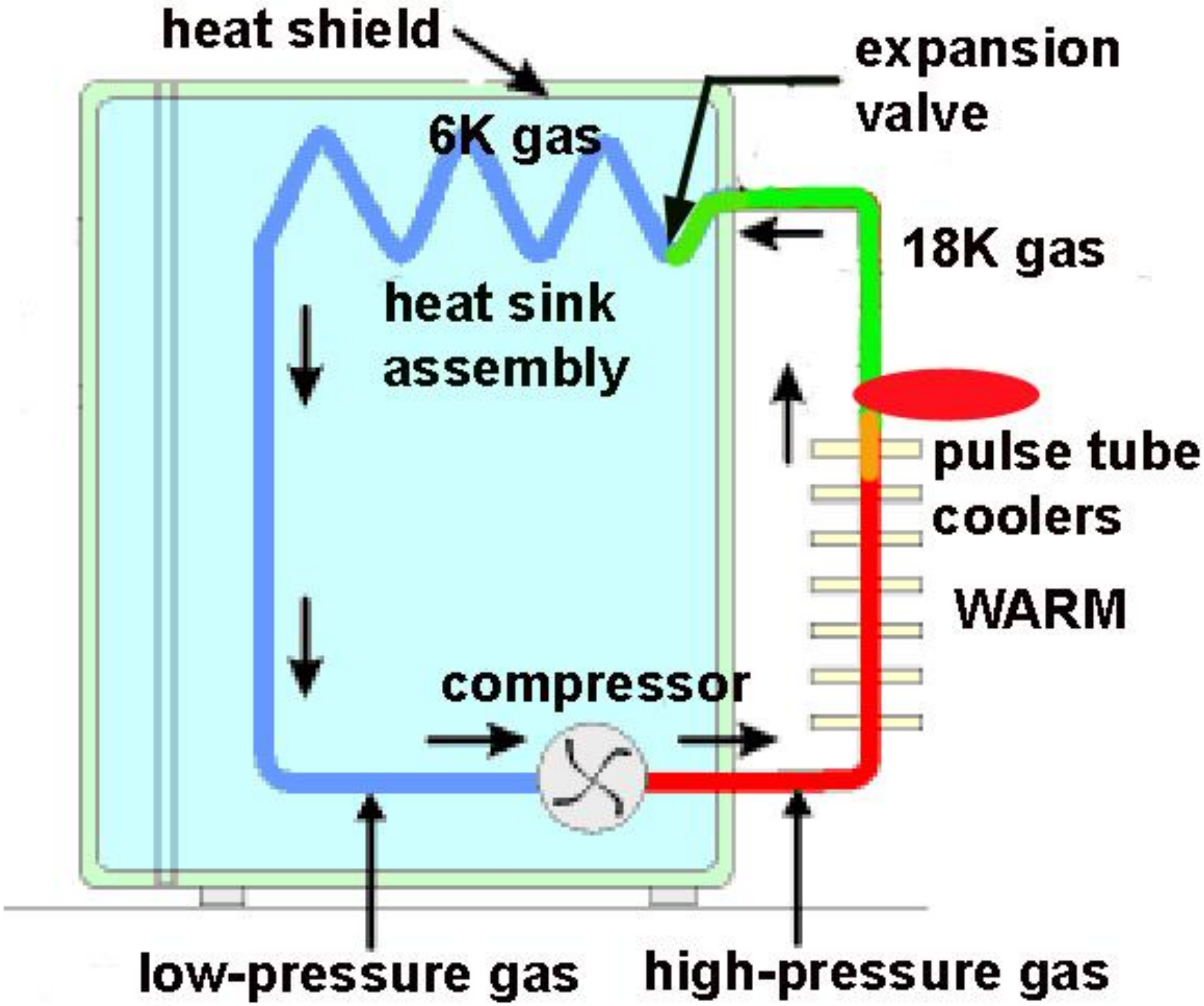
NASA/GSFC JWST Project Office — Spacecraft; ISIM
STScI, U. Arizona — Operations; DHAS, US PI
JPL — Detector System; Flight Software; Cryo-Cooler

A cryocooler (from NGAS) brings MIRI down to < 6.5K, and should allow it to operate for the life of JWST (i.e., > 10 years).



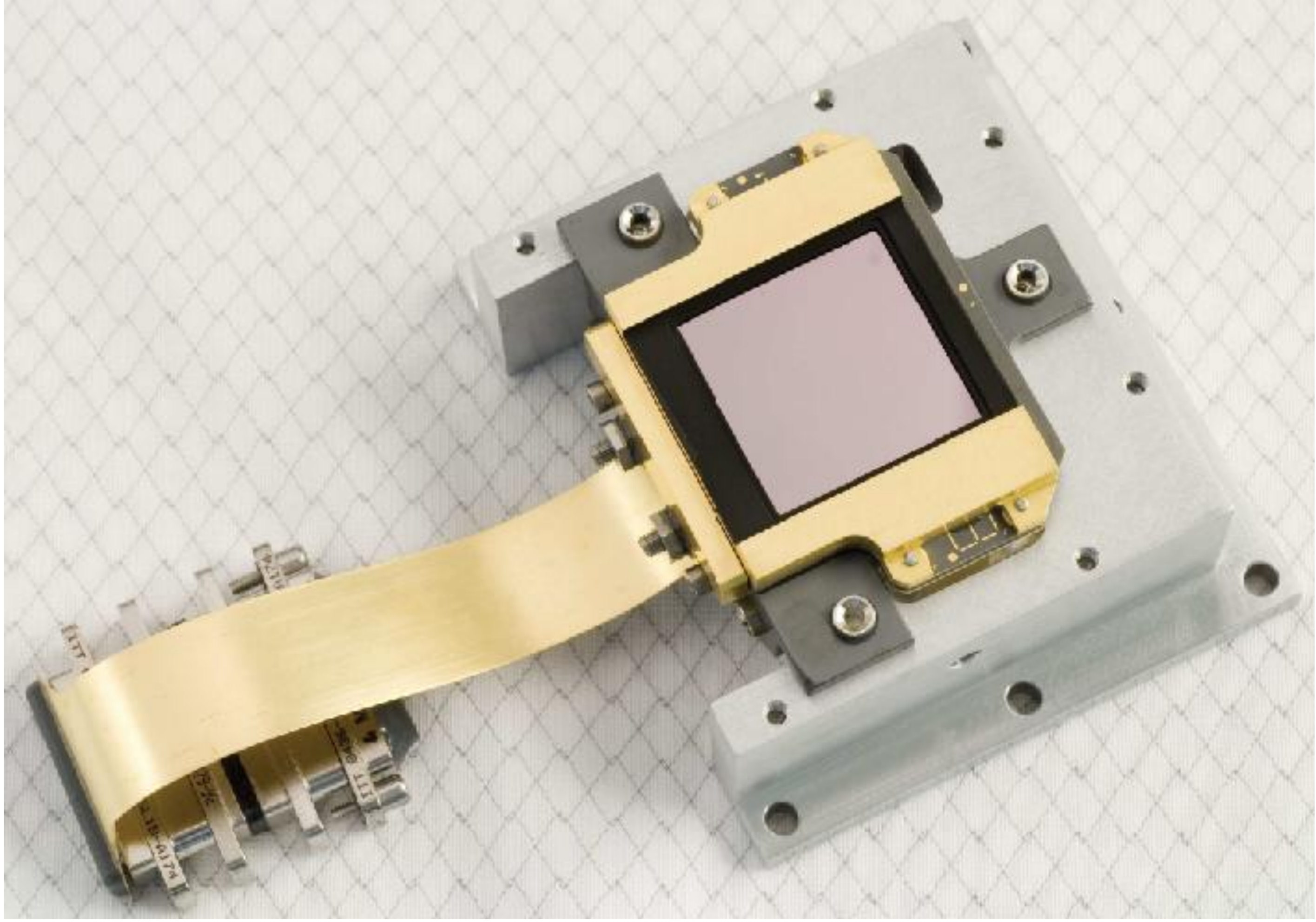
The operation of the cooler is similar to that of your refrigerator.

But much more complicated because of the low temperatures, integration with JWST, etc.



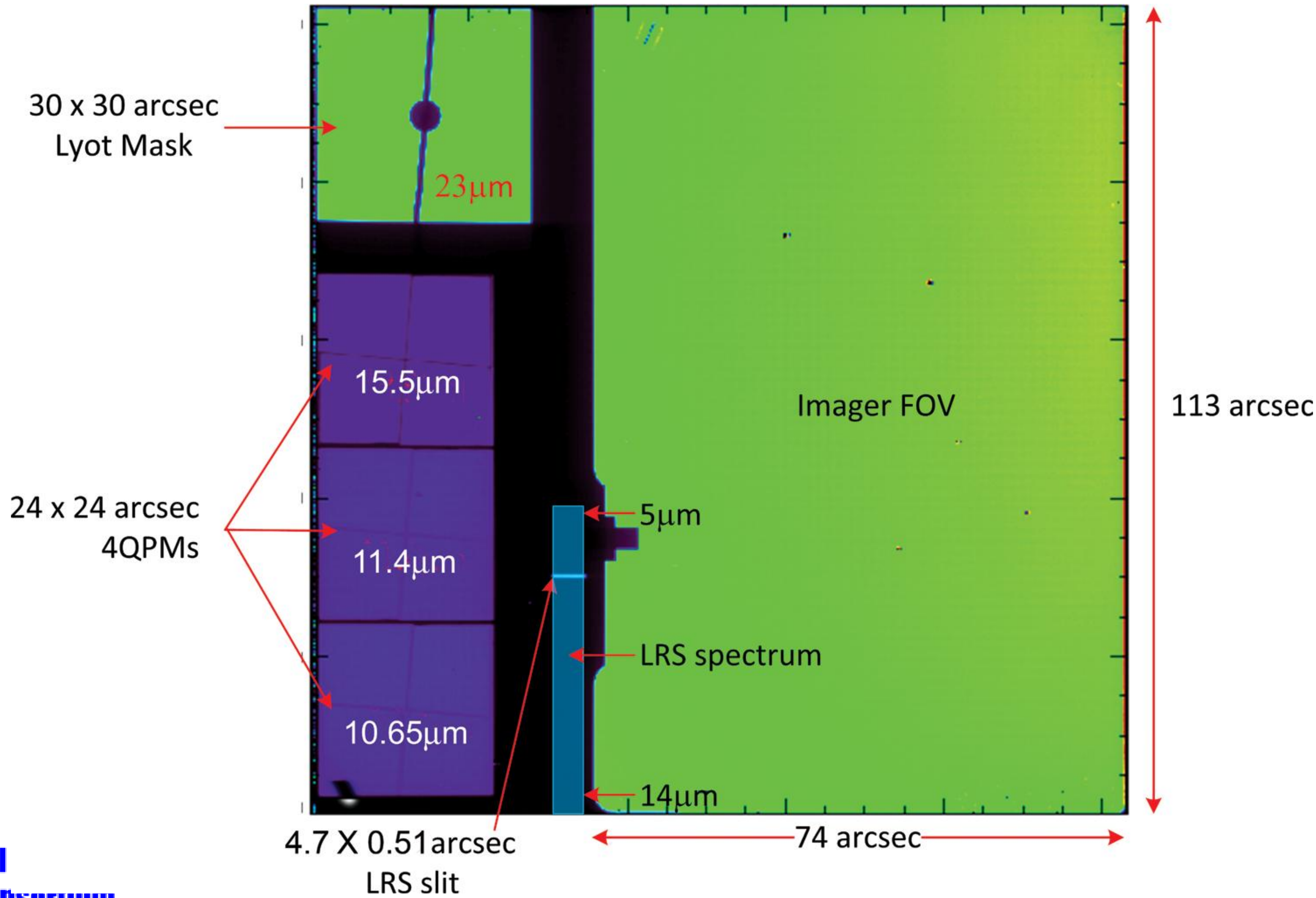
The MIRI detectors build on those developed for IRAC, IRS, and MIPS

They are 1024 X 1024 in format with per-pixel performance similar to that of the Spitzer detectors.



They were constructed at Raytheon Vision Systems.

The MIRI imager preserves the intrinsic diffraction limit: 0".1 pixels are slightly sub-Nyquist at 5.6 μm and better than Nyyquist at all other bands.



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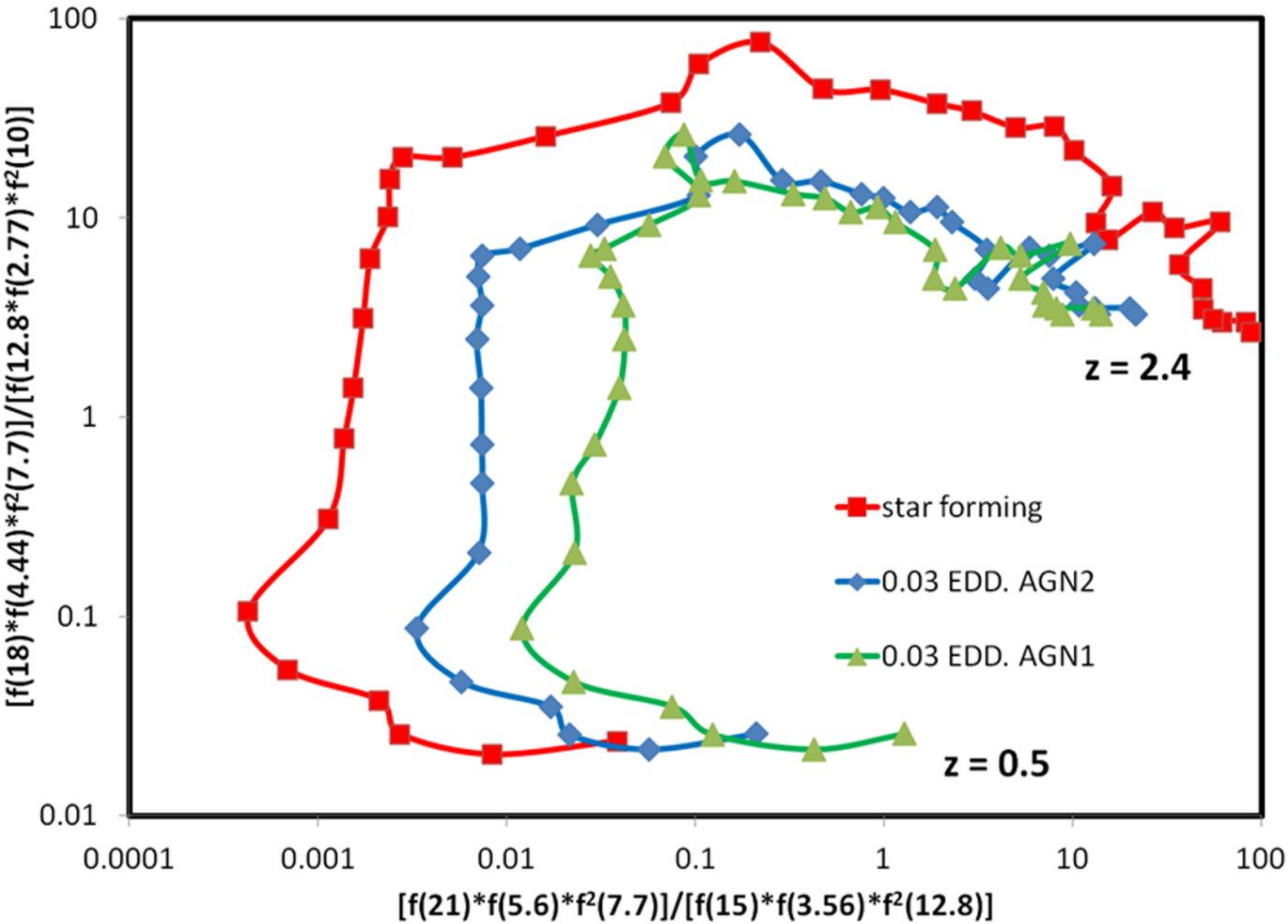
An important feature is a filter wheel!

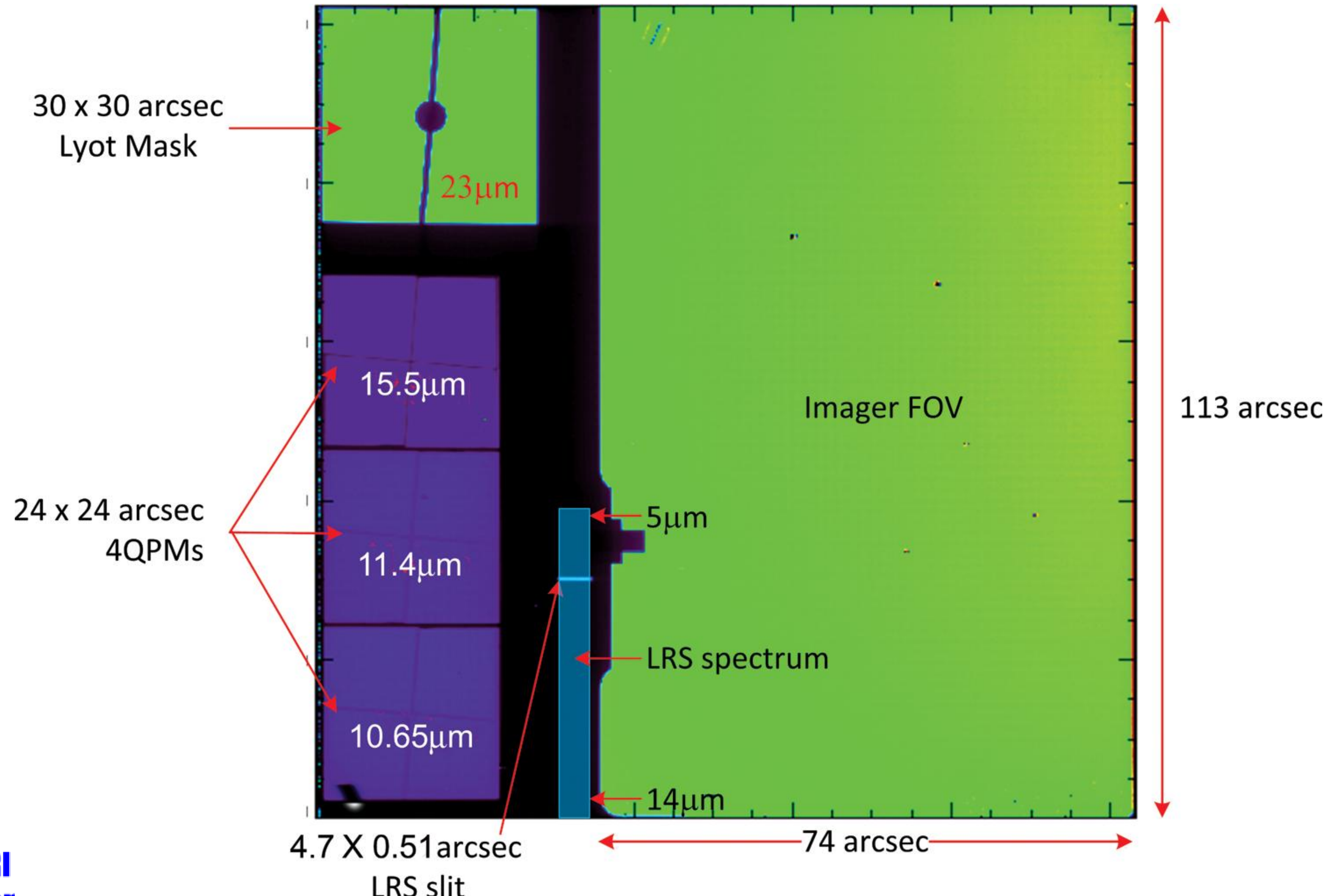
There are bands at 5.6, 7.7, 10, 11.3, 12.8, 15, 18, 21, and 25.5 μm.

A multi-filter example: the infamous color-color-color-color diagram

By combining all the MIRI bands and a few NIRCam ones, one can quickly identify AGN and star forming candidates and estimate their redshifts.



The coronagraphs share the field (and detector) of the imager.



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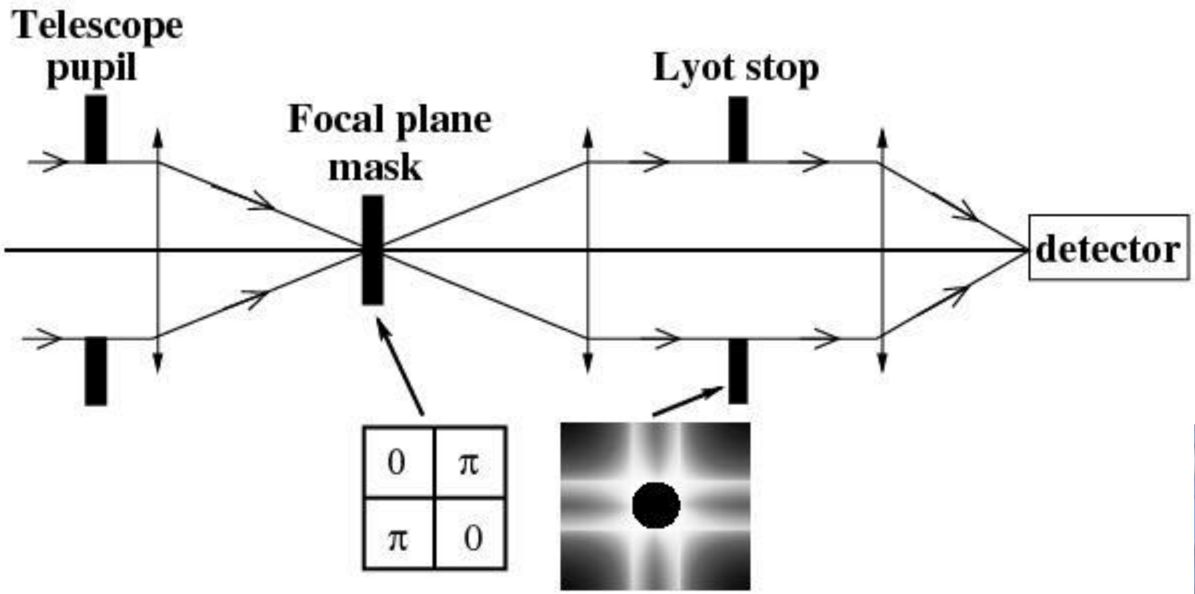
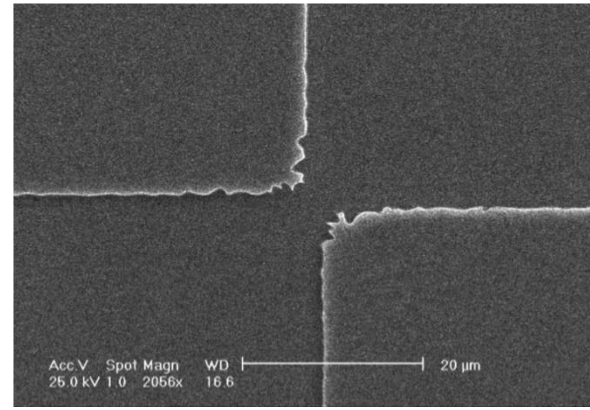
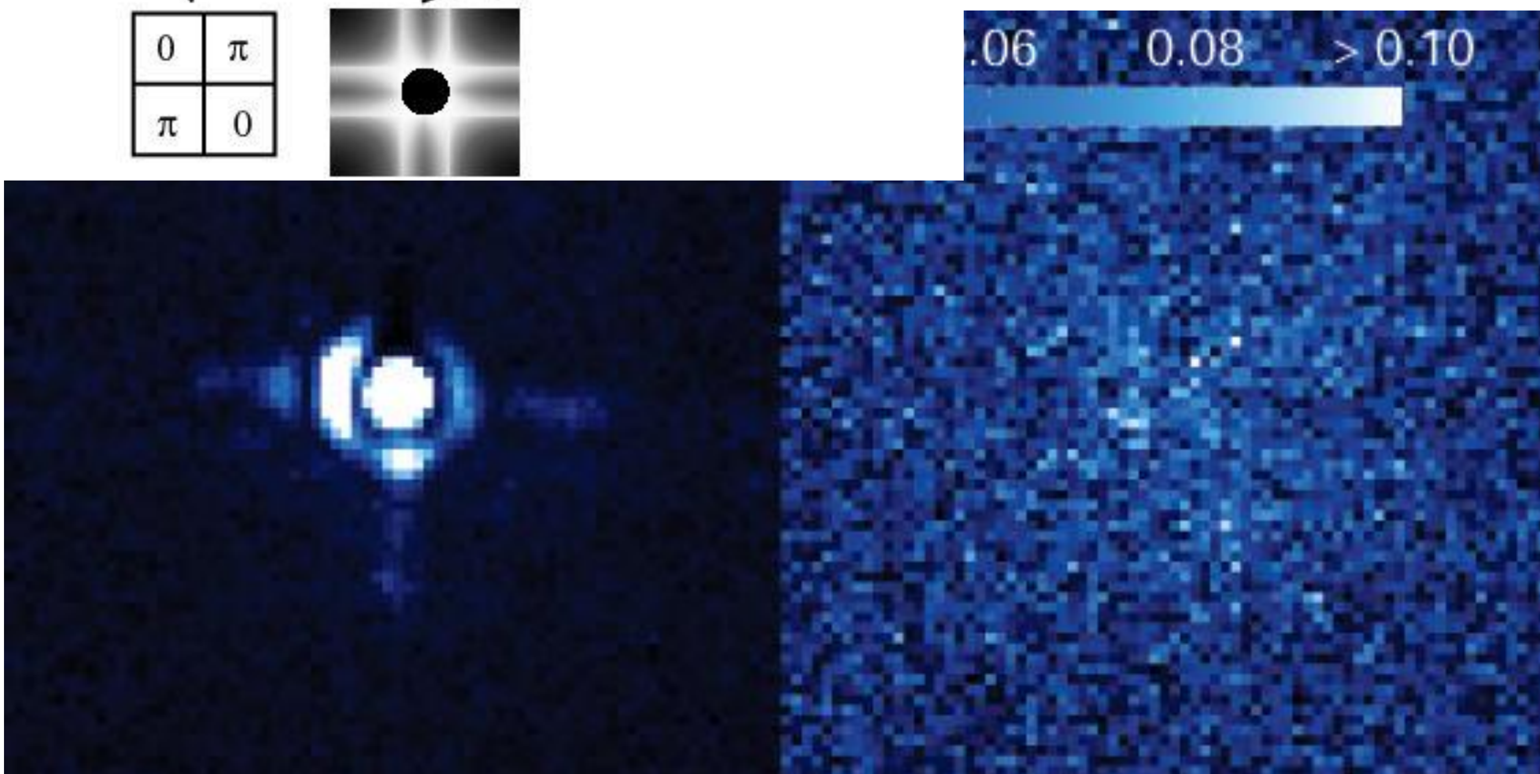
There is a conventional Lyot coronagraph at 23 μm and 4QPM ones at 10.65, 11.40, and 15.50 μm. The latter use a phase lag in quadrants to interfere a source placed in the middle of the field.







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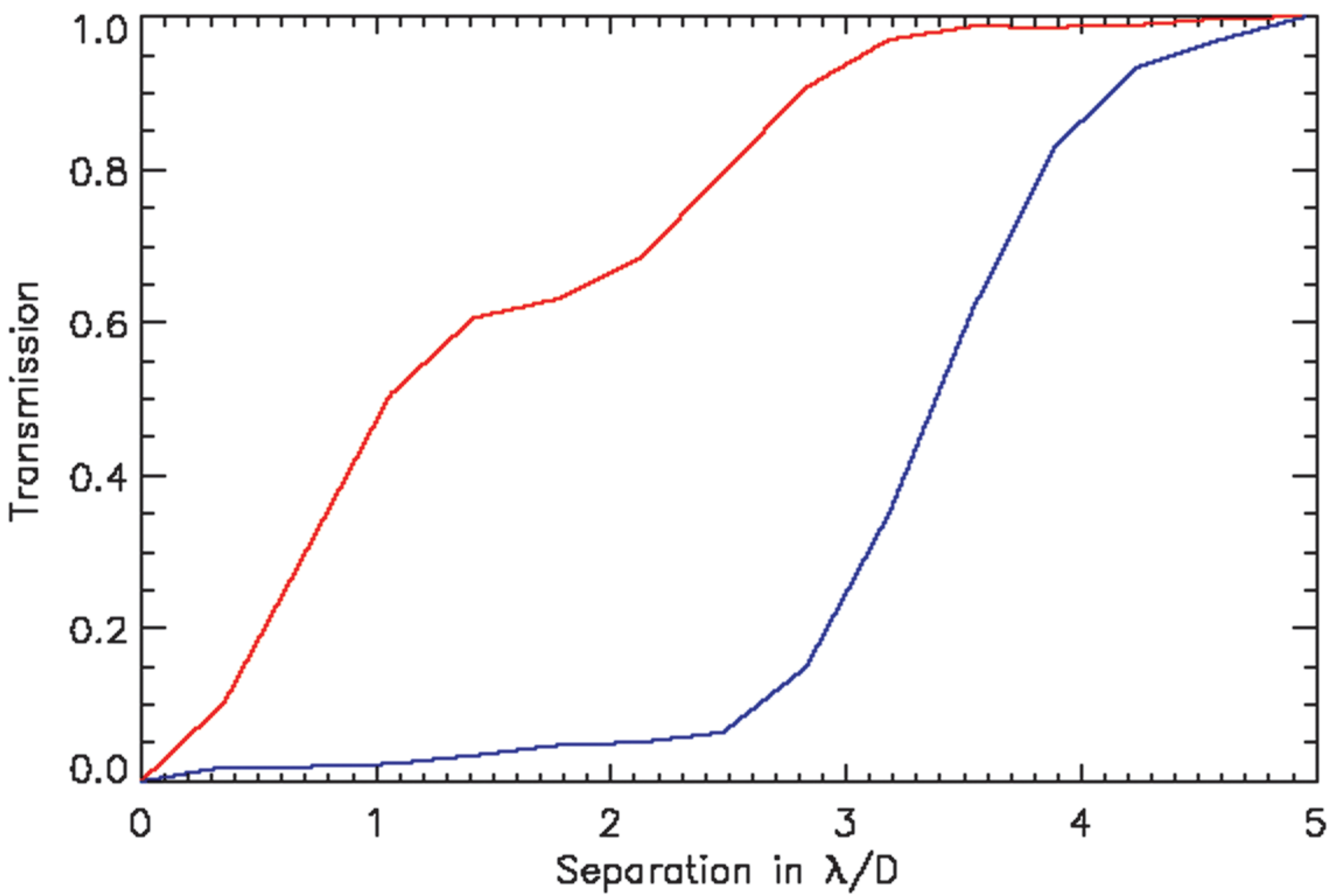
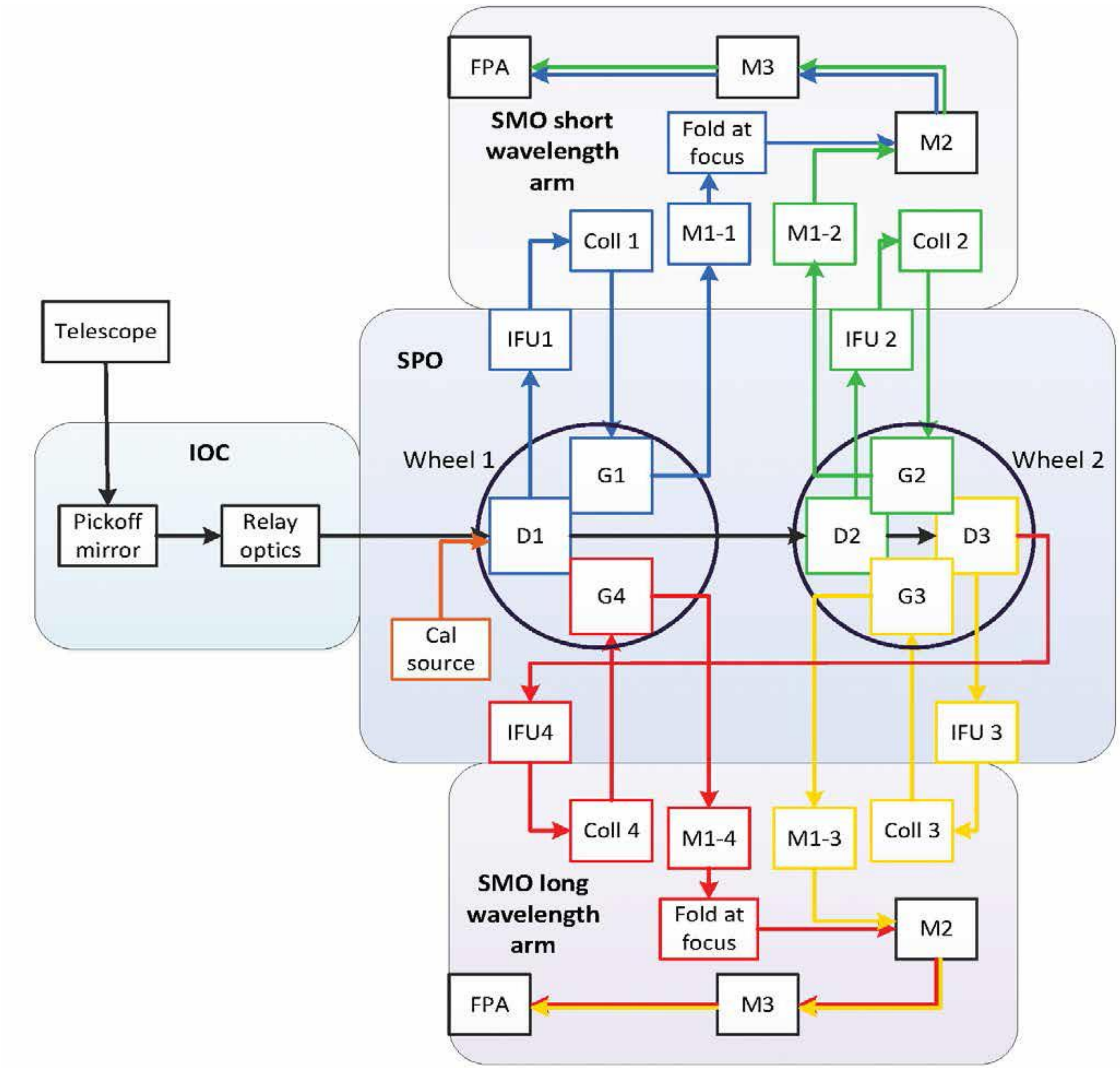
The contrast with the 4QPM is similar to that for a Lyot coronagraph.

However, the inner working angle (red curve) can be much smaller (compare blue curve).



However, perhaps the most impressive observational mode is provided by the Medium Resolution Spectrometer (MRS)!

MRS Optical Concept – simply impressive!



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Why so complicated? Well…

The Spitzer-IRS SH module had:

- slit size = 4.7″ × 11.3″ at a spatial resolution Θ = 3″ → 4 spatial elements
- Δλ = 9.9 – 19.6 μm at a spectral resolution R = 600 → 580 spectral elements
- → total = 4 × 580 = 2320 resolution elements
- …to fit on a 128 × 128 pixel detector → 4096 Nyquist sampled elements

The MIRI MRS has:

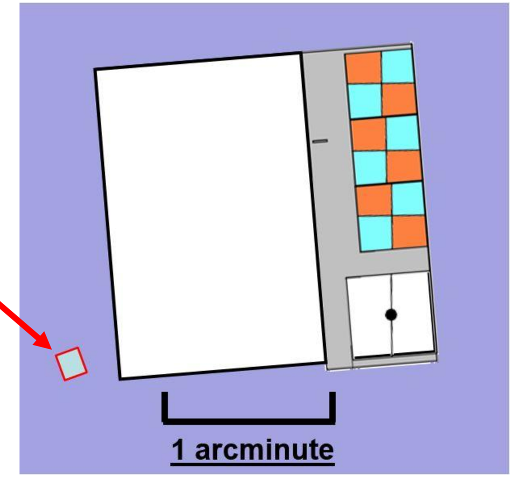
- slit size ~ 5″ × 5″ at a spatial resolution Θ = 0.4″ → 156 spatial elements
- Δλ = 5 – 28 μm at a spectral resolution R = 3000 → 6900 spectral elements
- → total = 156 × 6900 = 1,080,000 resolution elements
- …to fit on a 1024 × 1024 pixel detector → 262,000 Nyquist sampled elements

→ A different approach is needed

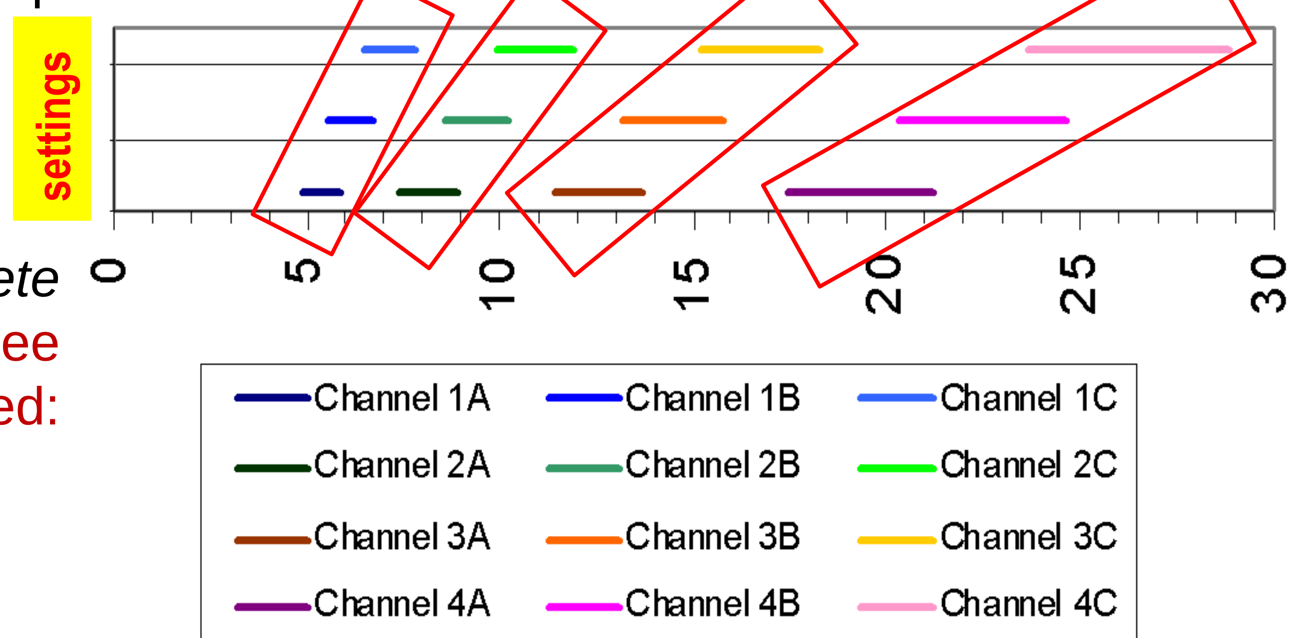
The MRS Concept

The MRS…:

- takes a small field (≤7″×7″) in the focal plane
- divides the full 5 – 28 μm range into four bands
- slices the field (in each band) into 12 – 21 strips
- disperses each set of strips by one dedicated grating
- projects each set of spectra onto one *half* of the two 1k × 1k Si:As BIB detectors.

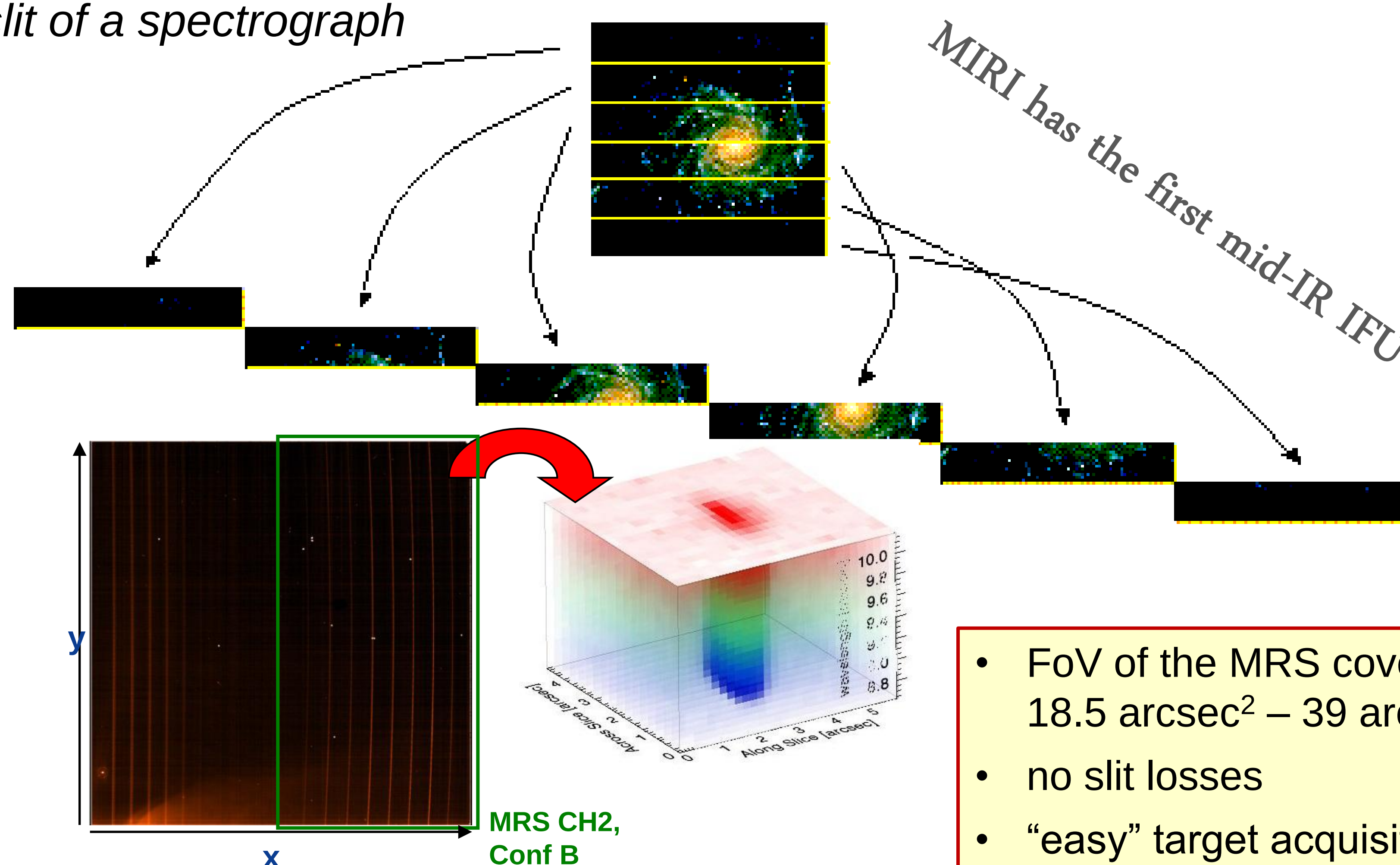


In order to fit the *complete* 5 – 28 μm range, three settings are needed:



Basic Principle of Image-slicing

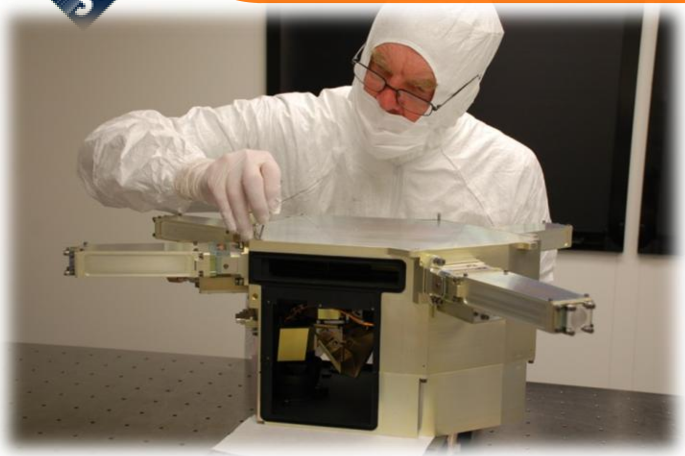
The image of a contiguous area of sky is sub-divided by slicing mirror and the separated sub-images are optically re-arranged to generate the entrance slit of a spectrograph

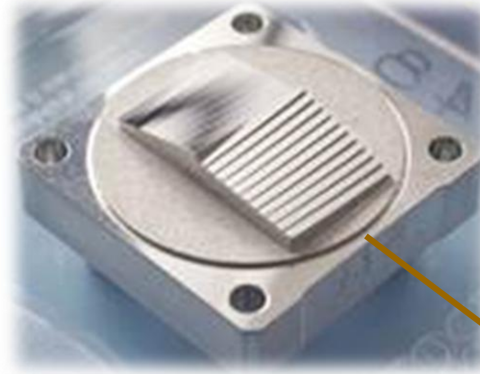


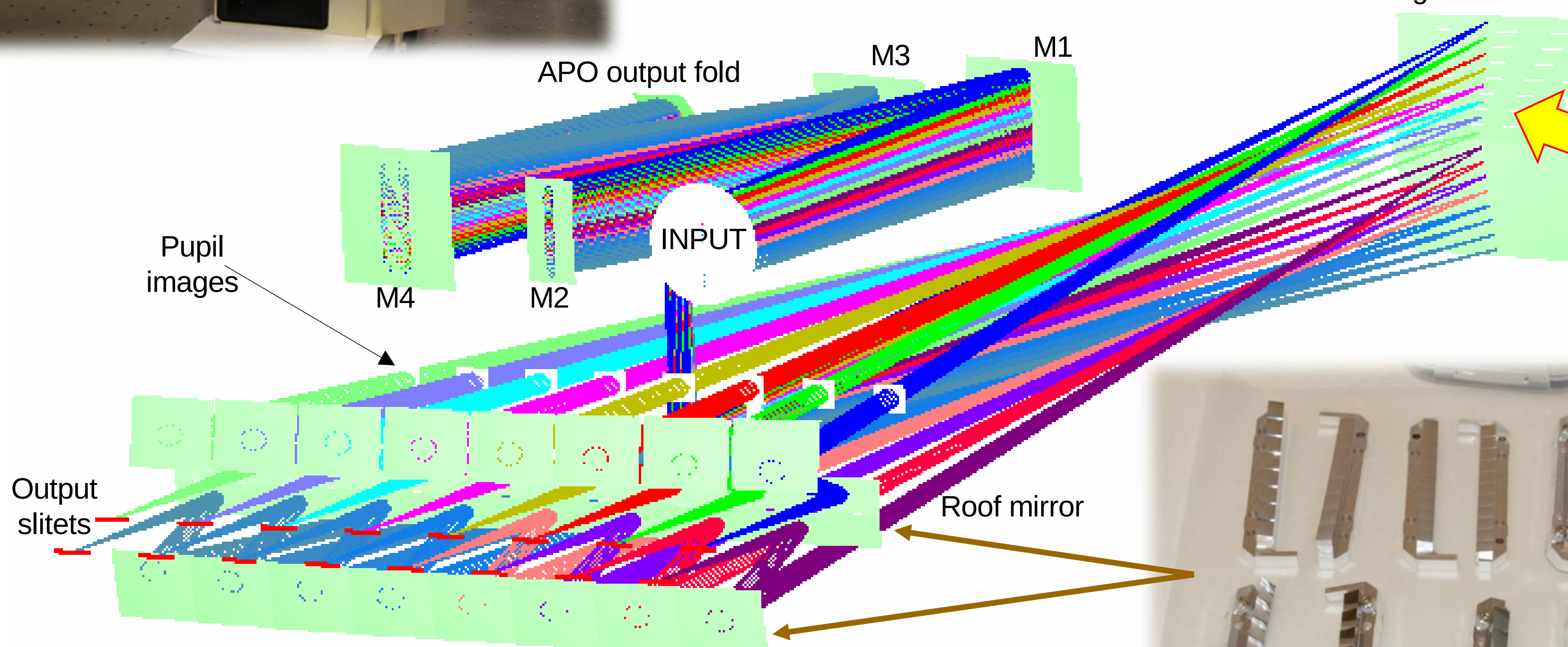
MIRI has the first mid-IR IFU in space.

- FoV of the MRS covers 18.5 arcsec^2 – 39 arcsec^2
- no slit losses
- “easy” target acquisition

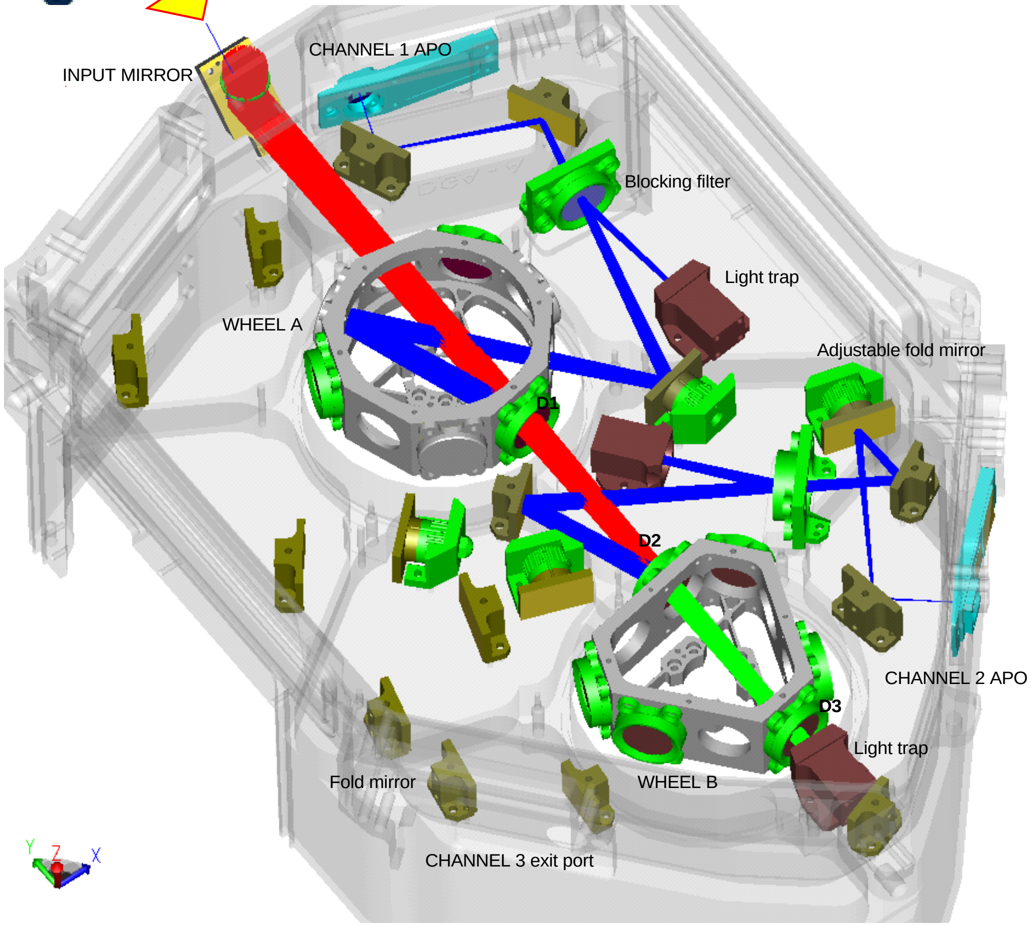
Image Slicer and Pre-Optics

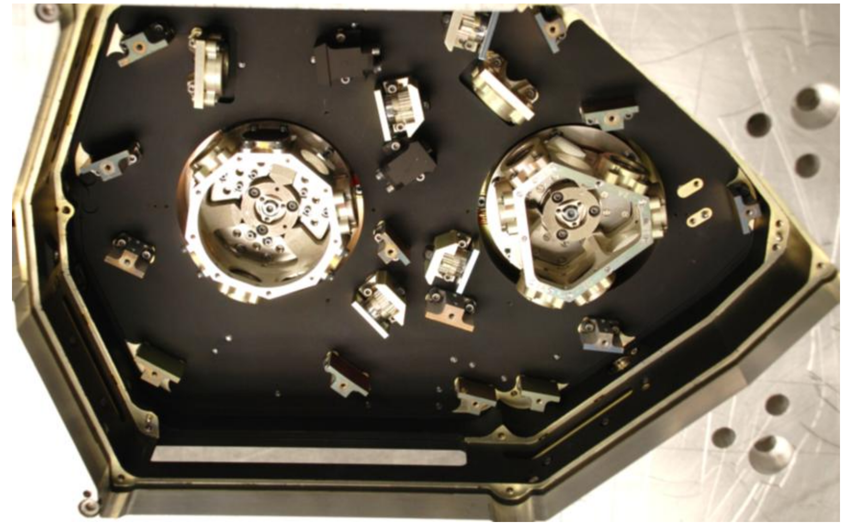


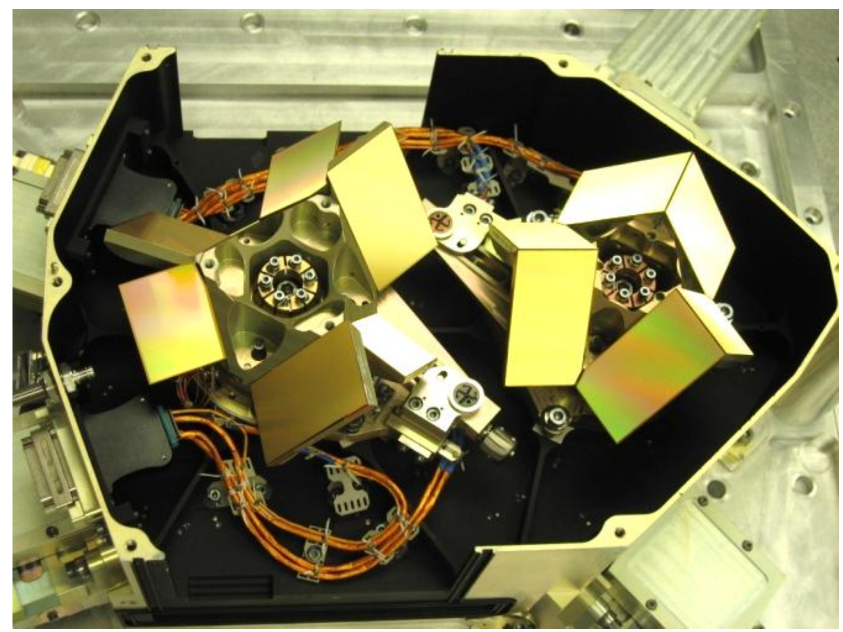


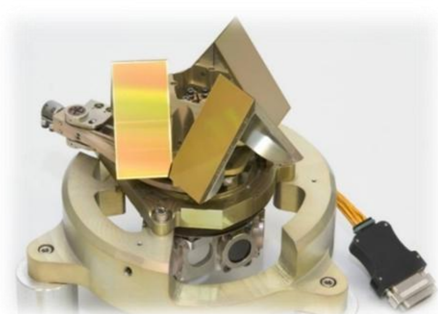


Dichroics, Gratings and Main-Optics









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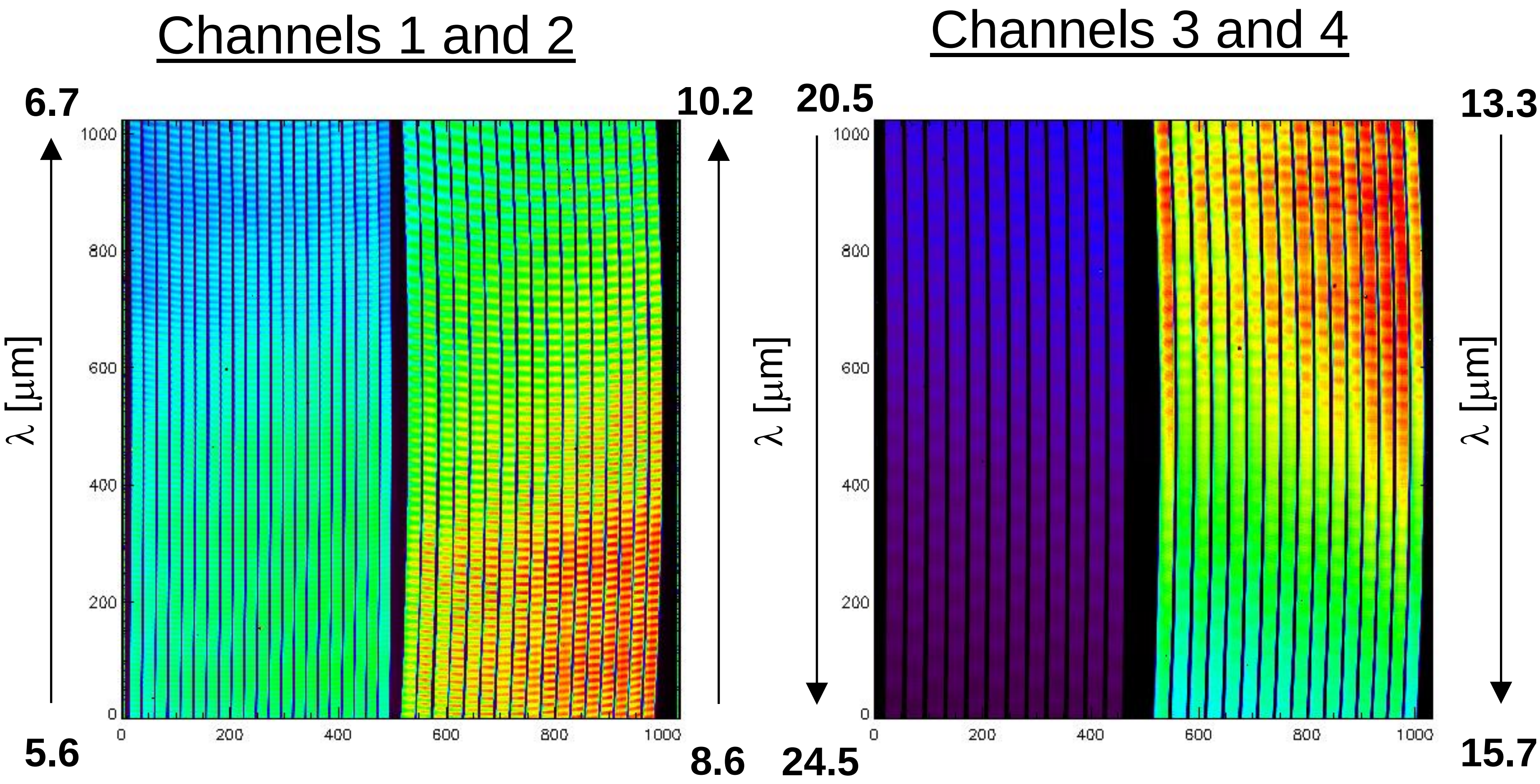
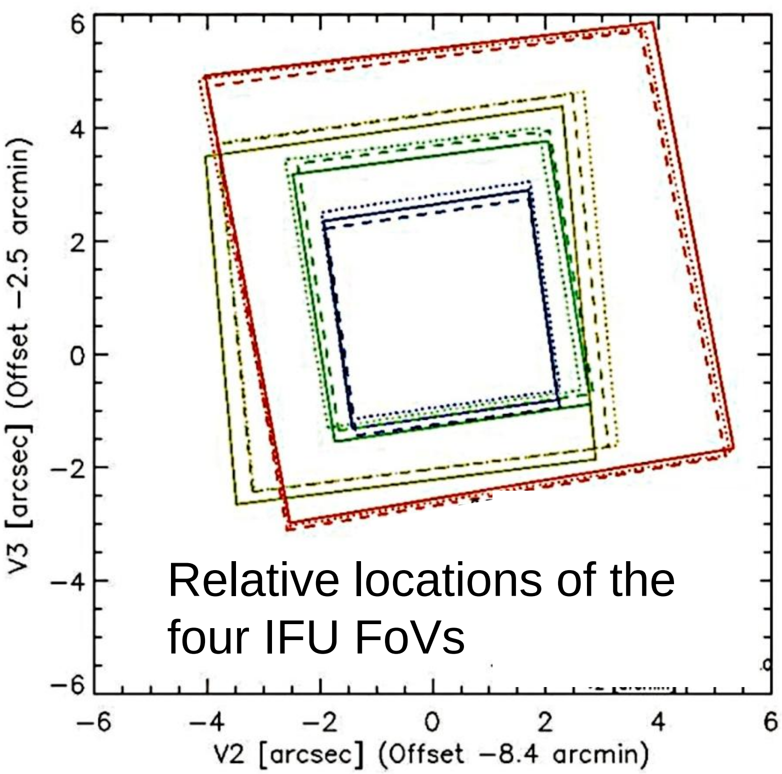
…and the MRS Focal Plane



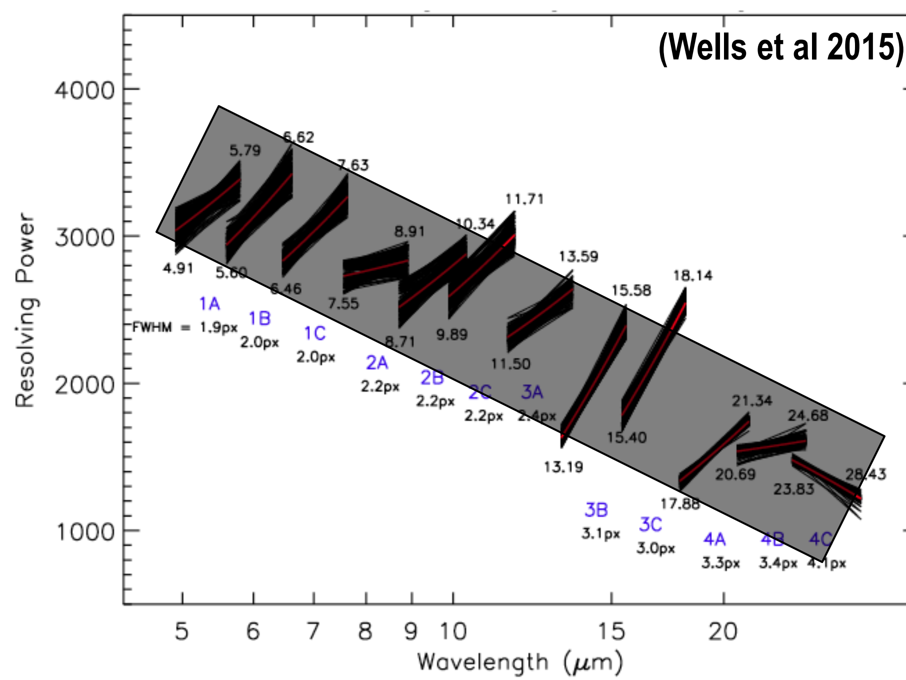
Remember: this represents *only one of three* grating settings (setting B)

Angular Resolution and Sampling per Channel

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

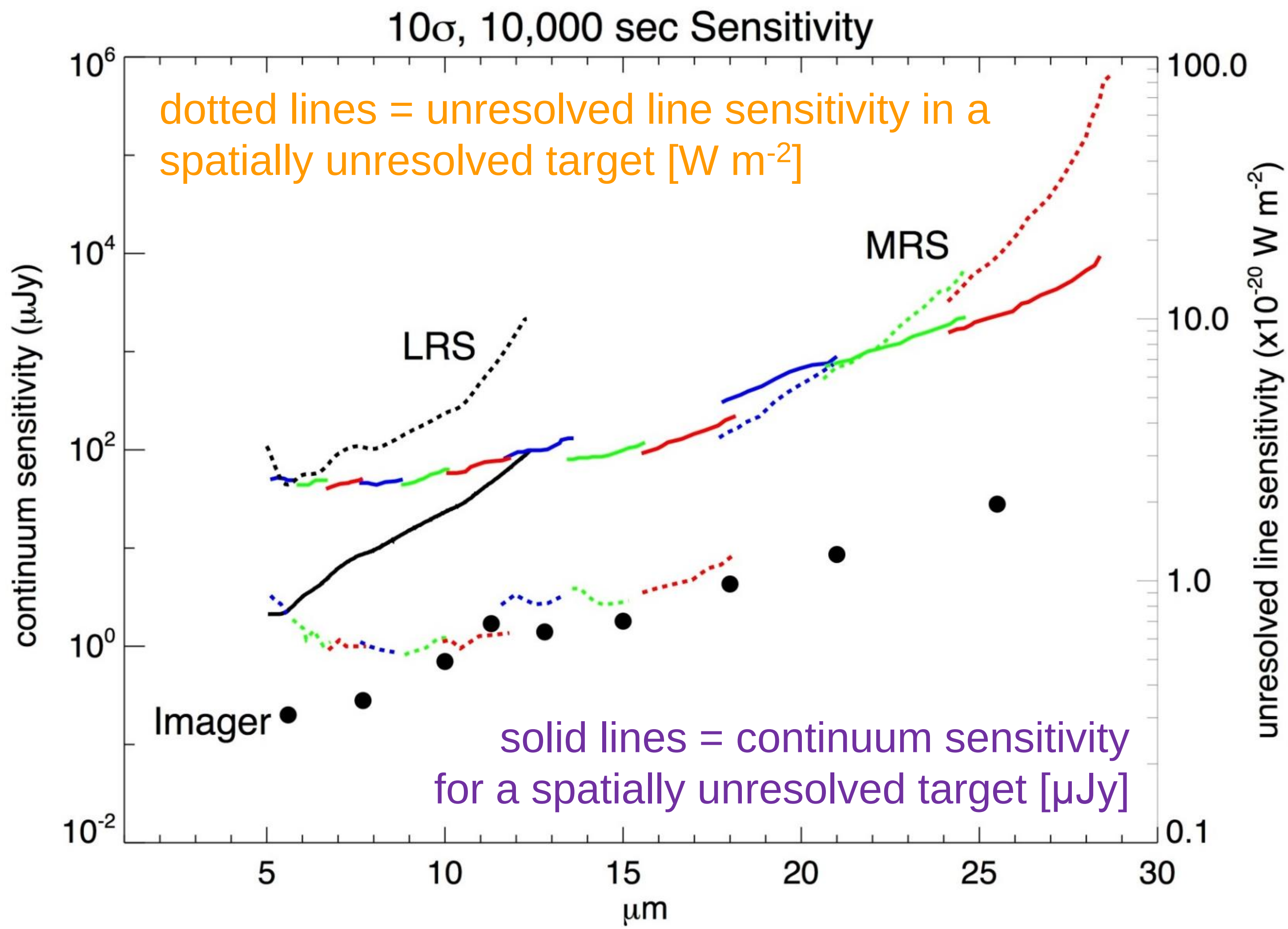


Relative locations of the four IFU FoVs



- $R \sim 1500 - 3500 = f\{\lambda\}$

MRS/LRS Line and Continuum Sensitivities



- Unprecedented line sensitivity ~10^{-20} W m^{-2}
- ~100× better than IRS-SH @10μm (D_{tel}, R, detector)

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The Universe at high-z

Galaxy activity near epoch of reionization:

- so far only 3 spectroscopically confirmed Ly-α emitters:
  EGS-zs8-1 (z=7.730), EGSY8p7 (z= 8.683), COS-zs7-1 (z=7.154)
- at z > 6.7 MIRI is the only JWST instrument that can trace Hα → SFR

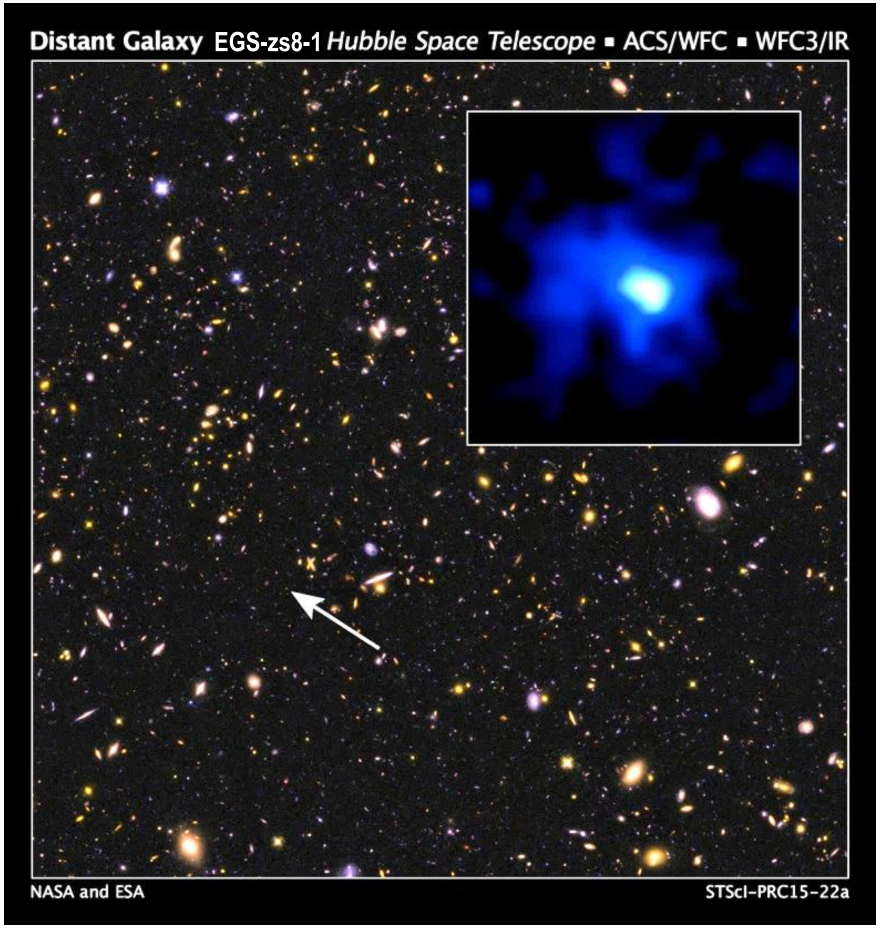
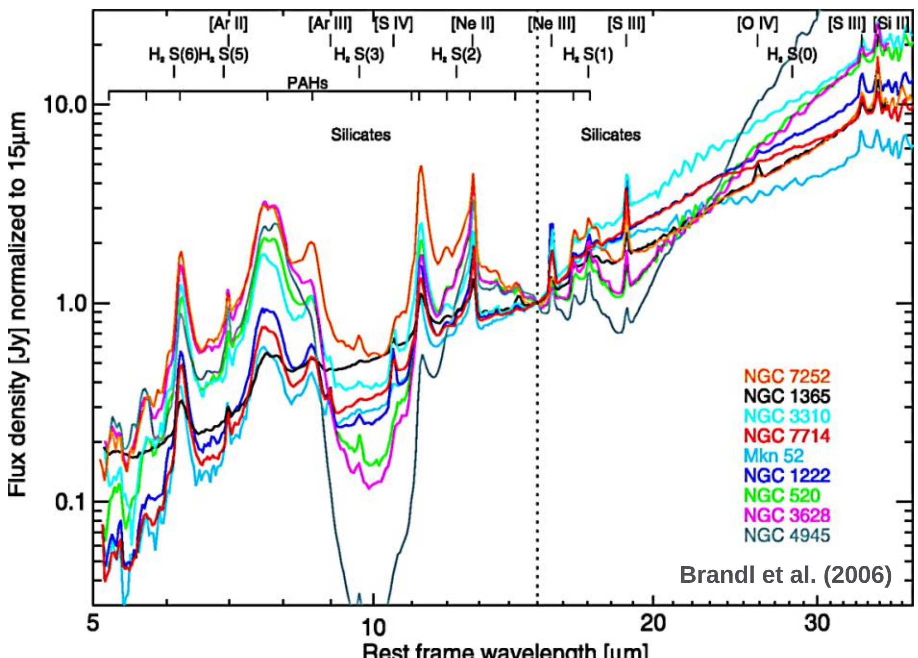


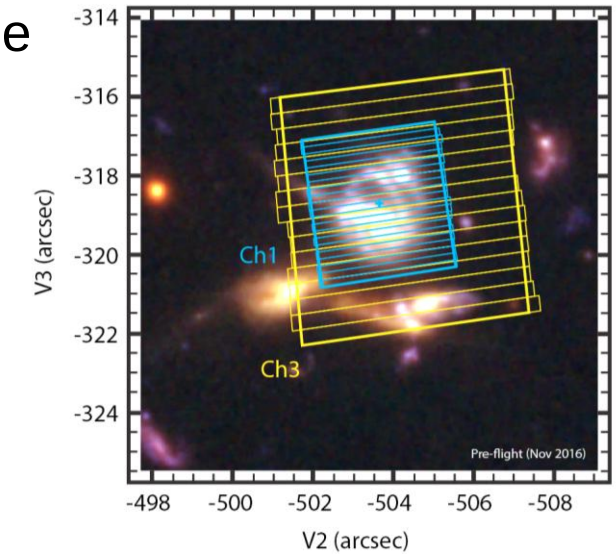
Image Credit: NASA, ESA, P. Oesch and I. Momcheva (Yale University), and the 3D-HST and HUDF09/XDF Teams

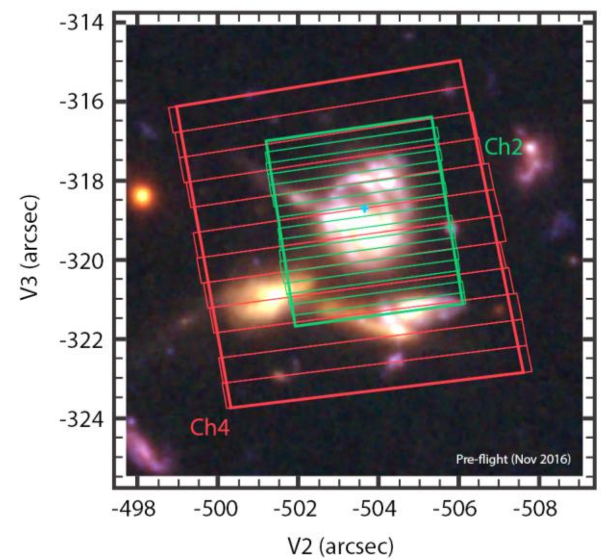
Nearby Galaxies

Spatially resolved* studies of SF, AGN, ISM

- * ~1-2 kpc for $z > 1$; ~100 pc for local galaxie
- kinematic studies of velocities ~100 km s^{-1}
- unveil faint diffuse extended emission
- wealth of weaker spectral lines for better diagnostics







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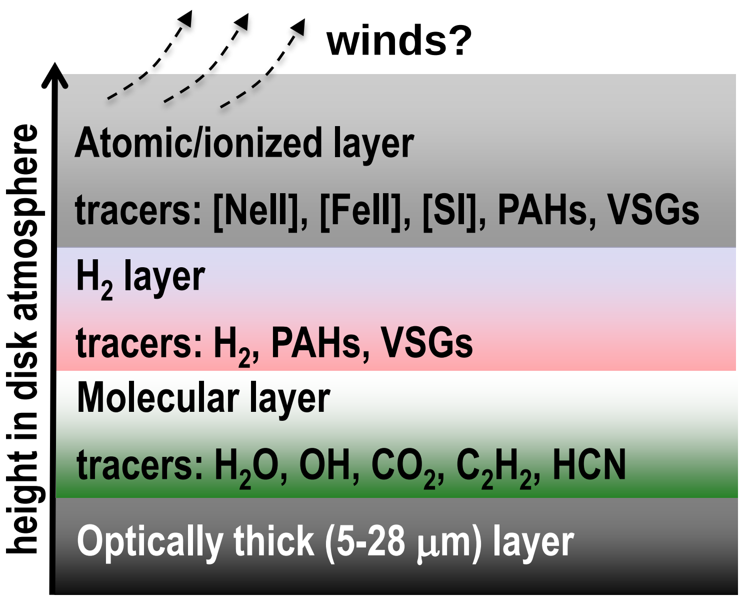
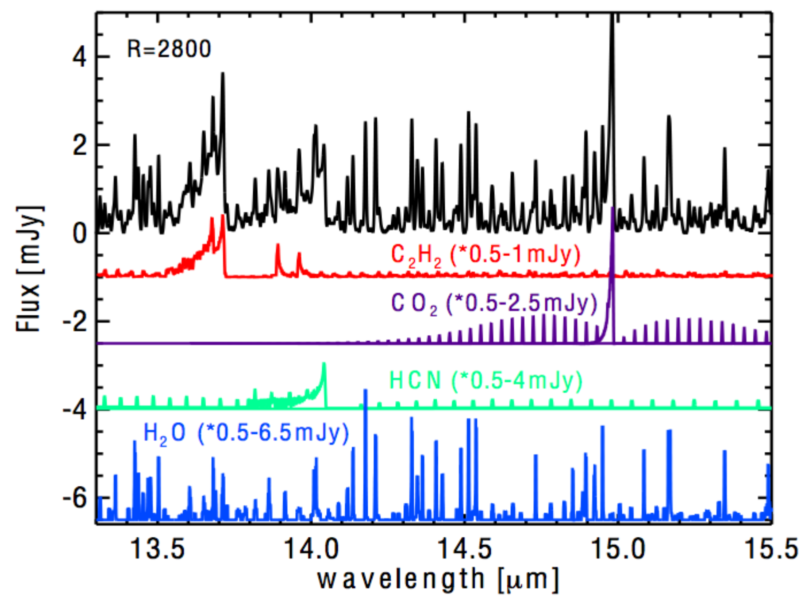
Proto-planetary Disks

Spectroscopy of disks around HAe stars, T Tauri stars, BDs and young debris disks at high resolution & high sensitivity

- Which disks make which kind of planets? T-Tauri ⇔ Herbig disks
- chemical inventory in terrestrial planet forming zone
- gas evolution into the disk dispersal stage





simulated mid-IR spectrum of a T Tauri disk (Kamp & Greenwood – ProDiMo+FLiTs)

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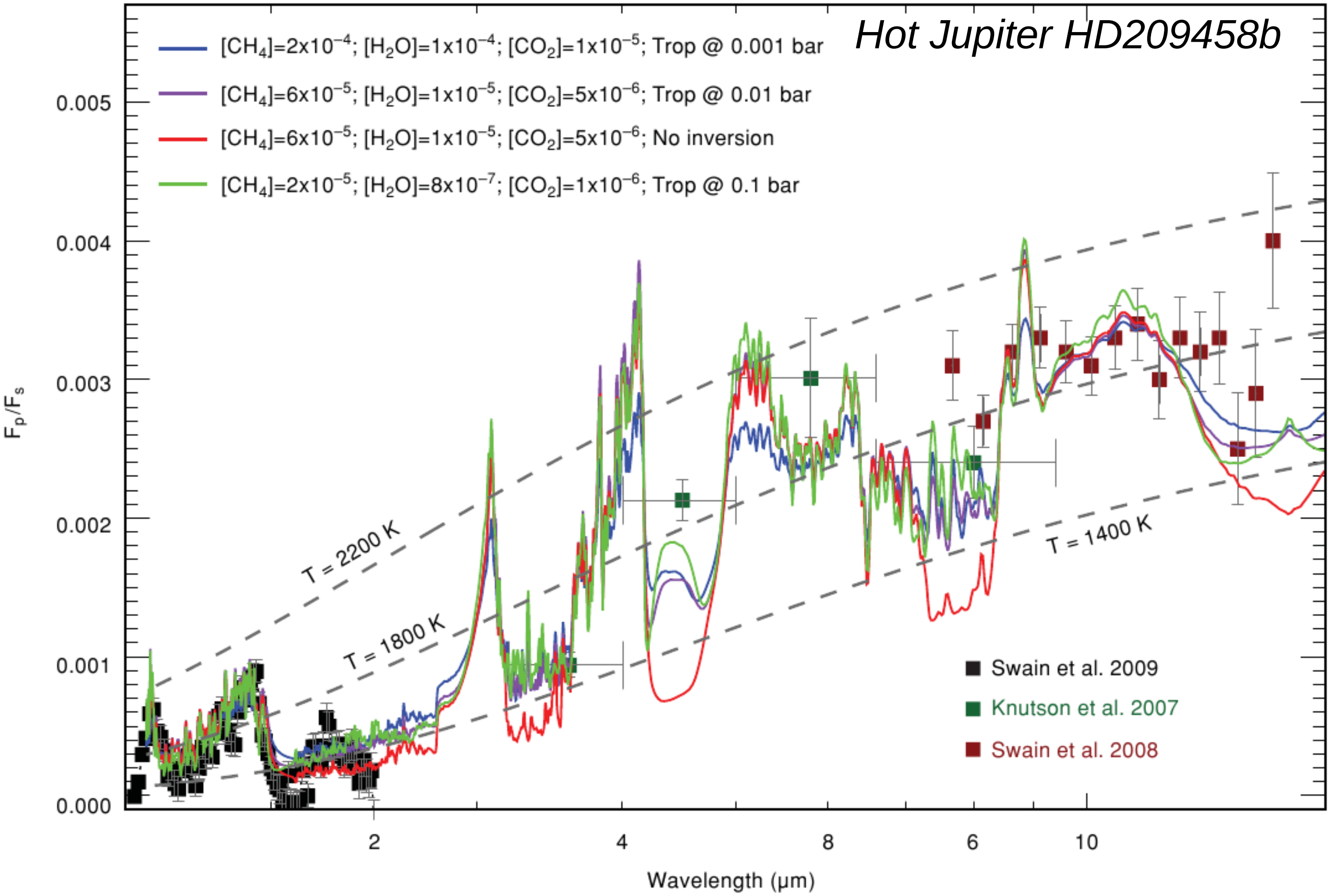
Exoplanets

Transmission and emission spectra from transits

- far less than a handful mid-IR spectra (from Spitzer)
- essential to detect and characterize exoplanet atmospheres



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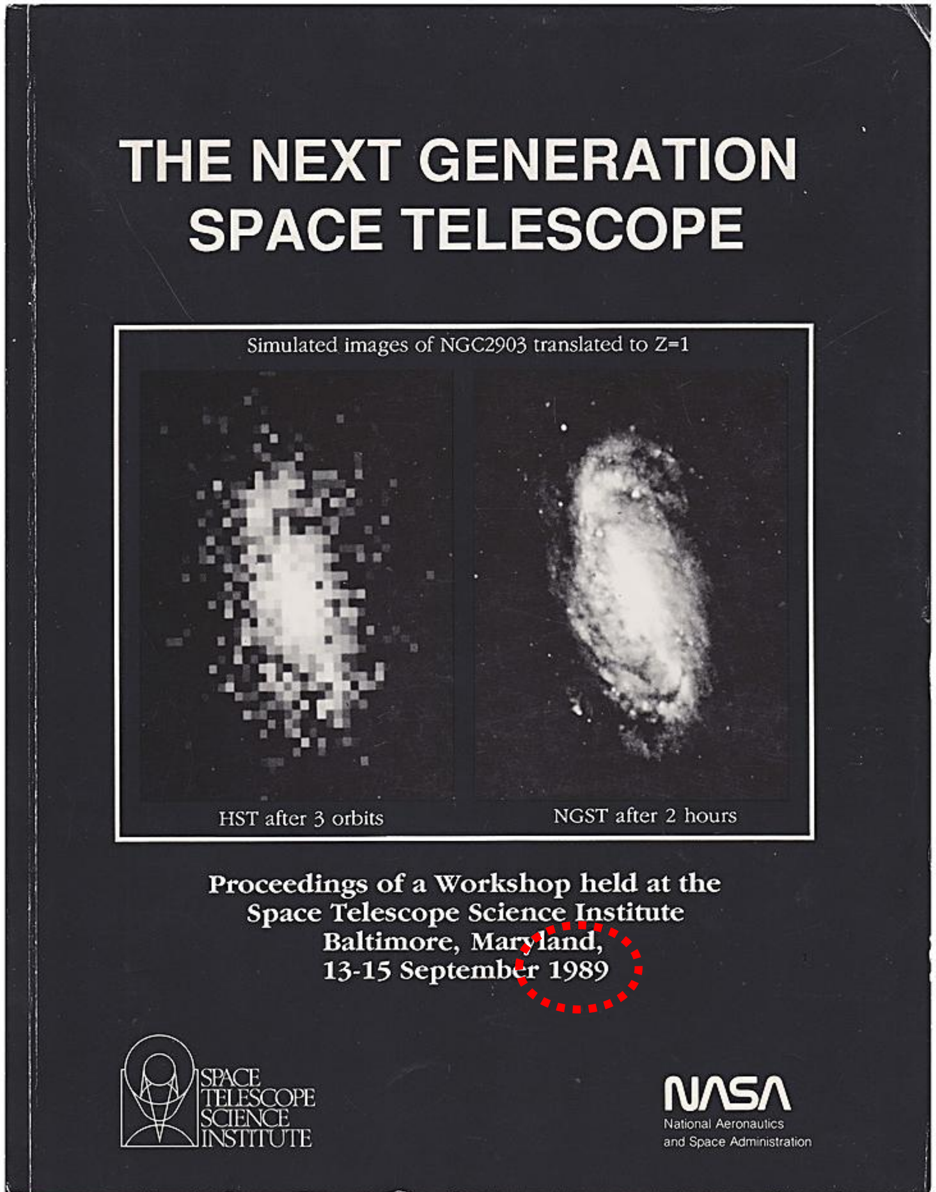
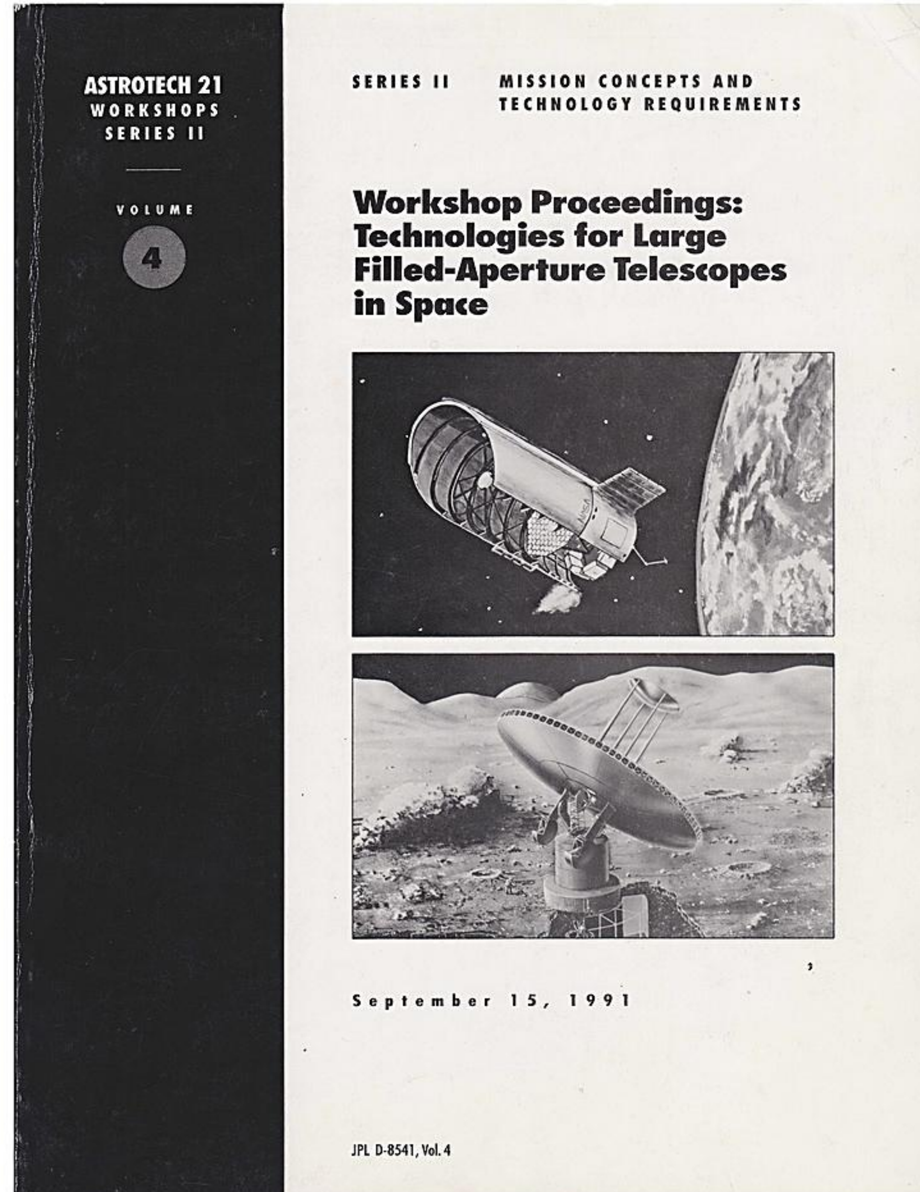
…and after almost 30 years …





… it's about time to launch!