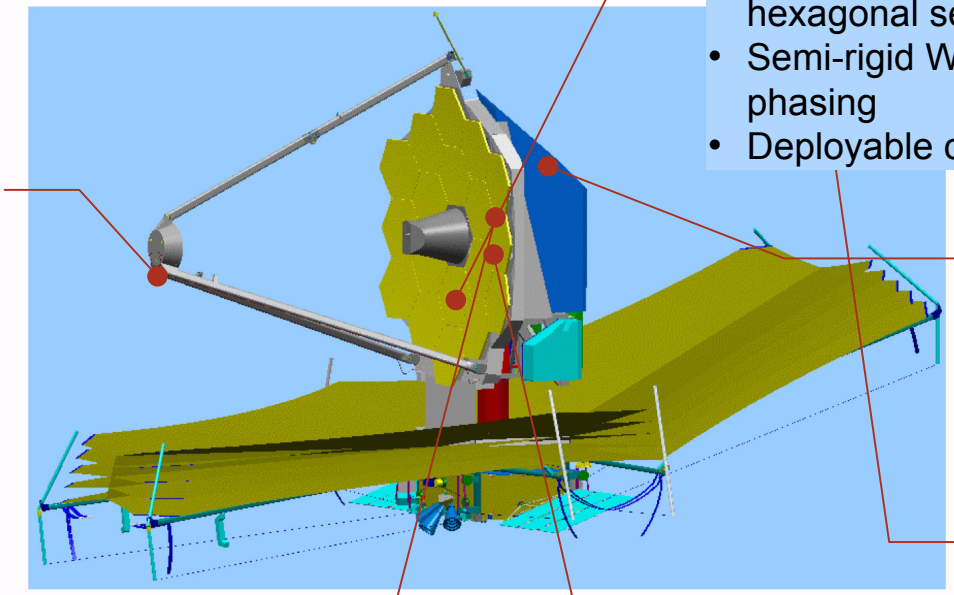
JWST, MIRI and RoPACS

David Barrado y Navascues
LAEX-CAB(INTA-CSIC)
RoPACS Kick-off meeting, Madrid 28-29 January 2009

Optical Telescope Element (OTE)



Primary Mirror (PM)
- 18 (1.315m) hexagonal segments
- Semi-rigid WFS&C for phasing
- Deployable chord fold

Secondary Mirror (SM)

ISIM
- MIRI
- NIRSpec
- NIRCam
- FGS

Sunshield
Passive cooling of ISIM/OTE to <40K

Spacecraft Bus

Tower

The JWST Mission

Themes:

- First Light (after the Big Bang)
- Assembly of Galaxies
- Birth of Stars and Protoplanetary Systems
- Planetary Systems and the Origins of Life

JWST will offer:

- Imaging from 0.6 to 27 mm.
- Coronagraphic imaging from 0.6 to 27 mm.
- Spectro-coronagraphy at R=100 from 1.2 to 5 mm.
- Low resolution spectroscopy from 0.6 to 10 mm.
- Medium resolution spectroscopy from 1 to 27 mm with multi-object capability between 1 and 5 mm and integral field capability over the whole range.

NASA **is committed** to the US Congress (mid-2008). JWST will be launched in **2013**, and **NO delay** is expected.

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INSTRUMENTS

The Fine Guidance Sensor and Tunable Filter Camera.- Short (1.2-2.4 mm) and long (2.5-5 mm) wavelength channels
The instantaneous observed bandpass will be R~ 100 with a limiting sensitivity of AB=25 at S/N=10 in 10,000 seconds. Coronagraphic capabilities

NIRCam.- Short (0.6-2.3mm) and long (2.4-5.0mm) wavelength. Coronograph.
Sensitivity: The NIRCam limiting sensitivity to point sources with S/N=10 in 10,000 seconds is AB=28.69 in F110W and AB=28.86 in F200W.

NIRSpec.- Near infrared multi-object dispersive spectrograph capable of simultaneously observing more than 100 sources over a 3x3arcmin FOV.
Sensitivity: 10,000 sec, point source, 3 micron, S/N=10 Mag(AB)=26.2. For emission lines at R=1000, 2 micron, 100,000 seconds is flux limt = 5.2 10-19 erg cm-2 s-1.

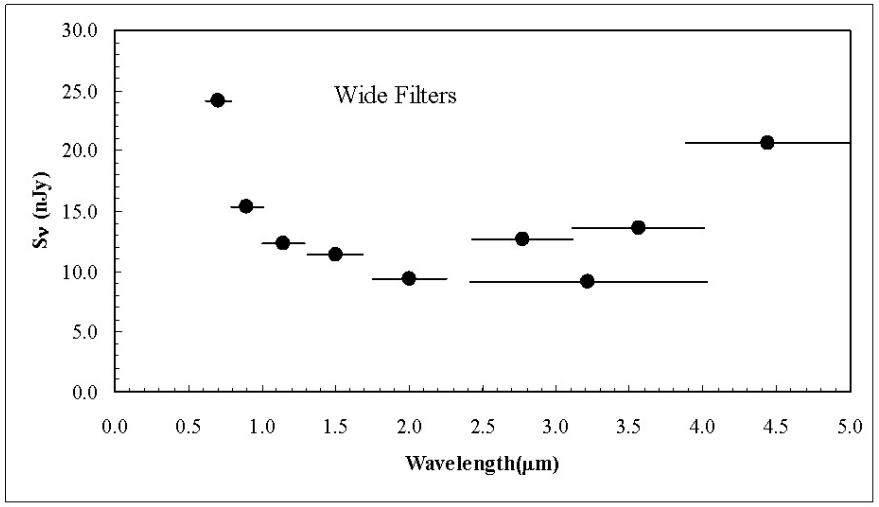
MIRI.- Imaging and spectroscopic measurements over the wavelength range 5-27 mm.
Sensitivity: *Limiting sensitivity in imaging at 10 and 20*mm *(S/N=10, 10,000 sec) are, respectively, AB=24.53 and AB=22.15. The limiting flux in 10,000 seconds for a resolving power of R=2400 and at 9.2*mm *is 3.4 10-18 erg cm-2 s-1.*

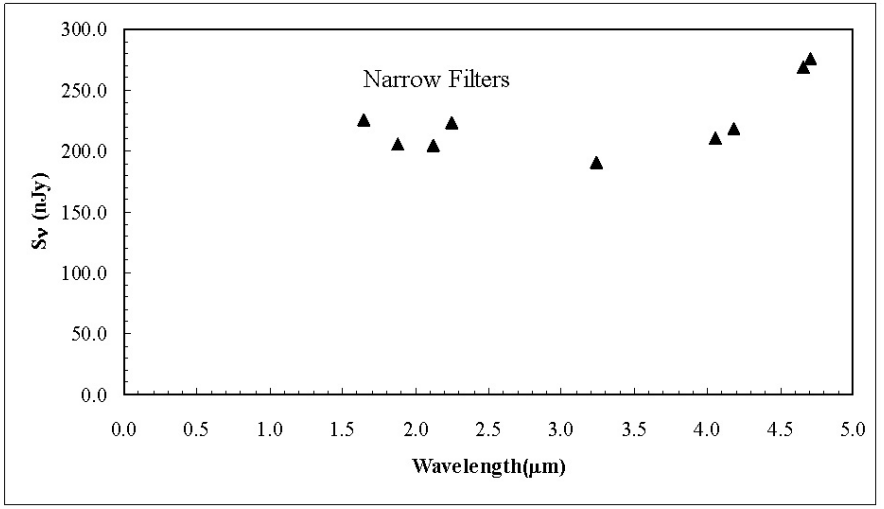
JWST: instruments

Table 1. Science Instrument Characteristics

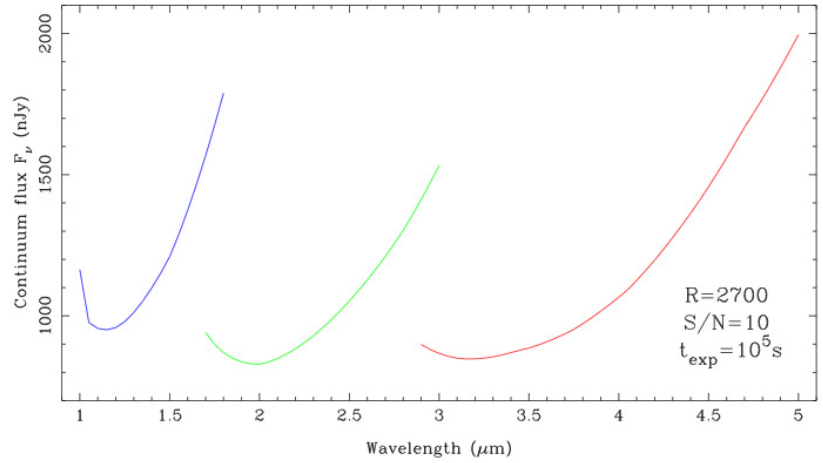
Instrument	Wavelength (μm)	Optical Elements	FPA	Plate Scale (milliarcsec/ pixel)	Field of View
NIRCam (Short Wave)	0.6 - 2.3	fixed filters (R~4, R~10, R~100), coronagraphic spots	Two 2×2 mosaics of 2048x2048 arrays	32	2.2′×4.4′
NIRCam (Long Wave)[1]	2.4 - 5.0	fixed filters (R~4, R~10, R~100), coronagraphic spots	Two 2048×2048 arrays	65	2.2′×4.4′
NIRSpec (prism, R=100)	0.6 - 5.0	transmissive slit mask: 4x384x175 micro-shutter array, 250 (spectral) by500 (spatial) milliarcsec; fixed slits 200 or 300 mas wide by 4″long	Two 2048×2048 arrays	100	3.4′×3.1′
NIRSpec (grating, R=1000)	1.0-5.0				
NIRSpec (IFU, R=3000)	1.0-5.0	integral field unit			3.0″×3.0″
MIRI (imaging)	5 - 27	broad-band filters, coronagraphic spots & phase masks	1024×1024	110	1.4′×1.9′ (26″×26″ coronographic)
MIRI (prism spectroscopy)	5 - 10	R ~ 100			
MIRI (spectroscopy)	5 - 27	integral field spectrograph (R~3000) in 4 bands	Two 1024×1024 arrays	200-470	3.6″×3.6″ to 7.5″×7.5″
Short-wavelength FGS-TF	1.2 - 2.4	Order-blocking filters+etalon (R~100)	2048×2048	68	2.3′×2.3′
Long-wavelength FGS-TF[2]	2.5 - 5.0	Order-blocking filters+etalon (R~100)	2048×2048	68	2.3′×2.3′

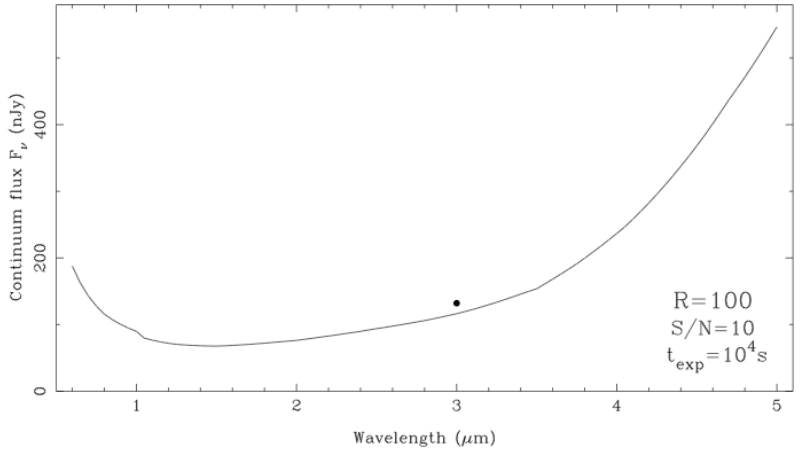
NIRCam sensitivity





NIRSpect sensitivities





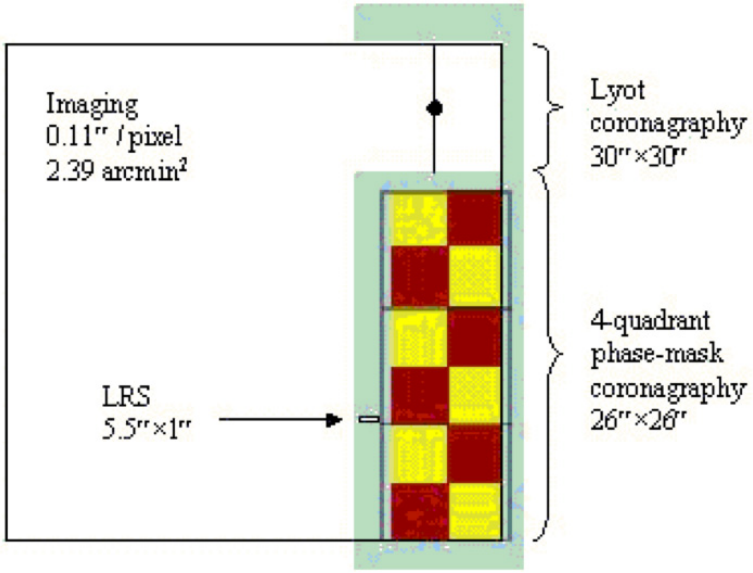
MIRI overview

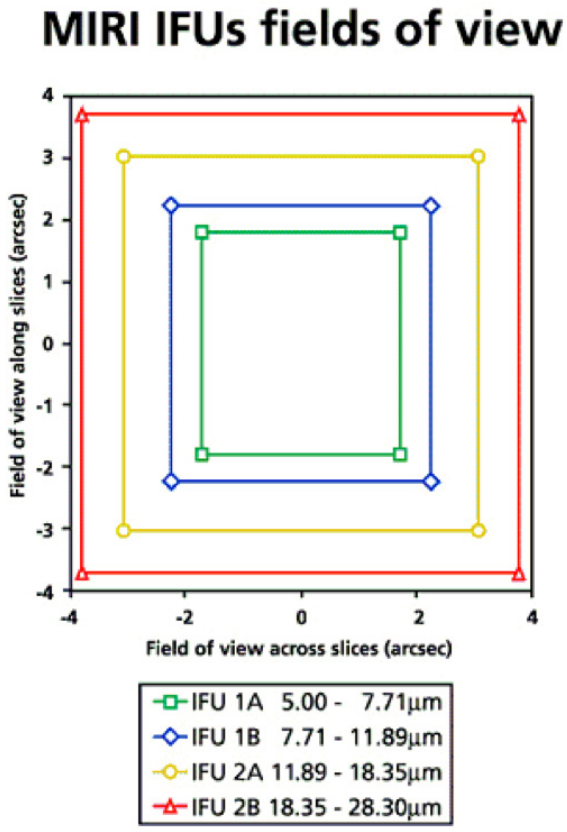
Mid Infra-Red Imager (MIRIM) provides:

- Photometric imaging between 5μm and 27μm, 1.4x1.9 arcmin, 0.11 arcsec/pic
- Coronography between 10μm and 27μm, 26x26 arcsec
- Low resolution **(R=100)** slit spectros of single sources between 5μm and 10μm.

Spectrometer (SPE) provides:

- Medium resolution (~ 100 km/sec), integral field spectroscopy between 5μm and 28.3μm





MIRI versus other telescopes

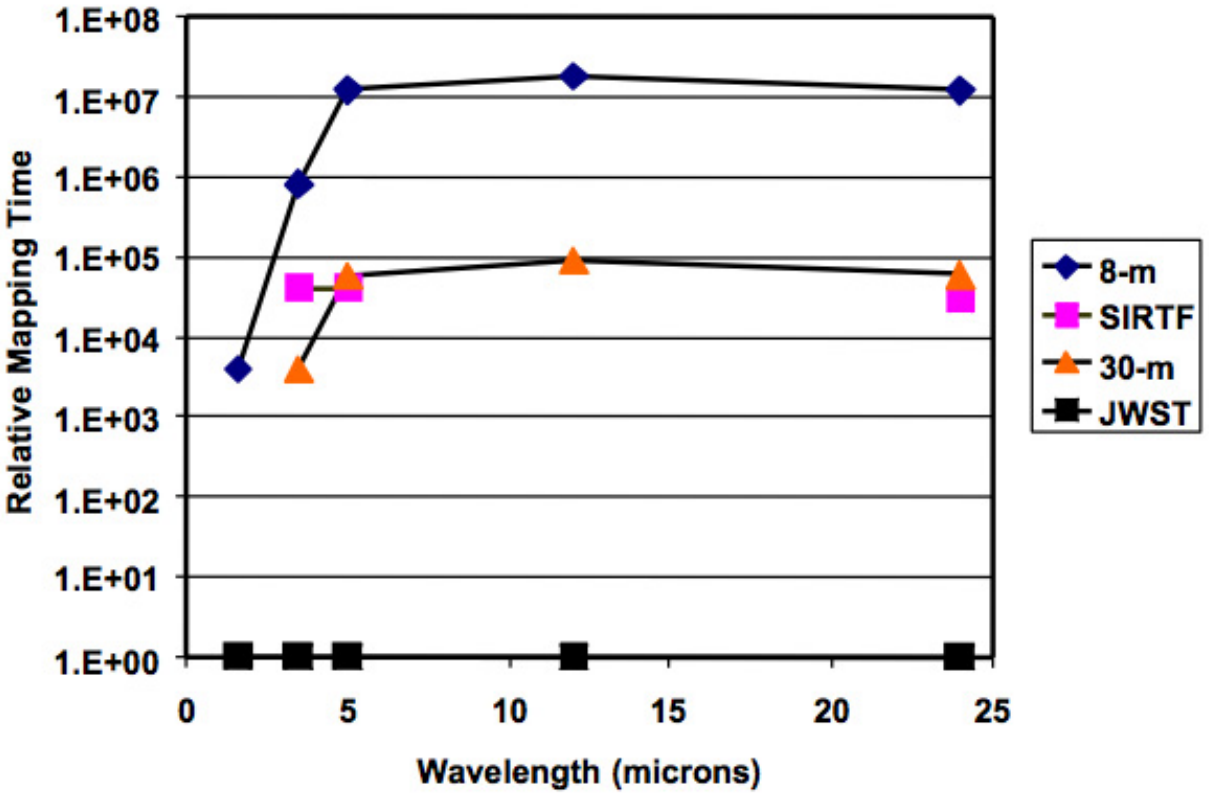


Figure 1. Gain in survey speed (astronomical capability) of MIRI on JWST over Gemini, SIRTF, and a 30-m diffraction limited groundbased telescope. For the latter telescope, the performance at the shorter wavelengths depends critically on Multi-Conjugate Adaptive Optics and hence has not been included in the figure.

MIRI sensitivity

The MIRI science team has provided the following tables for the MIRI photometric and spectrograph sensitivities. All estimates assume a low zodiacal background (important below 10 microns), a point source, and 10 sigma measurement after 10,000s.

Low resolution spectroscopy
(5-10 microns)

3000 nJy at 7.5 microns

Medium resolution spectroscopy
(IFU, 10,000s per setting)

Lambda (Microns)	Line Flux (W/m^2)
6.4	7.00E-21
9.2	1.00E-20
14.5	1.20E-20
22.5	6.00E-20

MIRI Camera

Lambda (Microns)	Flux (microJansky)
5.6	0.2
7.7	0.28
10	0.7
11.3	1.7
12.8	1.4
15	1.8
18	4.3
21	8.6
25.5	28

MIRIM – Focal Plane

- **Imaging Mode**
- **Coronagraphic Mode (1 Lyot mask +3 4QPM)**
  - ***Focal plane***
  - ***4 QPM tilt***
  - ***Diaphragms and image quality***
- **Low Resolution Spectroscopic Mode**

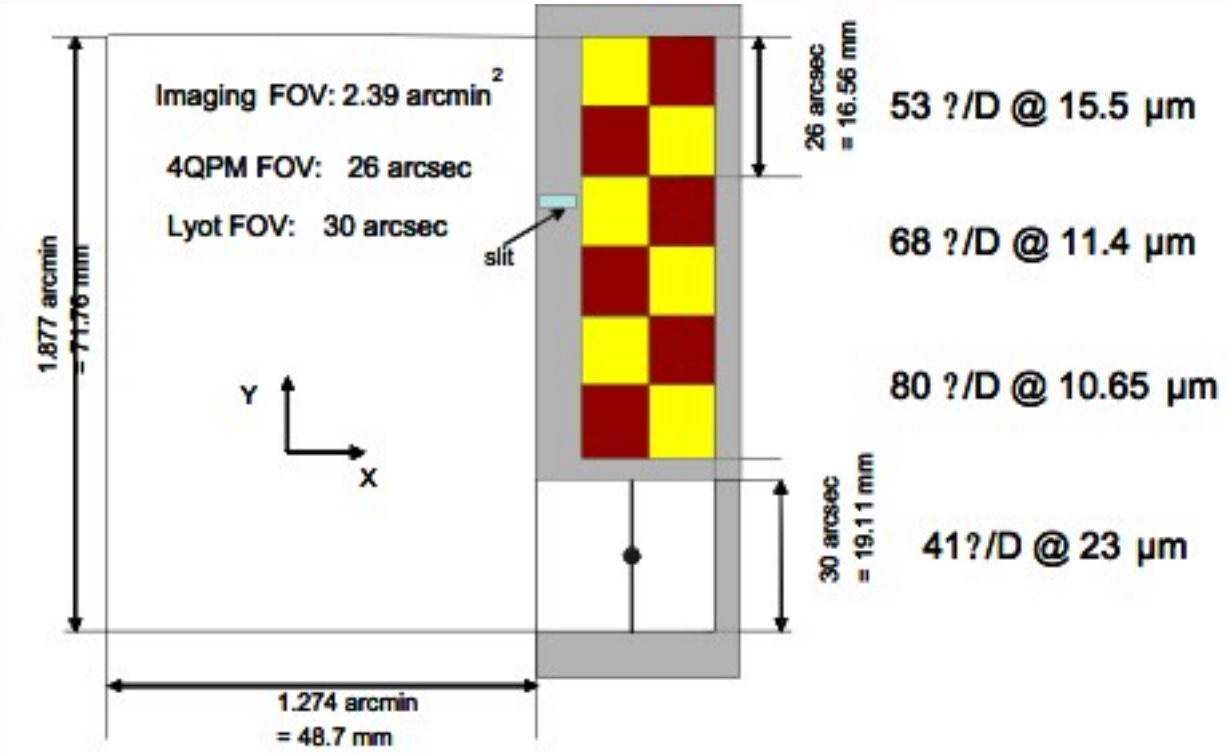
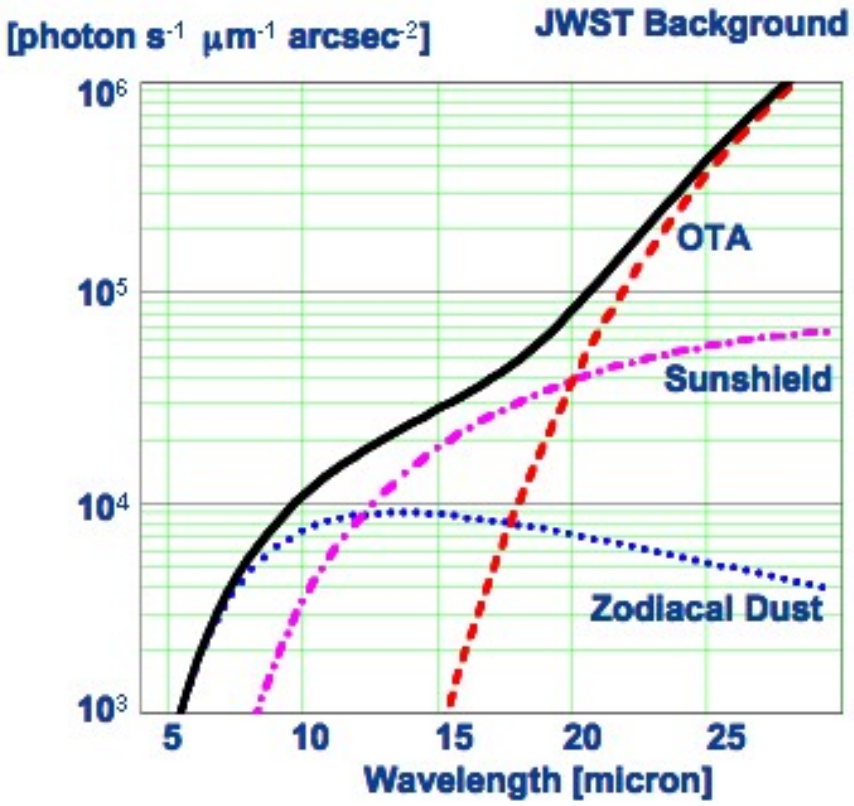
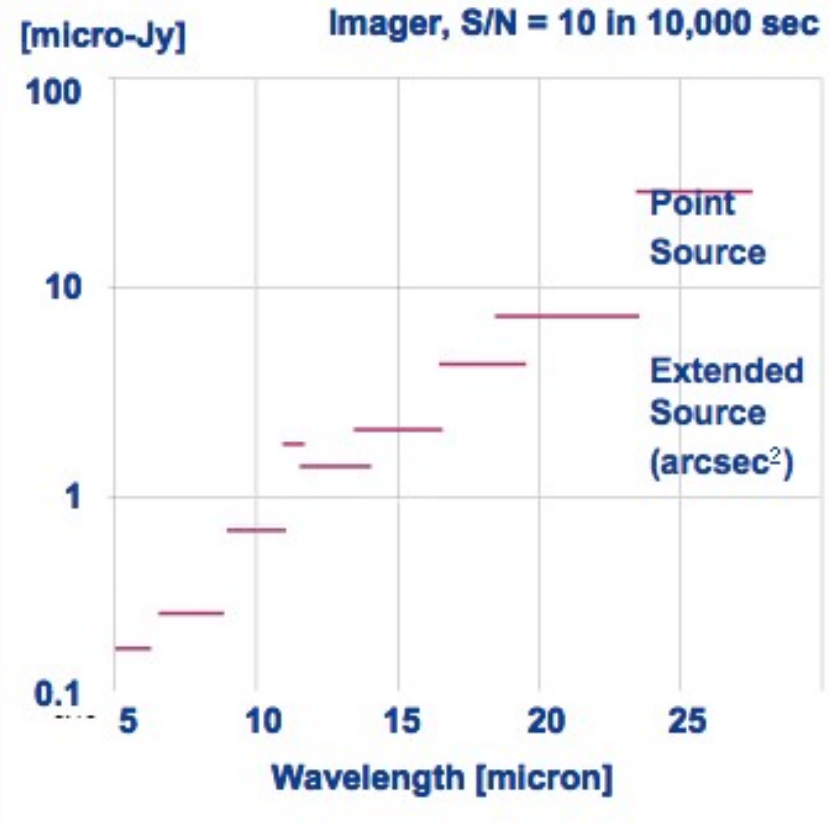


Table 4. MIRI Filters

	λ_0 (μm)	$\Delta\lambda$ (μm)	**Comment**
B1	5.6	1.2	broad band
B2	7.7	2.2	PAH, broad band
B3	10	2	Silicate, broad band
I1	11.3	0.7	PAH, broad band
I2	12.8	2.4	Broad band
B4	15	3	Broad band
I3	18	3	Silicate, broad band
B5	21	5	broad band
B6	25.5	~4	broad band
B6'	25.5	~4	redundant filter, risk reduction
ND#	neutral dens.		for coron. acquis.
NIR	near-IR, TBD		testing
	blackened blank	N/A	for darks

Imager sensitivity





Medium Resolution Spectrometer

Integral Field Spectroscopy with > 3 arcsec field of view from 5 to 28.5 μm.

10 arcseconds

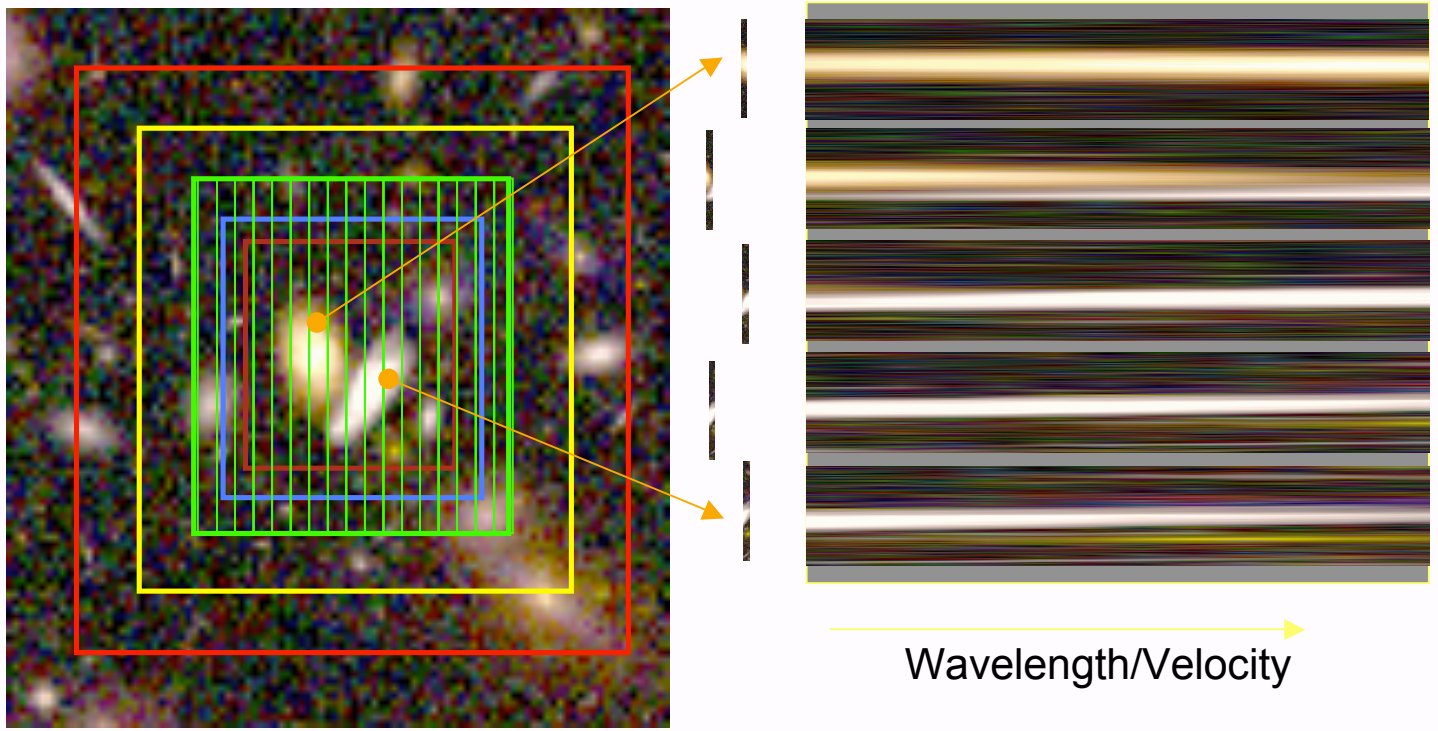
Each channel's field of view is sliced, dispersed and detected.

Channel 1
(4.9 - 7.7 μm)

Channel 2
(7.4 - 11.8 μm)

Channel 3
(11.4 - 18.2 μm)

Channel 4
(17.5 - 28.8 μm)



Wavelength/Velocity

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Spectrometer: λ Ranges, R,

WAVELENGTH CHANNEL:		1	2	3	4
λ-limits (μm):		5.86–7.74	7.43–11.84	11.44-18.20	17.53-28.75
		λ-range (μm) $R_{spectral}$	λ-range (μm) $R_{spectral}$	λ-range (μm) $R_{spectral}$	λ-range (μm) $R_{spectral}$
Exp. A	Δλ:	4.86–5.81	7..43-8.88	11.44-13.64	17.53-21.16
	R:	2450-3710	2480-3690	2510-3730	2070-2490
Exp. B	Δλ:	5.61-6.71	8.59-10.26	13.22-15.76	20.43-24.66
	R:	2450-3710	2480-3690	2510-3730	2070-2490
Exp. C	Δλ:	6.48-7.74	9.91-11.84	15.27-18.20	23.82-28.75
	R:	2450-3710	2480-3690	2510-3730	2070-2490
IFU main parameters					
slice width (arcsec):		0.176	0.277	0.387	0.645
slice length (arcsec):		3.70	4.51	6.13	7.74
number of IFU slices:		21	17	16	12

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Transits Follow-up with JWST

	Validate	Primary Light Curve	Secondary Light Curve	1-2.4 μm Spectra	2.4-5 μm spectra	5-20 μm spectra
NIRCAM						
NIRSPEC						
MIRI						

See JWST White paper s by Clampin et al (2007), Seager (2008)

Taken from C. Beichman

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JWST setups for transits

SI	λ (μm)	Spectral Resolution (λ/δλ)	FOV	Mode	Comments	Application
NIRCam	0.6 - 2.3 2.4 - 5.0	4, 10, 100 4, 10, 100	2 x (2.2' x 2.2') 2 x (2.2' x 2.2')	Imaging Imaging	Photometric Imaging	High precision light curves of transits from photometry of point source images. Wavelength coverage permits photometric monitoring of primary or secondary eclipses.
NIRCam	0.6 – 2.3	4, 10, 100	2 x (2.2' x 2.2')	Phase diversity imaging	Defocusing of images to 57 or 114 pixel diameters	High precision light curves of transits associated with bright objects which need to be defocused to avoid saturation within the minimum integration time
NIRCam	2.4 – 5.0	2000	2 x (2.2' x 2.2')	Long-λ Grism	Backup capability for WFSC. Used with F277W, F322W, F356W, F410M or F444W	Emission spectroscopy of hot gas giant transiting planets
NIRSpec	1.0 – 5.0	100, 1000, 2700	0.1" x 2.0", 0.2" x 3.5", 0.4"x 4.0"	Spectroscopy	Fixed long slits	Low and intermediate resolution transmission and emission spectroscopy of transiting planets.
NIRSpec	0.7 - 5.0	2700	3" x 3"	Spectroscopy	Integral Field Unit	Intermediate resolution, transmission and emission spectroscopy of transiting planets.
MIRI	5 – 29	4-6	1.9' x 1.4'	Imaging	Photometric Imaging	
MIRI	5 - 11	100	5" x 0.2"	Spectroscopy	Fixed Slit or Slitless	Light curves of transits from photometry of point source images.
MIRI	5.9 – 7.7 7.4 – 11.8 11.4 – 18.2 17.5 – 28.8	3000 3000 3000 3000	3.7" x 3.7" 4.7" x 4.5" 6.2"x 6.1" 7.1"x7.7"	Spectroscopy	Integral field unit	Intermediate resolution, emission spectroscopy of transiting planets.
TFI	1.6 – 2.5	100	2.2' x 2.2'	Imaging	Selectable central λ	High precision light curves of transits from photometry of point source images. Wavelength coverage permits photometric monitoring of primary eclipses.
TFI	3.2 – 4.9	100	2.2' x 2.2'	Imaging	Selectable central λ	High precision light curves of transits from photometry of point source images. Wavelength coverage permits photometric monitoring of secondary eclipses.

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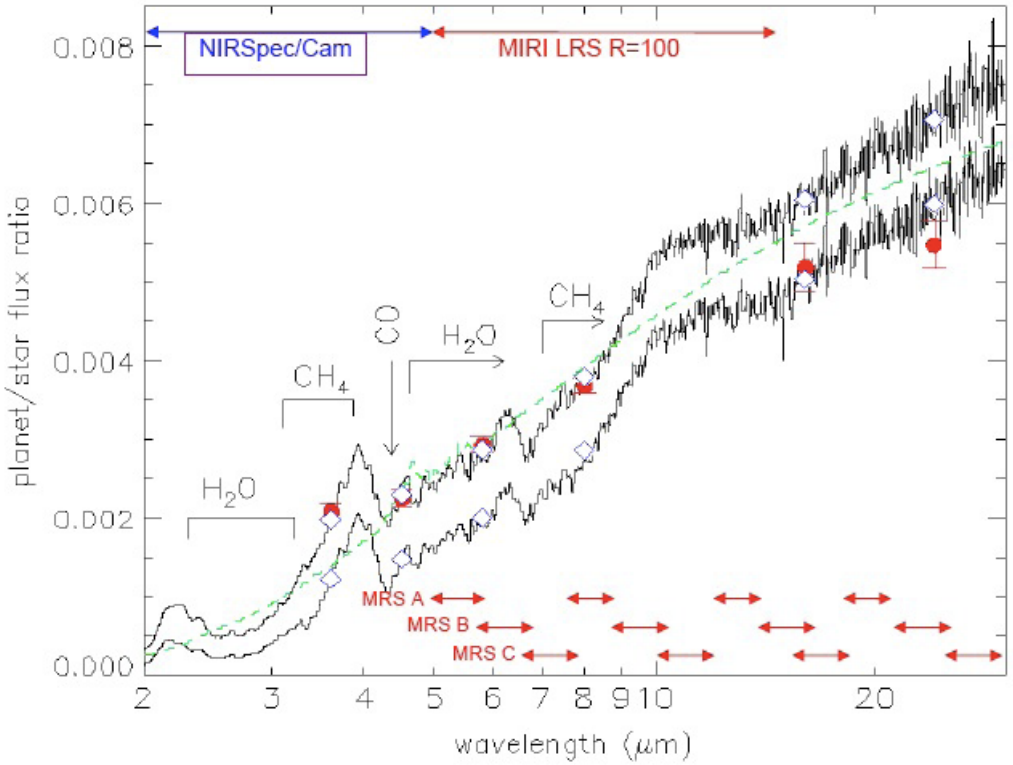
Clampin 2008

JWST spectroscopy



CH4, CO, H2O constrain temperature and C abundance

Red symbols are measurements;

Top curve has fluz absorbed on day side only; bottom has uniform energy redistribution

Dashed line is BB

Charbonneau, Knutson, Barman, Allen, Mayor, Megeath, Queloz, & Udry (2008)

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MIRI Observations of Transits

---Greene, Rieke

- MIRI images with filters for temperature determination
- Disperse w. slitless prism for R~100 spectra (5 – 14 μm)
- Hot Jupiters (spectra) & Hot Super-Earths (photometry)
- Warm (HZ) Super-earths around M stars (no spectra)

Exoplanets 0.1 AU from a G2 V star at 15 pc distance			
Planet	**10 μm R=5**	**21 μm R=4**	**LRS (10 μm R=30)**
1 R_{Jup} Itime (hr) S/N=30	0.1 hr	0.1 hr	1 hr
1 R_{Jup} contrast	8.0E-04	1.5E-03	8.0E-04
2 R_{Earth} Itime (hr) S/N=5	3 hr	4 hr	19 hr
2 R_{Earth} contrast	2.7E-05	5.0E-05	2.7E-05
Exoplanets 0.05 AU from a M5 V star at 10 pc distance			
1 R_{Jup} Itime (hr) S/N=30	4.6 hr	0.4 hr	36 hr
1 R_{Jup} contrast	3.0E-04	2.0E-03	3.0E-04
2 R_{Earth} Itime (hr) S/N=5	118	11	925
2 R_{Earth} contrast	1.0E-05	7.0E-05	1.0E-05

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Taken from C. Beichman 2009

Spectroscopy of exoplanets

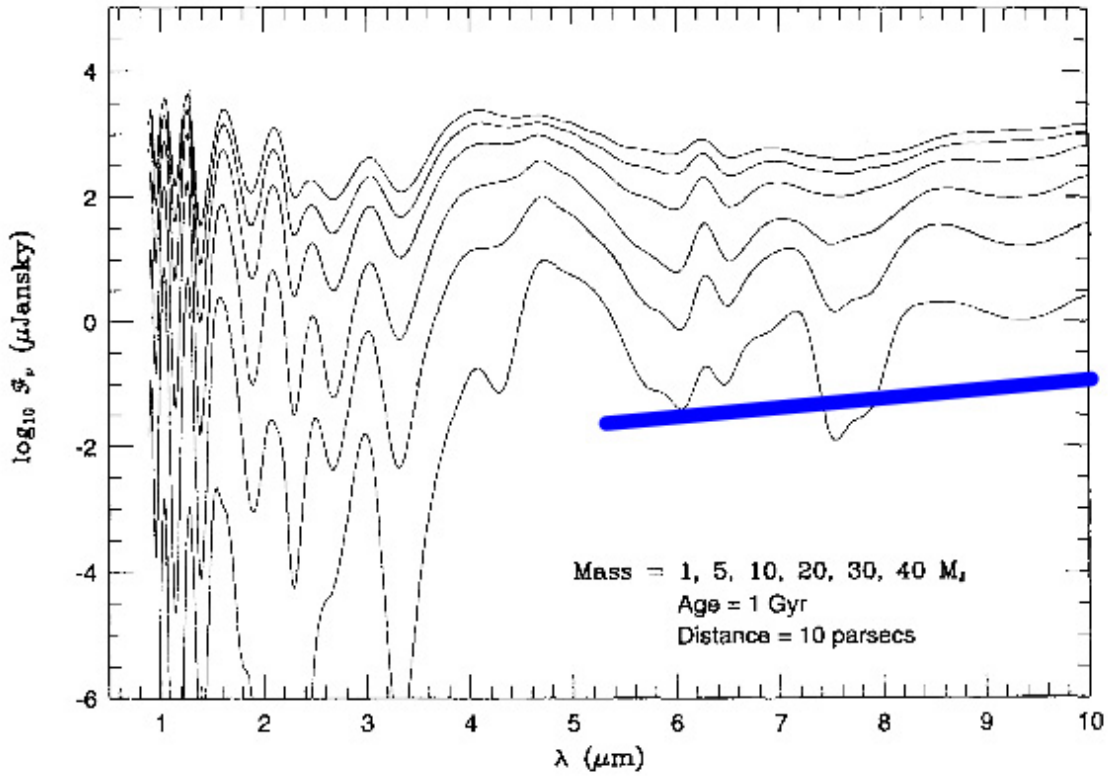
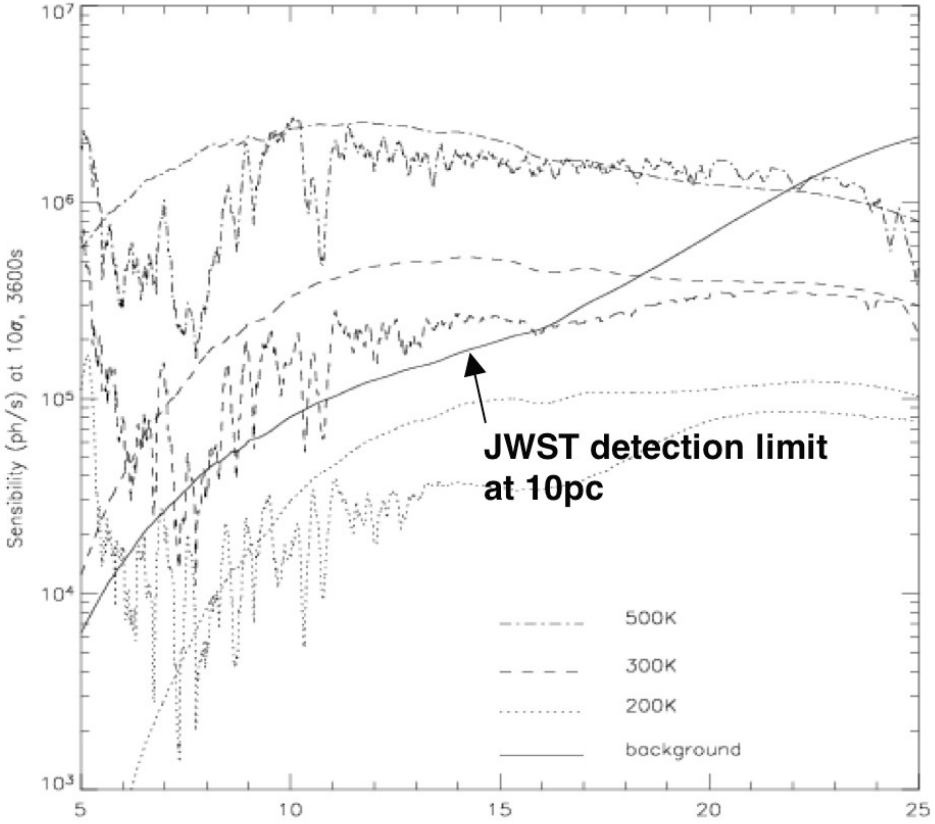


Figure 14. Spectra of giant planets at an age of 1 GYr (Burrows et al. 1997),. The heavy line shows the 1-sigma detection limit for MIRI at a spectral resolution of R = 100 after 10,000 seconds.

MIRI Coronography

Figure 11: Detection limits for JWST, overplotted on spectra of EGPs from Allard et al. (2001).



MIRI will be able to detect gas giant planets with a broad range of characteristics. In Figure 11, we show the MIRI detection limit, for a range of extrasolar giant planet spectra computed by France Allard.

ExoPTF Whitepaper Coronagraphic Detection of Exosolar Planets with JWST

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Additional info

JWST primer: ww.stsci.edu/jwst/externaldocs/technicalreports/JWST-STScI-000930.pdf

JWST Science White Papers: www.stsci.edu/jwst/science/whitepapers/
Clampin et al. 2007 Coronagraphic Detection of Exosolar Planets with the James Webb Space Telescope
Clampin et al. 2007 Detection of Planetary Transits with the James Webb Space Telescope
Seager et al. 2004 A report to NASA recommending addition or optimization of the James Webb Space Telescope capabilities to maximize astrobiology science return.

Astrobiology and the JWST: www.stsci.edu/jwst/science/whitepapers/JWST-astrobio.pdf

Exo-Planet Task Force (ExoPTF) A Strategy for the Detection:
www.nsf.gov/attachments/108113/public/Lunine_ExoPTF_Interim_Report_updated.ppt

MIRI Europe: www.roe.ac.uk/ukatc/consortium/miri/index.html

MIRI USA: http://ircamera.as.arizona.edu/MIRI/page2.htm

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