The MIRI instrument and Exoplanet GTO

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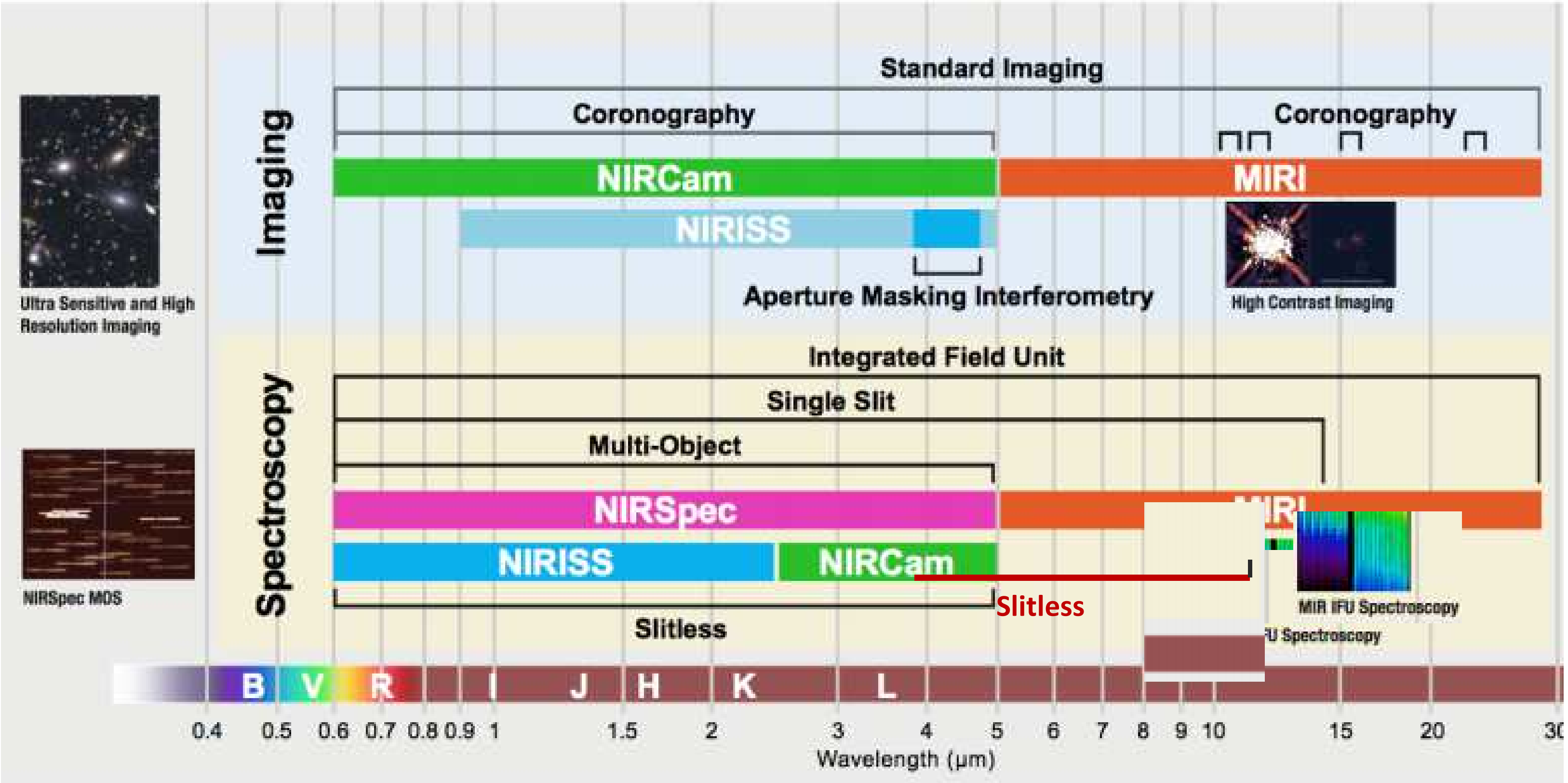
CEA – Saclay
On behalf of the MIRI European Consortium

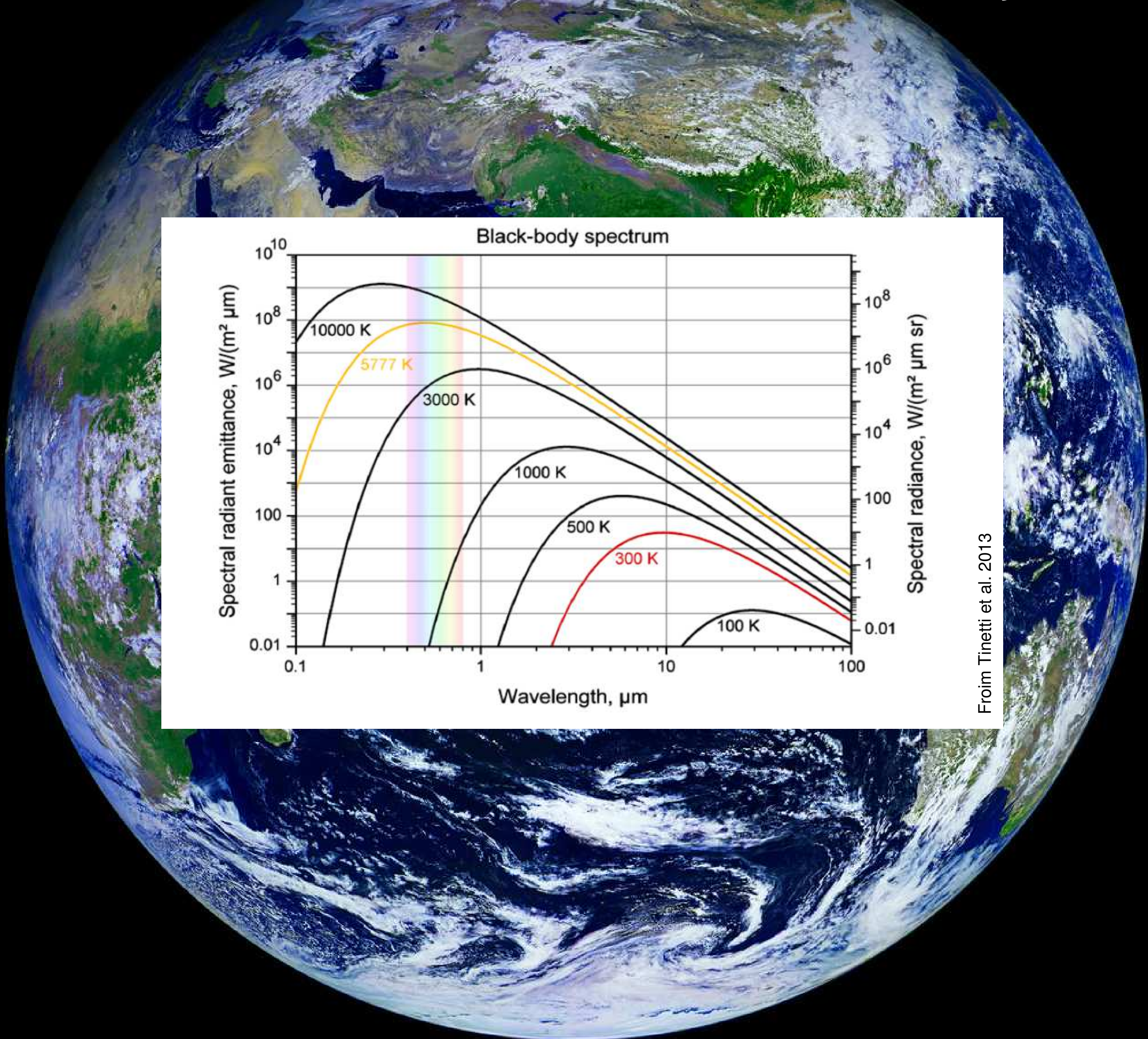
MIRI THE JWST instrument covering the 5 – 28 microns range

MIRI European Consortium



Adapted from STScI

5 – 27 microns → BB peak emission with T 600 K - 165 K.
MIRI best suited to detect the emission of “cool” objects.



Froim Tinetti et al. 2013

Main molecules in exoplanet atmosphere have bands in the Mid-IR

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Molecule	$\Delta\nu = 2B_0$ cm^{-1}	λ (S_{max}) 2–5 μm	S_{max} cm^{-2} am^{-1}	R 2–5 μm	λ (S_{max}) 5–16 μm	S_{max} cm^{-2} am^{-1}	R 5–16 μm
H_2O	29.0	2.69 (ν_1, ν_3)	200	130	6.27 (ν_2)	250	55
HDO	18.2	3.67 ($\nu_1, 2\nu_2$)	270	150	7.13 (ν_2)		77
CH_4	10.0	3.31 (ν_3)	300	300	7.66 (ν_4)	140	130
CH_3D	7.8	4.54 (ν_2)	25	280	8.66 (ν_6)	119	150
NH_3	20.0	2.90 (ν_3)	13	170	10.33	600	50
		3.00 (ν_1)	20		10.72 (ν_2)		
PH_3	8.9	4.30 (ν_1, ν_3)	520	260	8.94 (ν_4)	102	126
					10.08 (ν_2)	82	110
CO	3.8	4.67 (1-0)	241	565			
CO_2	1.6	4.25 (ν_1)	4100	1470	14.99 (ν_2)	220	420
HCN	3.0	3.02 (ν_3)	240	1100	14.04 (ν_2)	204	240
C_2H_2	2.3	3.03 (ν_3)	105	1435	13.7 (ν_5)	582	320
C_2H_6	1.3	3.35 (ν_7)	538	2300	12.16 (ν_{12})	36	635
O_3	0.9				9.60 (ν_3)	348	1160

Table 5 Main molecular signatures and constraints on the spectral resolving power. $\Delta\nu$ is the spectral interval between two adjacent J-components of a band. S_{max} is the intensity of the strongest band available in the spectral interval. R is the spectral resolving power required to separate two adjacent J-components

From Tinetti et al. AAR 2013

Another interesting specificity of the mid-IR domain: silicate dust feature

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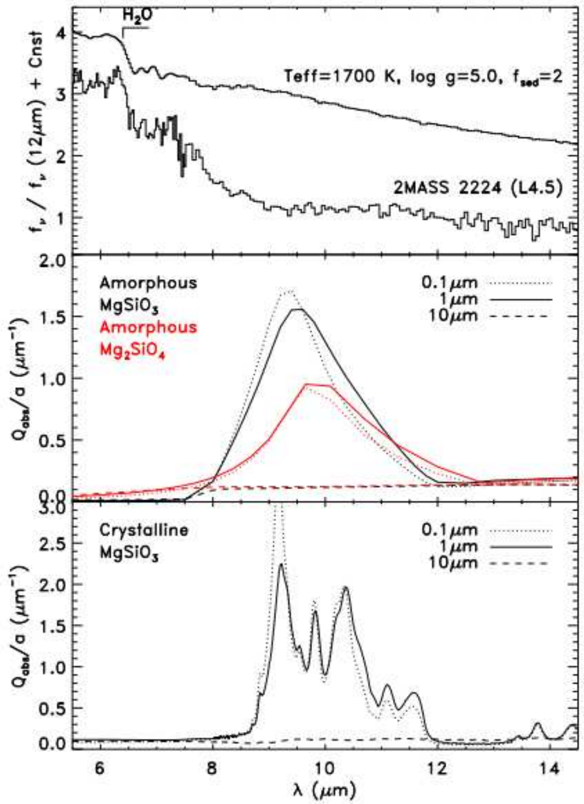


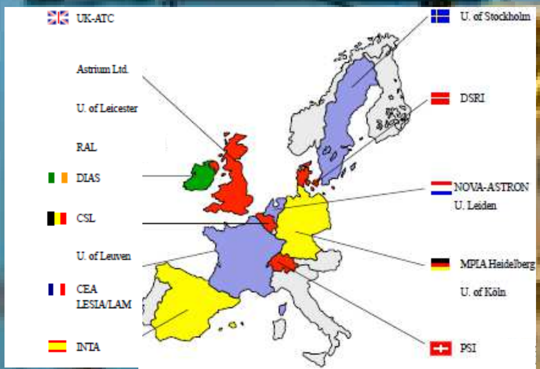
FIG. 9.— *Top*: Spectrum of 2MASS 2224 (L4.5) and a model (T_{eff}=1900 K, log g=5.0, f_{sed}=2) appropriate for an L4.5 dwarf from M.S. Marley et al. (in preparation). *Middle*: Optical absorption (Q_{abs}/a) for amorphous enstatite ($MgSiO_3$; black) and forsterite (Mg_2SiO_4; red) for three different particle sizes 0.1 μm (*dotted lines*), 1 μm (*solid lines*), and 10 μm (*dashed lines*). *Bottom*: Optical absorption (Q_{abs}/a) for crystalline enstatite ($MgSiO_3$) for three different particle sizes 0.1 μm (*dotted lines*), 1 μm (*solid lines*), and 10 μm (*dashed lines*).

Tentively used to interpret the plateau observed in some brown dwarfs (Stanimir Metchev et al.)

MIRI : the JWST mid-IR imager and spectrometer

A 50%-50% Europe-US share project
European PI: G. Wright (ATC, UK),
US PI: G. Rieke (Arizona University, US)

Europe:
Opto mechanics + global Integration and tests by a nationally funded consortium of European Institutes



US :
Detector and cryocooler (JPL)
Unlike the other JWST instruments, MIRI has to be cooled to 7K
→ Dedicated cryocooler

Location of MIRI in the telescope focal plane

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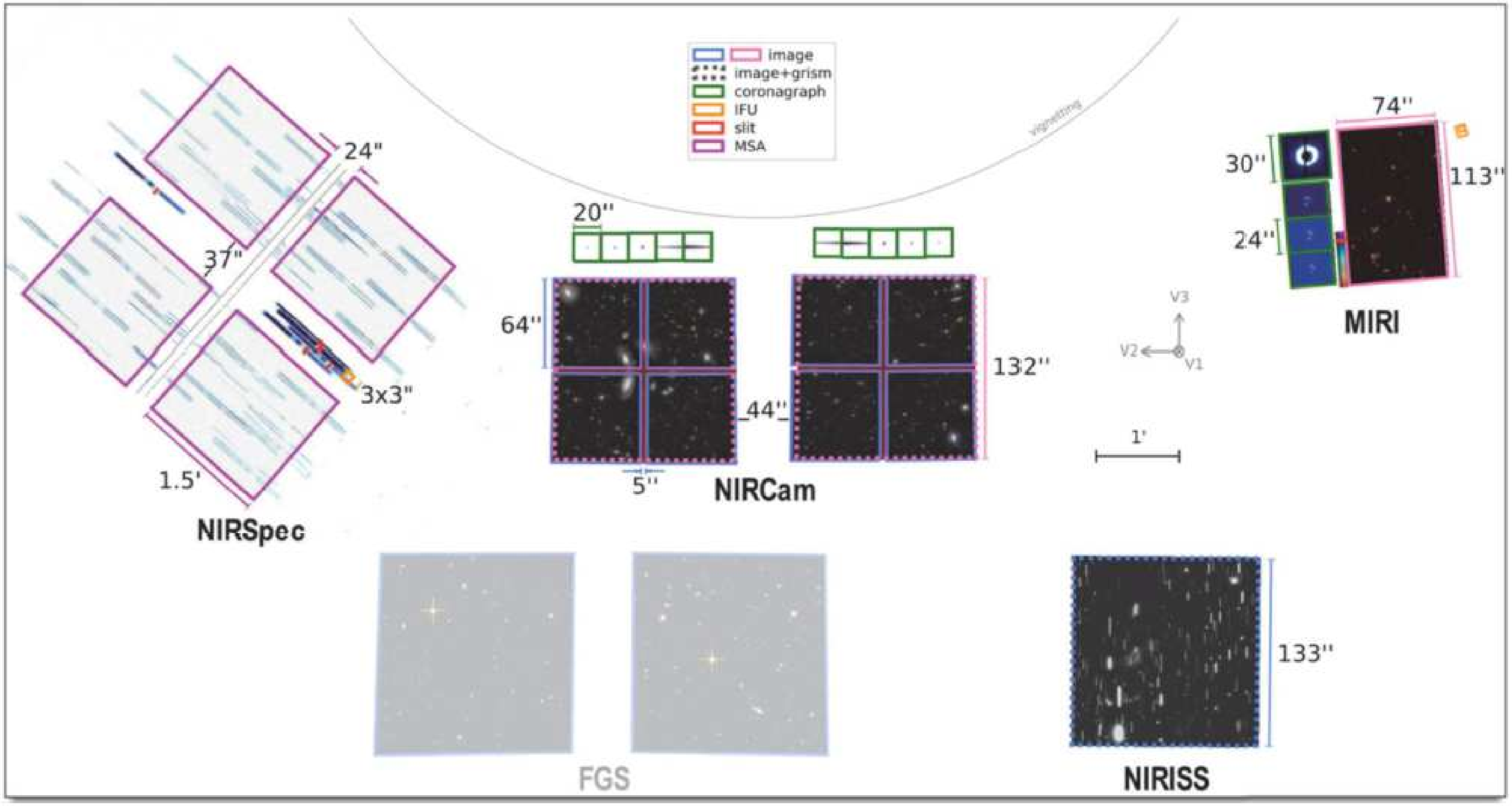

Credit: STScI

MIRI Observing modes

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‘IMAGER’

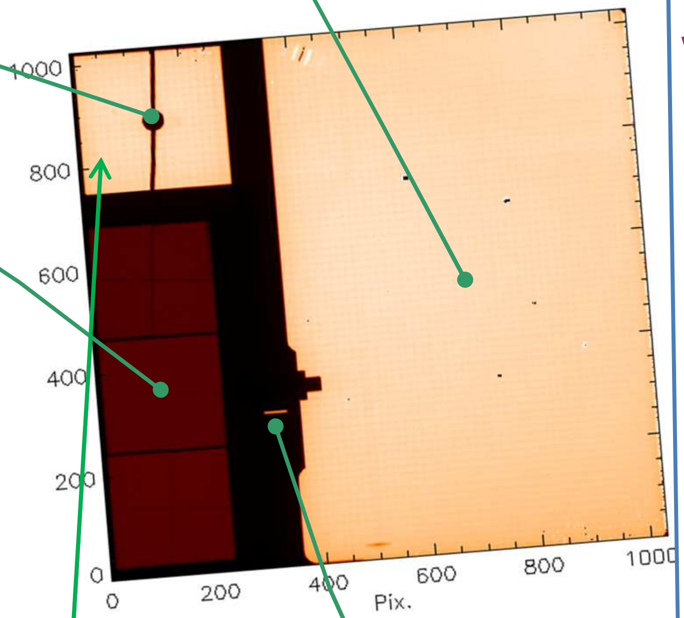
‘SPECTROMETER’

High contrast Imaging
Coronography

Lyot Coronagraphy
Mask 23µm
30 x 30 arcsec²

4QPM Coronagraphy
10.65µm
11.4µm
15.5µm
24 x 24 arcsec²

‘ Normal ‘Imaging
74 x 113 arcsec²



Integral Field
(> 3.5 x 3.5 arcsec²)
Medium Resolution
(about 1000)
Spectroscopy
(MRS)

Slitless	Slit (4.7 x 0.51 arcsec²)
Low Resolution Spectroscopy (LRS)	

All the modes will be used for exoplanets observations in GTO

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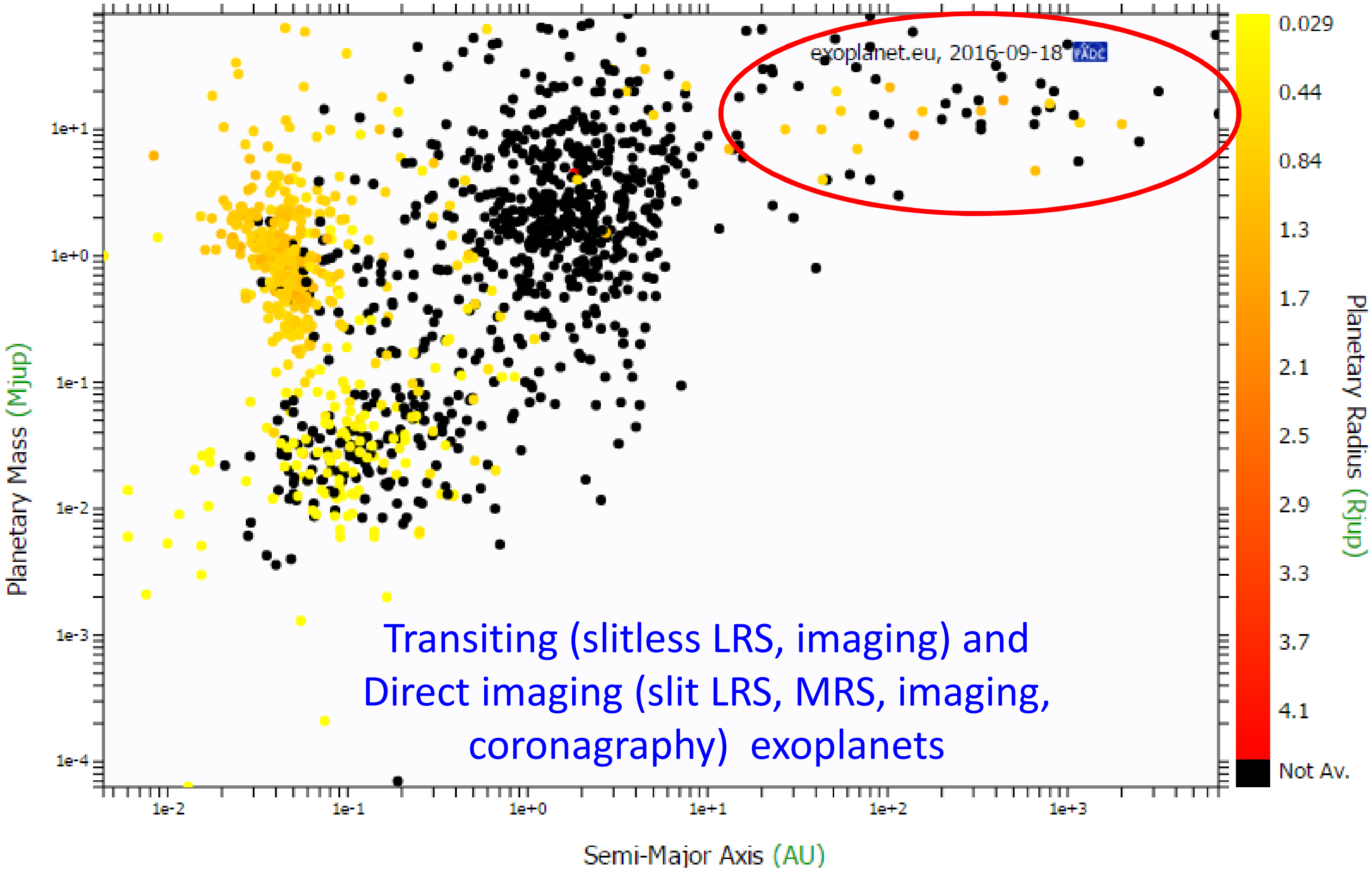
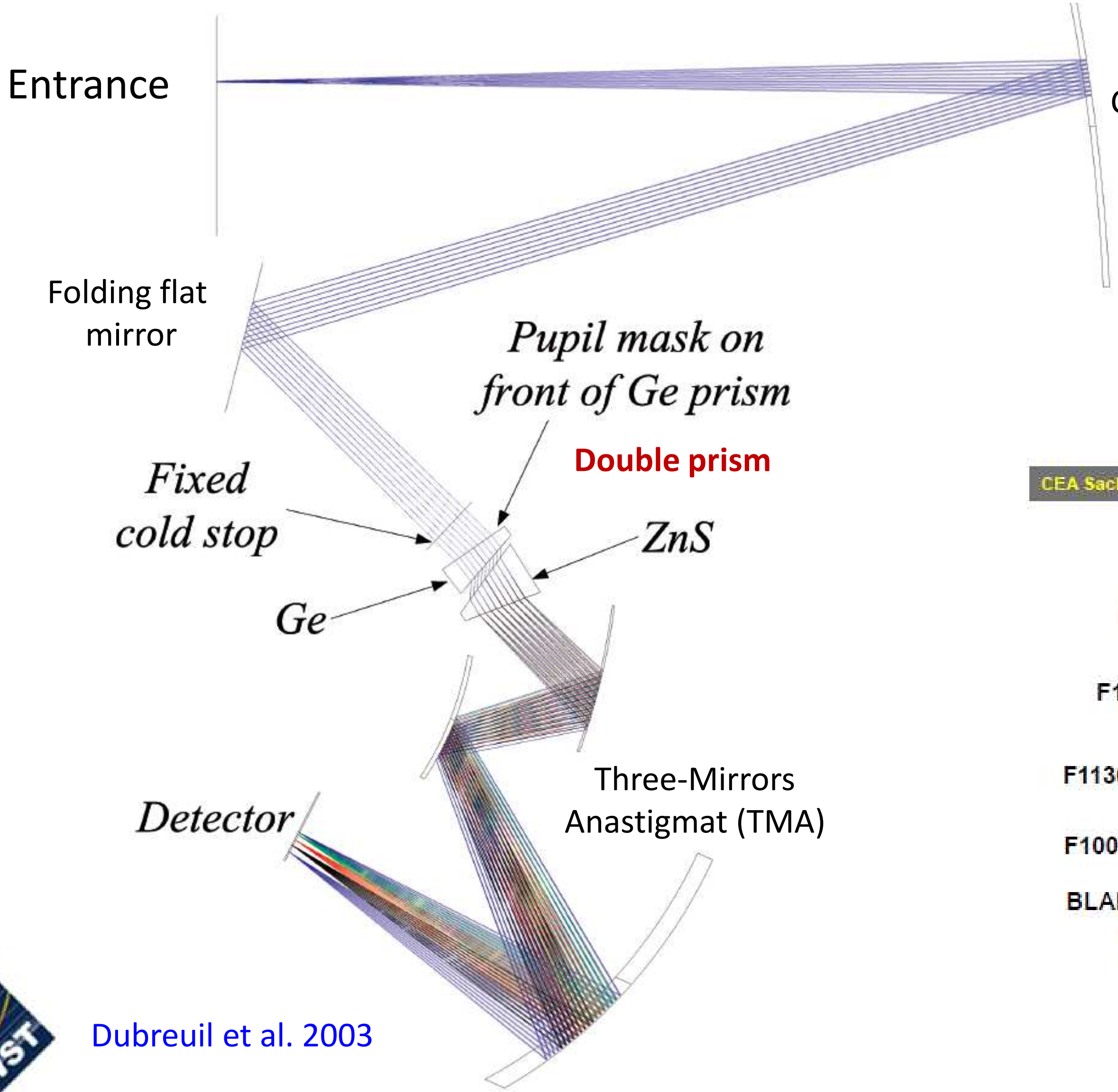


Transiting (slitless LRS, imaging) and Direct imaging (slit LRS, MRS, imaging, coronagraphy) exoplanets

Low Resolution Spectrometer (LRS) : optical design

MIRI European Consortium

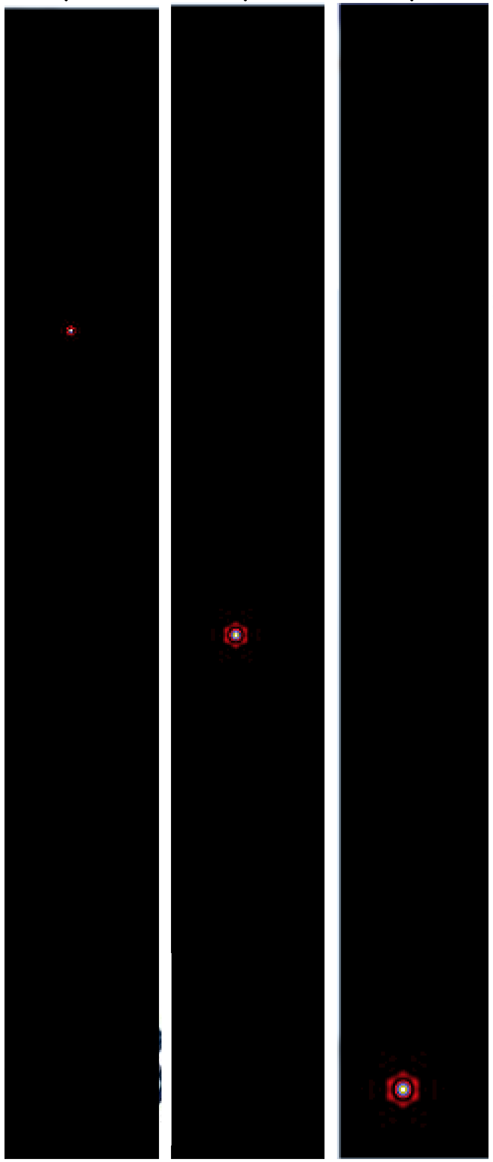


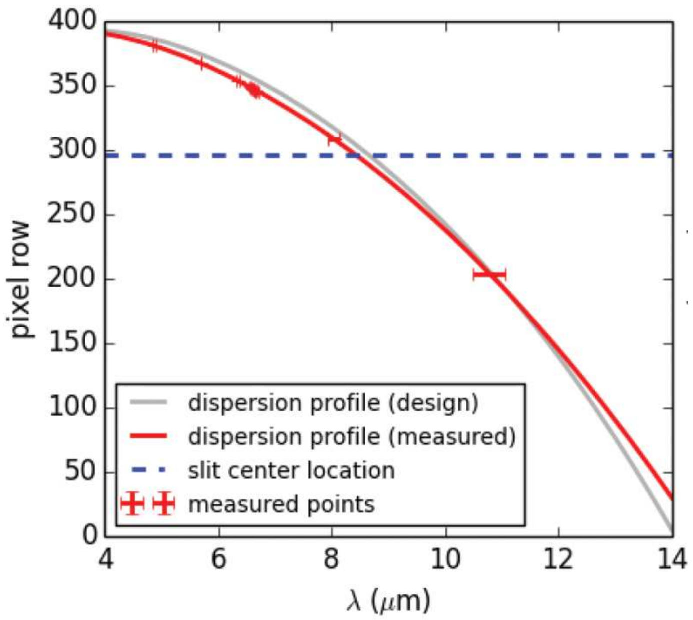
Dubreuil et al. 2003

Only one mechanism for a wheel in the pupil plane

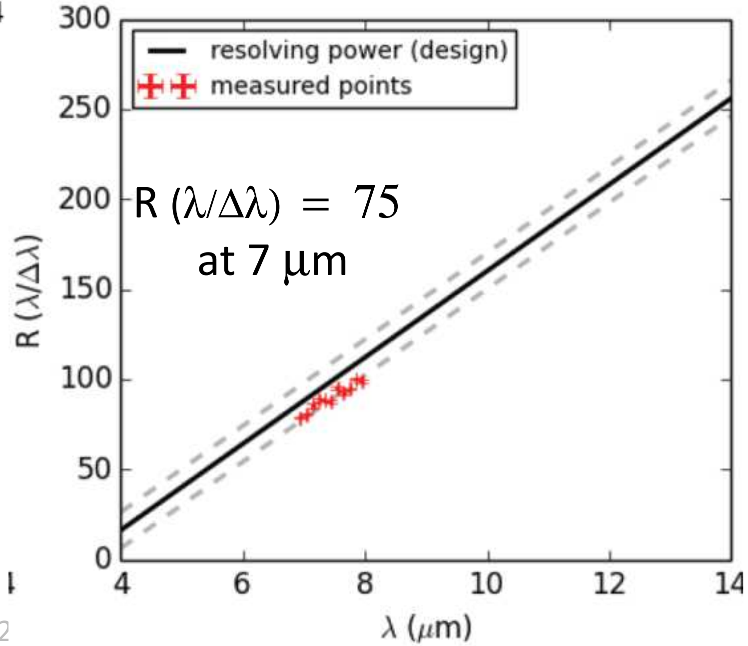
Low Resolution Spectrometer (LRS) : Spectral Resolution

4 µm 10 µm 14 µm





S. Kendrew et al. PASP 2015



Low Resolution Spectrometer (LRS) : Slitless versus Slit

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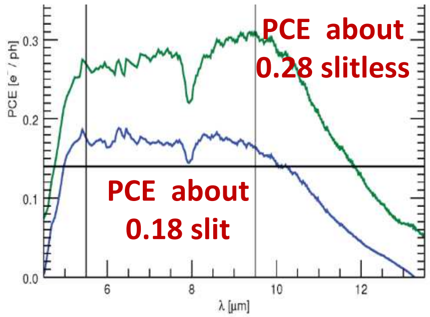
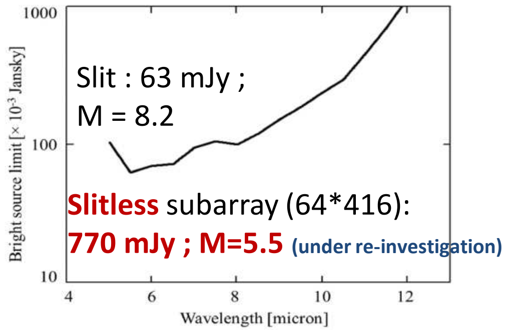
Slitless mode introduced specifically for the observations of transiting exoplanets

Advantages :

Better immunity to photometric variations due to telescope jitter

Better throuput

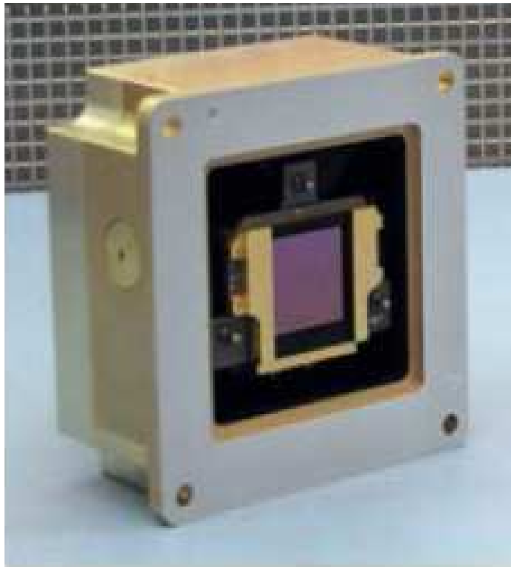




Saturation limit pushed

MIRI detector array properties

The Si:As IBC MIRI focal planes were produced by Raytheon Vision Systems (RVD)



M. Ressler et al. : "The Mid-Infrared Instrument for the JWST : VIII The MIRI Focal Plane System, PASP, 2015

Table 1. Detector Performance Parameters

Parameter	baseline array	contingency array
format	1024 x 1024	1024 x 1024
pixel size	25 μm	25 μm
IR-active layer thickness	35 μm	30 μm
IR layer As doping	7×10^{17} cm^{-3}	5×10^{17} cm^{-3}
read noise*	14 e$^-$	14 e$^-$
dark current	0.2 e$^-$/s	0.07 e$^-$/s
quantum efficiency**	$\geq$ 60%	$\geq$ 50%
nominal detector bias***	2.2V	2.2V
well capacity	$\sim$ 250,000 e$^-$	$\sim$ 250,000 e$^-$

*Fowler-eight sampling, used for comparison purposes; the read-out is normally operated in a sample-up-the-ramp mode.

**At peak wavelength

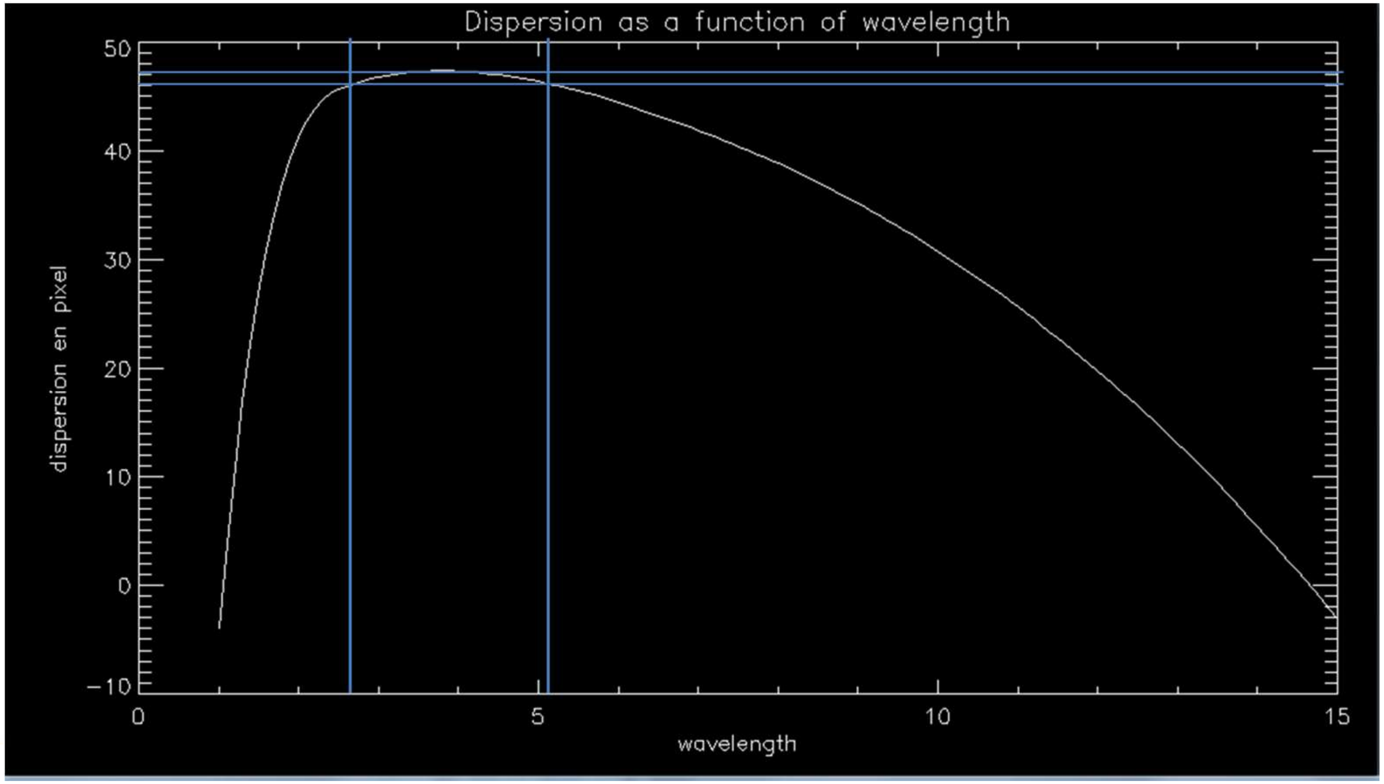
***Consisting of 2 V applied directly plus $\sim$ 0.2 V from clocking signal feedthrough

Low Resolution Spectrometer (LRS) : Slitless versus Slit

A word of caution :

On each wavelength : background integrated over the whole wavelength range

Spectral folding in the 5 – 6 microns spectral range



Difficult observations

Relatively safe down to 100 ppm but aims at going down tp 10 pm

Example of subtil effects : spectrometer franging and jitter (effect below 100 ppm)

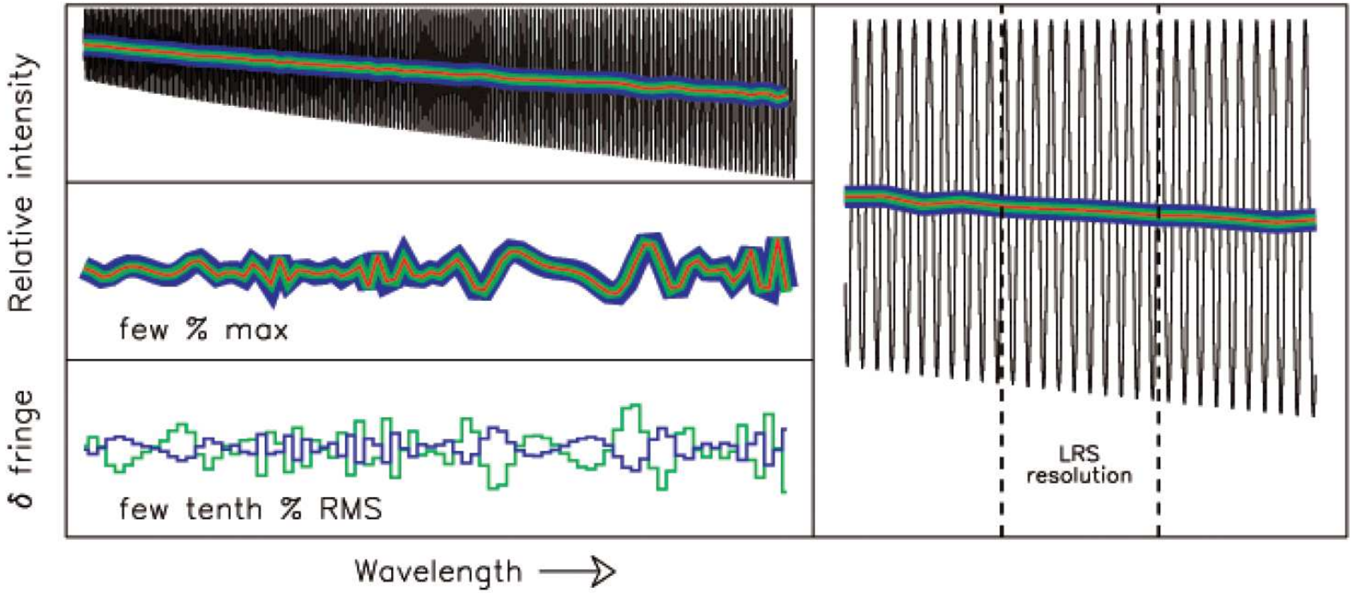


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Fig. 8.— Synthesized LRS fringes over a fraction of the LRS band. Th panel on the right shows a strong zoom-in down to the LRS resolution. Black shows the resolved fringe pattern (based on Integrated Field Unit MRS Short Wave measurements) and the red, green and blue curves show the fringes at LRS resolution for three pointings (red at nominal pointing and blue and green with small sub-pixel offsets). The lower left panel shows the variation in the fringe patterns as a result of small pointing offsets. S. Kendrew et al. PASP 2015

MIRI European Consortium GTO (E-PI G. Wright) : 450 hours

MIRI European Consortium

Three 100 hours class programs

- High Redshift galaxies
- Protoplanetary Disks
- **Exoplanets and Brown dwarfs**

One intermediate size program (in the 50 hours range)

- Protostars and Outflows

Four 10 hours class programs

- Nearby Galaxies
- PDR regions
- Supernovae 1987A
- Solar system

Not attributed yet (for example reserve for other cycles) : about 20 hours

So many targets, which one to choose?

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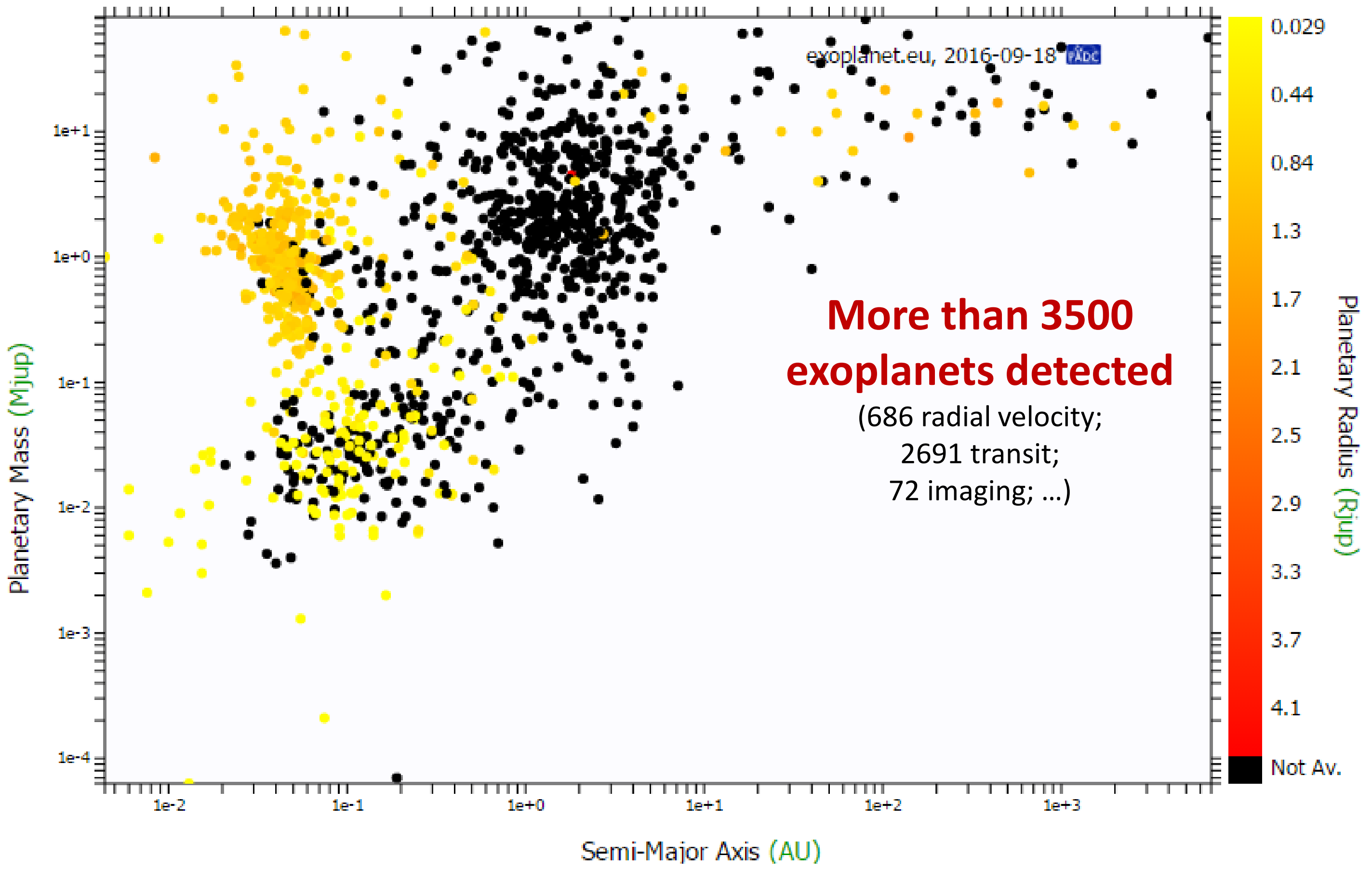
Let's now considering the transiting exoplanets

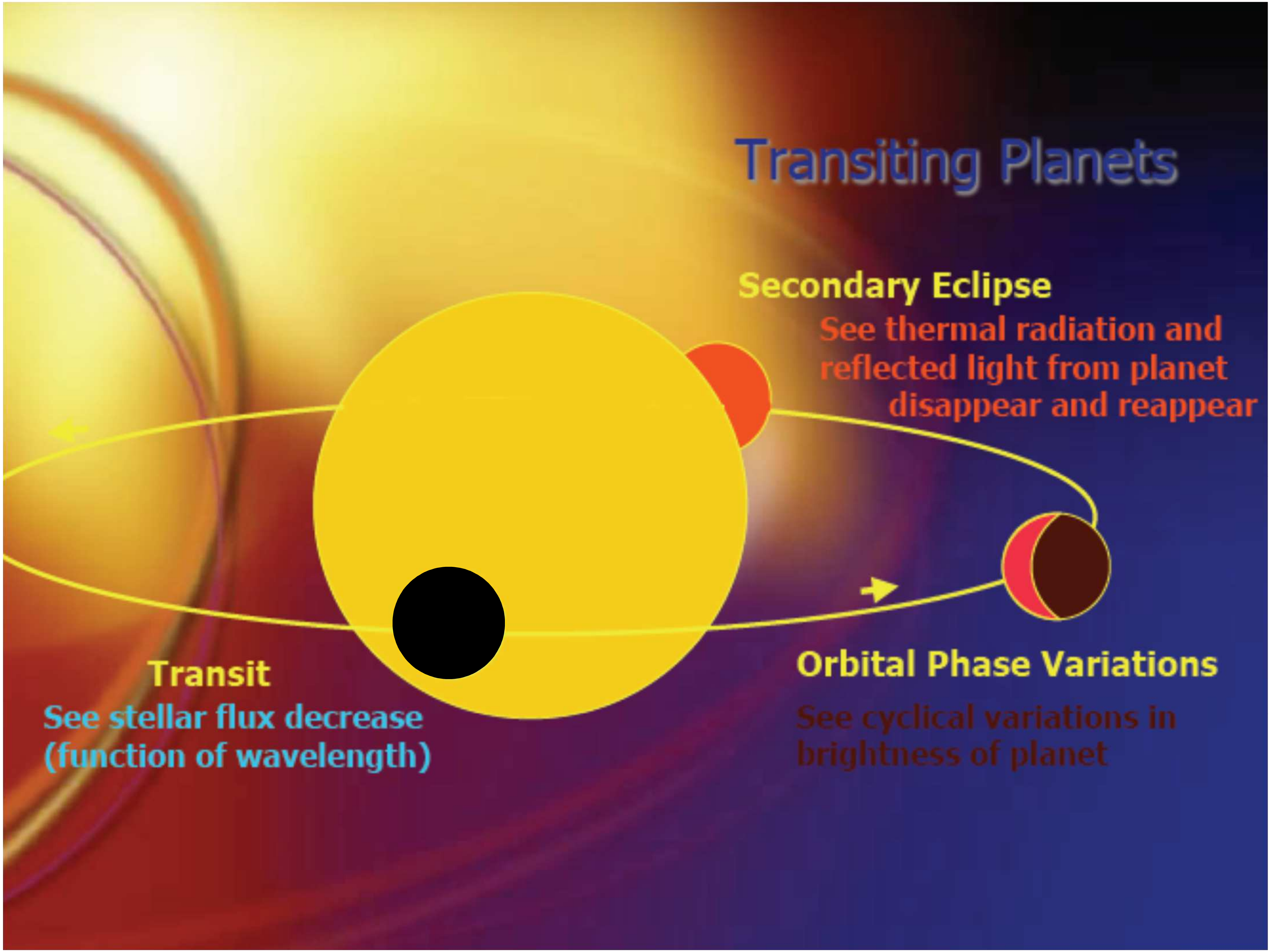


More than 3500 exoplanets detected

(686 radial velocity;
2691 transit;
72 imaging; …)

One key advantage is that we can probe **smaller mass exoplanets**

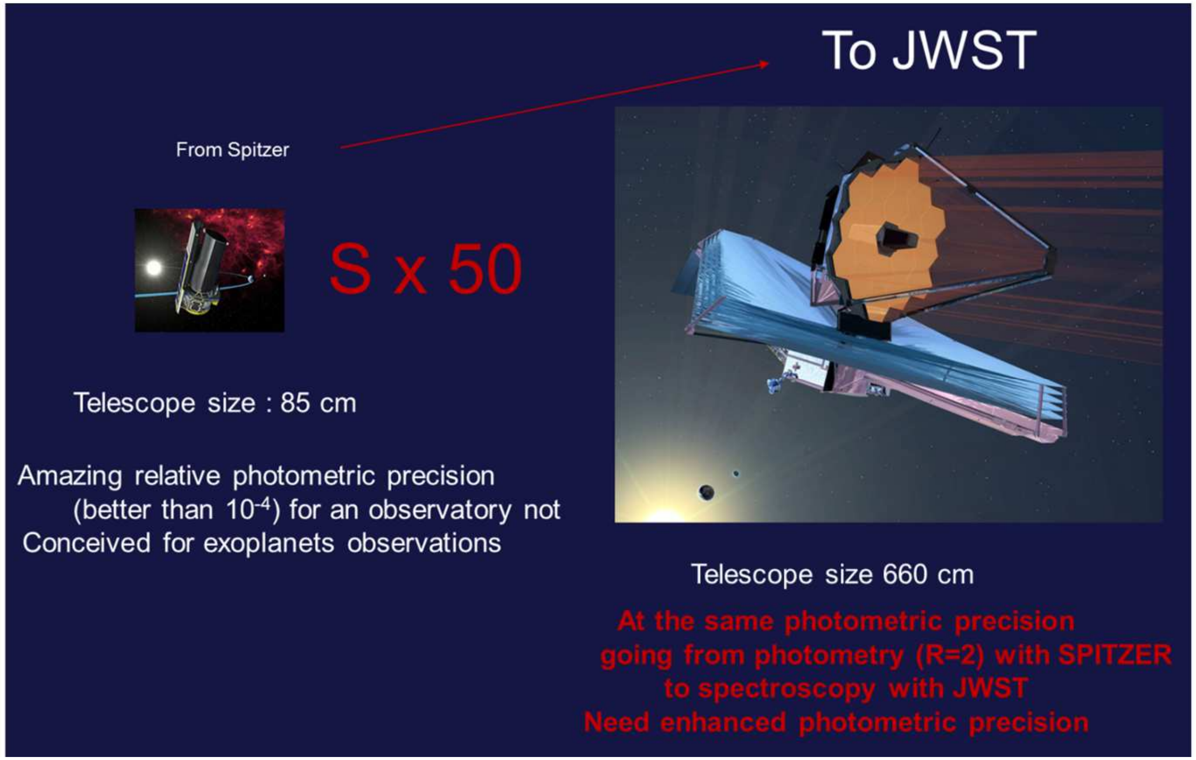
Another advantage is the **knowledge of the radius**


Transiting Planets
Secondary Eclipse
See thermal radiation and reflected light from planet disappear and reappear
Transit
See stellar flux decrease (function of wavelength)
Orbital Phase Variations
See cyclical variations in brightness of planet

Selection sources: Giant exoplanets

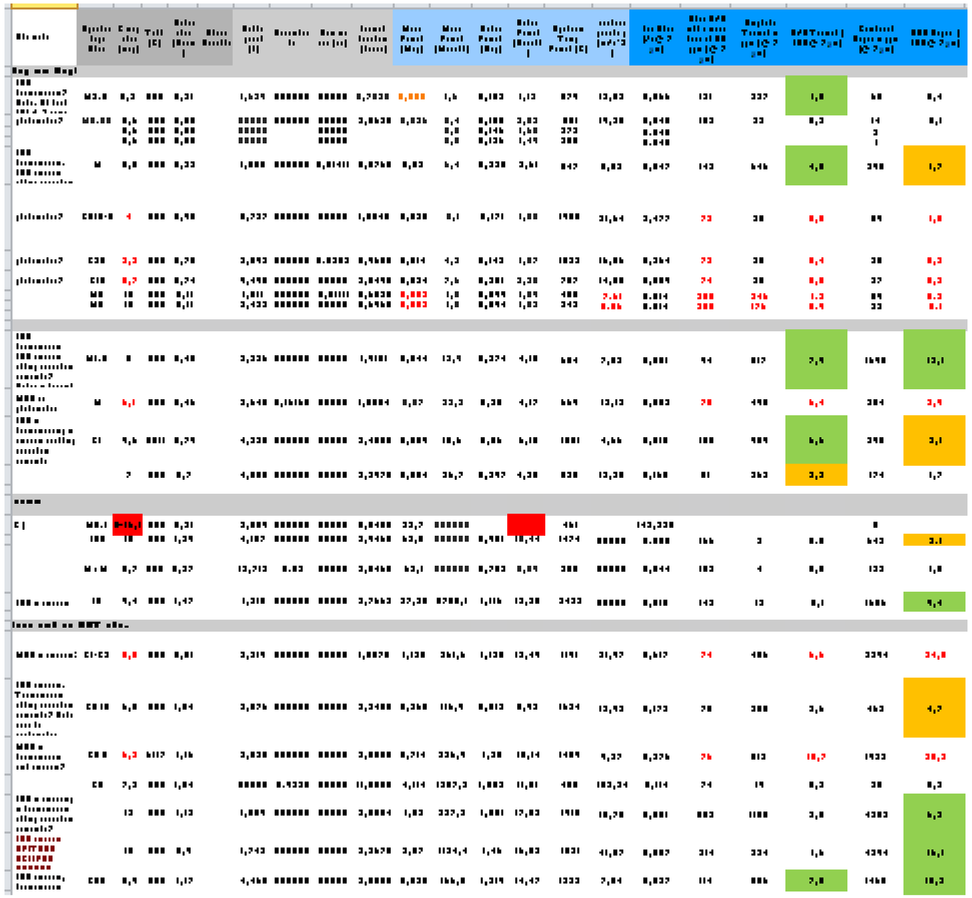
Three criteria:

- detected by SPITZER,
- brightness of the star fainter than a K mag of 7 (for saturation possible issues),
- high Signal over Noise ratio (>5 for LRS) during one transit or eclipse.



Fifty sources met the criteria when observed **in emission**

Among these, a dozen have also a >5 S/N **transmission** spectra in one transit.



Selecting exoplanets with Teff < 1000K

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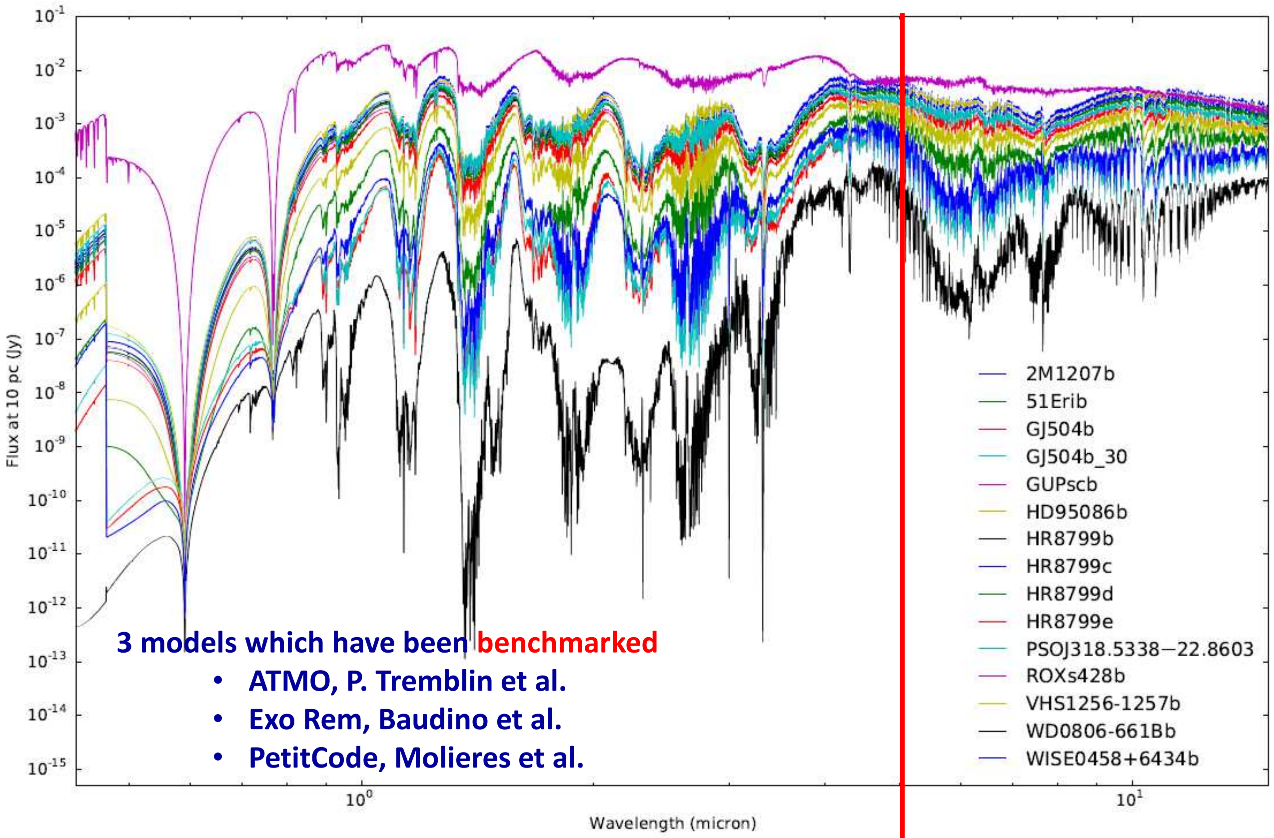

3 models which have been benchmarked

- **ATMO, P. Tremblin et al.**
- **Exo Rem, Baudino et al.**
- **PetitCode, Molieres et al.**

NIRSPEC | MIRI

Important to have a broad wavelength coverage

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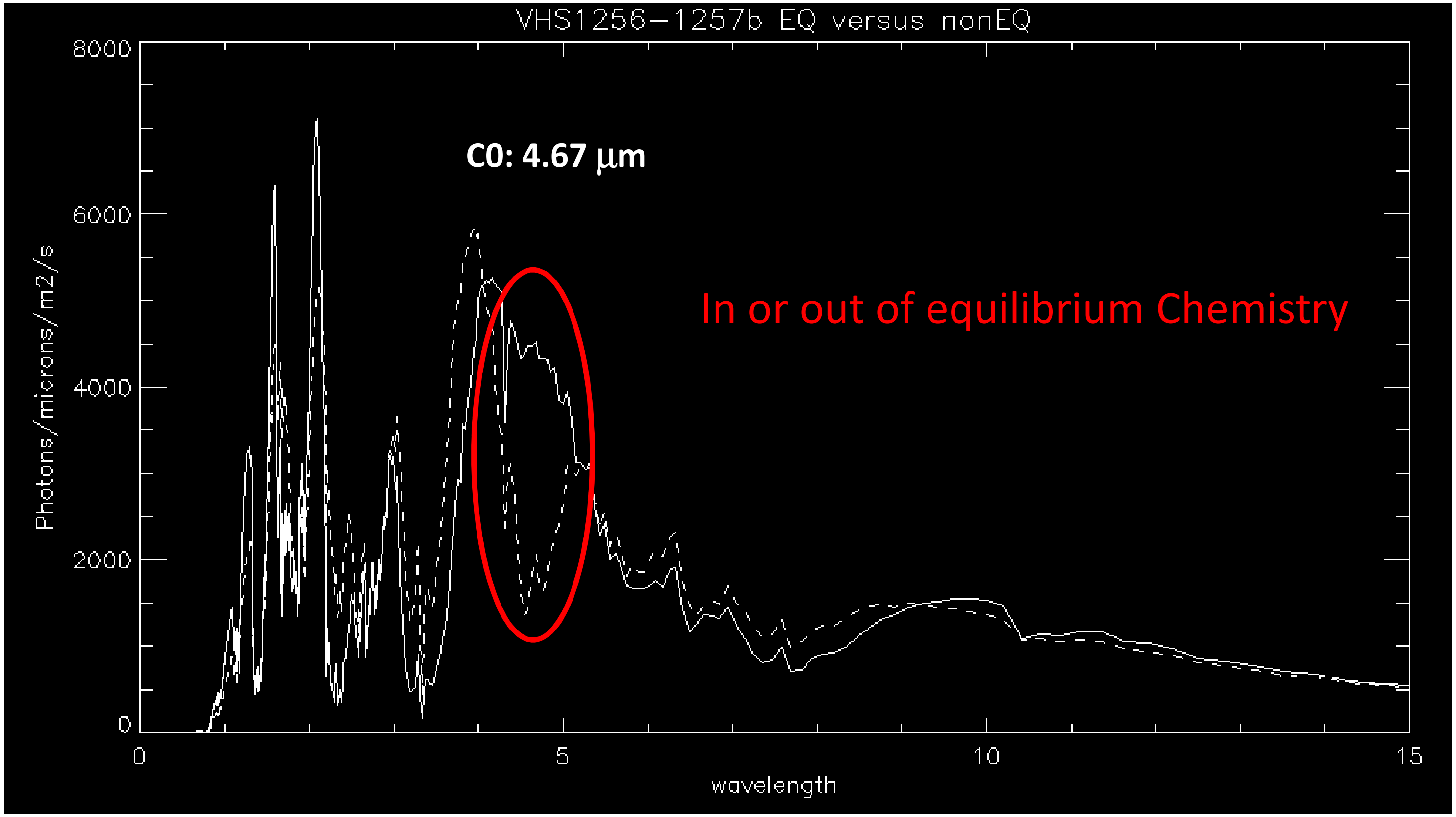
An example:



→ **Observe a limited number of targets but with full wavelength coverage**

We end up with 9 targets :

6 giant exoplanets

HAT-P-12 b, HAT-P-19 b, WASP-80 b, HAT-P-20 b, WASP-10 b, WASP-8-b

with masses ranging from 0.21 to 3.1 Jupiter mass and a log g from 2.6 to 4.

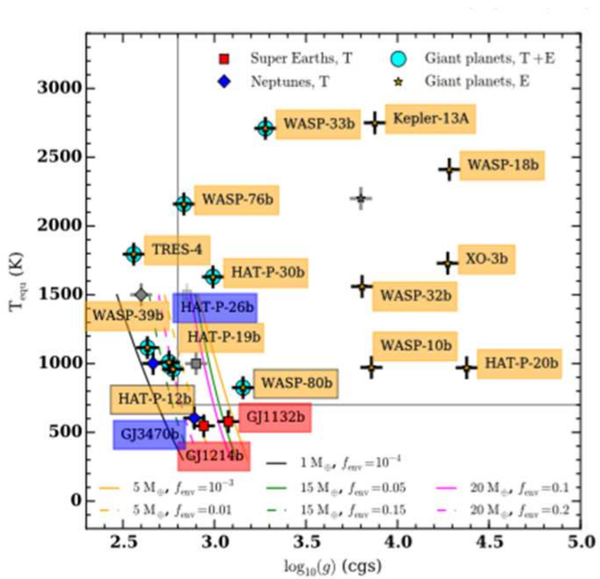
And 2 Neptune mass

HAT-P-26 b, GJ 3470b

+ recently **WASP 107 b** (740 K)

mass : 38 Earth masses

(intermediate Giant, Neptune mass)



Paul Mollière et al. ApJ

Imaging observations for Super-Earth and Earth mass planets

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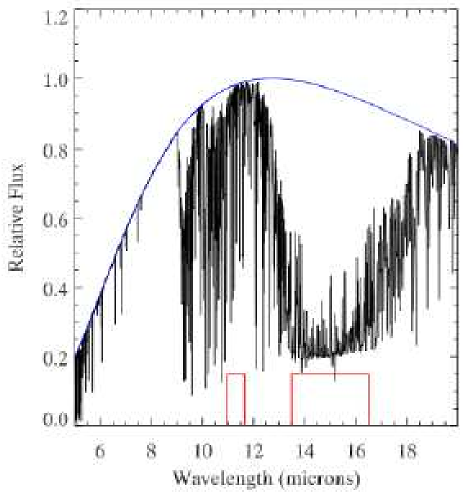

Deming et al. 2009

Feasible for GJ 1214 b

S/N of about 10 (BB) in 1 eclipse

for filters F1130W to F2550W

For **GJ 1132 b**

S/N of about 3 (BB) in 1 eclipse

Filter name (and wavelength)	Pass band Δλ (μm)
F560W	1.2
F770W	2.2
F1000W	2.0
F1130W	0.7
F1280W	2.4
F1500W	3.0
F1800W	3.0
F2100W	5.0
F2550W	4.0

But time of the eclipse?

GTO Imaging observations of Trappist 1 b

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Green = to be observed during MIRI-EC GTO	Obs mode	Spectral type Star	K mag star (mag)	Orbital period (d)	Semi mjr axis (au)	transit duration (hours)	Mass Planet (Mjup)	Mass Planet (Mearth)	Radius Planet (Rjup)	Radius Planet (Rearth)	Equilibrium Temp Planet (K)	Star N/S with a noise floor at 50 ppm (@ 7 µm)	Amplitude Transit in ppm (@ 7 µm)	SNR Transit	Contrast Eclipse in ppm (@ 7 mu)	SNR Eclipse
Low mass exoplanets (M <10 Earth masses)																
Proxima b	Filter 18 microns,			1.186				0,0			350					20
Trappist b,c,d	Filter 18 microns,	M8		1.510848		0,7000				0.993	340					1.5

Search for therma emission of Trappist b (400 K) by looking for 5 transits with the 12.80 microns filter

S/B of 5 expected

In coordination with Tom Greene
5 transits with the 15.00 microns filter

Paving the way to detect ozone : SQRT ($N_{eclipses}$ or $N_{transits}$)

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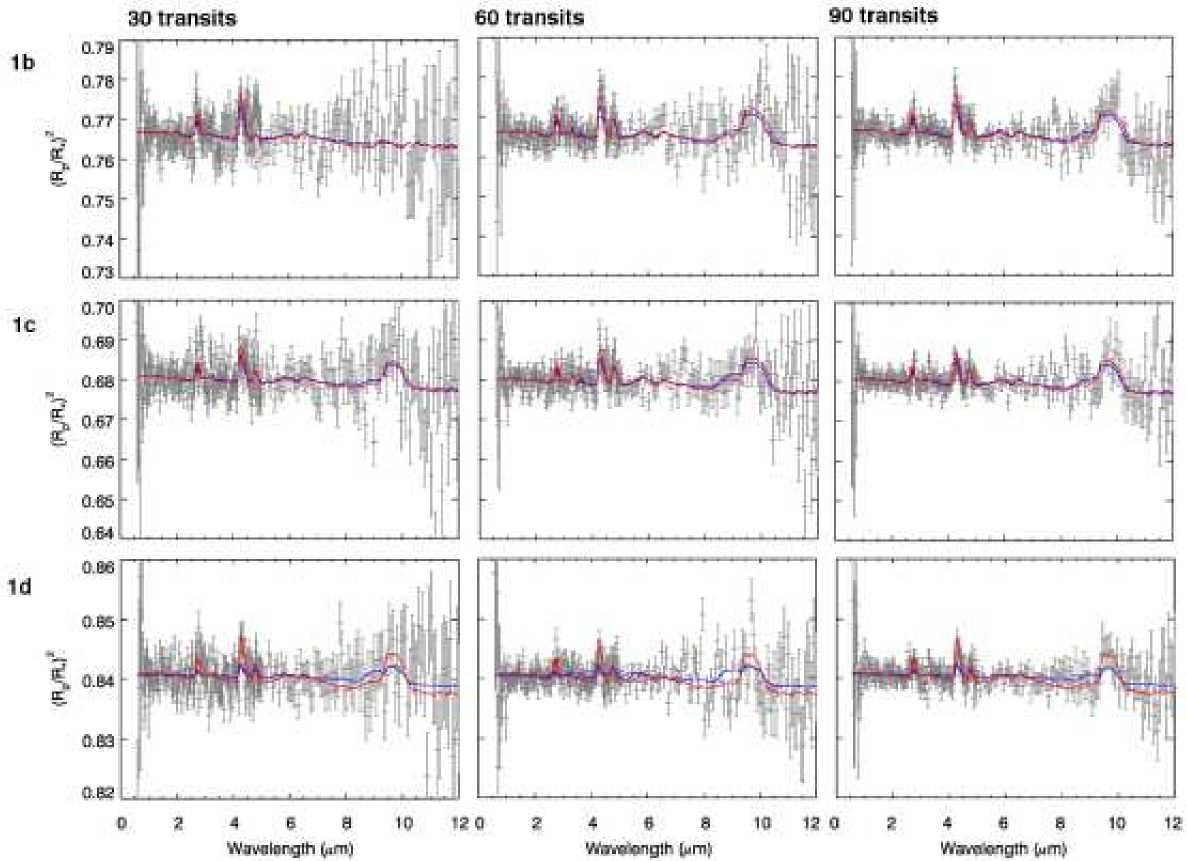
Trappist b, c, d



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[2] Atmospheric, Oceanic and Planetary Physics, Clarendon Laboratory, Department of Physics, University of Oxford, UK

Figure 2. Simulated *JWST* observations of the TRAPPIST-1 planets, assuming 30, 60 and 90 transits are observed. Fits to the synthetic observations are shown for each case in blue (coldest equilibrium temperature) and red (hottest equilibrium temperature). For TRAPPIST 1b, at least 60 transits would be required with each instrument for O_3 to be detected, but for 1c and 1d 30 is sufficient.

Transiting exoplanets: Summary MIRI EC GTO

Giant planet	HAT-P 12	Only 2 spectra in the mid IR obtained with cold Spitzer
Intermediate mass Giant - Neptune	WASP 107 b	Terra quite incognita
Earth mass Planet	Trappist 1 b	Terra incognita

MIRI EC GTO program on exoplanets

Team leader: P.-O. Lagage

Transiting exoplanets

Observation ID number	Target name	Total time charged in h.	Comment/Collaboration
WRIGHT_0039	TRAPPIST-1 b	5,019	Eclipse MIRI filter F1280W
WRIGHT_0040	TRAPPIST-1 b	5,019	Eclipse MIRI filter F1280W
WRIGHT_0041	TRAPPIST-1 b	5,019	Eclipse MIRI filter F1280W
WRIGHT_0042	TRAPPIST-1 b	5,019	Eclipse MIRI filter F1280W
WRIGHT_0043	TRAPPIST-1 b	5,019	Eclipse MIRI filter F1280W
WRIGHT_0044	WASP-107 b	10,05	Transit MIRI LRS
WRIGHT_0045	HAT-P-12 b	8,033	Transit MIRI LRS
WRIGHT_0046	HAT-P-12 b	8,033	Eclipse MIRI LRS
WRIGHT_0047	HAT-P-12 b	8,03	Transit NIRSPEC
WRIGHT_0048	HAT-P-12 b	8,03	Eclipse NIRSPEC
		67,3	

For a transit time of 36 minutes

(slew time, stability detecteur, out of eclipse, 16% overvatory calibration)

MIRI obs Transiting exoplanets: Tom Greene GTO

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HD 189733 b	5.5	1190	12.5	360	1.82	Eclipse	1	NC F322W2	7.8	MIRI
WASP-80b	8.4	850	10.7	180	2.11	Eclipse	1	LRS	8.9	MIRI
WASP-80b	8.4	850	10.7	180	2.11	Transit	1	LRS	8.9	MIRI
HAT-P-19b	10.5	1010	12.7	93	2.84	Eclipse	1	LRS	10.6	MIRI
GJ436b	6.1	700	4.2	22	0.76	Eclipse	2	LRS	11.5	MIRI
HAT-P-26b	9.6	1000	6.2	19	2.46	Transit	1	LRS	9.7	MIRI
TRAPPIST-1b	10.3	400	1.1	0.9	0.61	Eclipse	5	F1500W	26.8	MIRI

60.3 h
+
16.5 h NIRCAM GTO

En combinaison avec NIRCAM GTO observations
for short wavelength coverage

Characterisation of exoplanets detected by direct imaging

MIRI European Consortium

Young (typically a few tens of Million years)
Giant (several Jupiter masses)
→ still in the cooling phase
→ Luminosity can constrain the planet formation theory

At **large distance** from their star →
« uncontaminated » by the physical effects related to the proximity to the host star (high irradiation, tidal effect...)

Not so numerous so far (especially if we limit to those with a « relatively » well known mass lower than about 13 Jupiter masses) : **a dozen**

So far only detected from ground-based observations

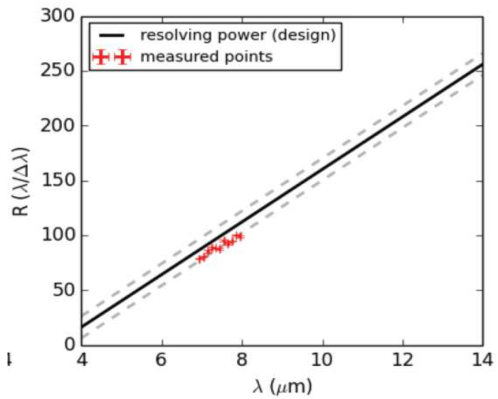
All those detected from the ground (8 m class telescope) can be observed with JWST
→ which will bring the **first ever** observations above 5 microns, and a complete coverage at shorter wavelength (not limited to ground-based atmospheric windows)

MIRI observing modes : II) Spectroscopic modes

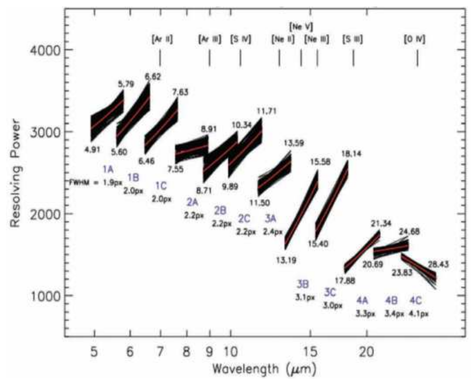
If the angular distance star – exoplanet is large enough (> 2-3 arcsec)
→ spectroscopic observations

either
MIRI Low resolution Spectrometer (LRS)
or bright enough exoplanet
MIRI Medium Resolution Integral field Spectrometrer (MRS)

SLIT (5''*0.5 '')
LOW RESOLUTION SPECTROSCOPY
5-10 (→12) μm



IFU
MEDIUM RESOLUTION SPECTROSCOPY
5-28.5 μm in 3 settings



Taking advantage of the high angular resolution of the JWST (6.5 m)

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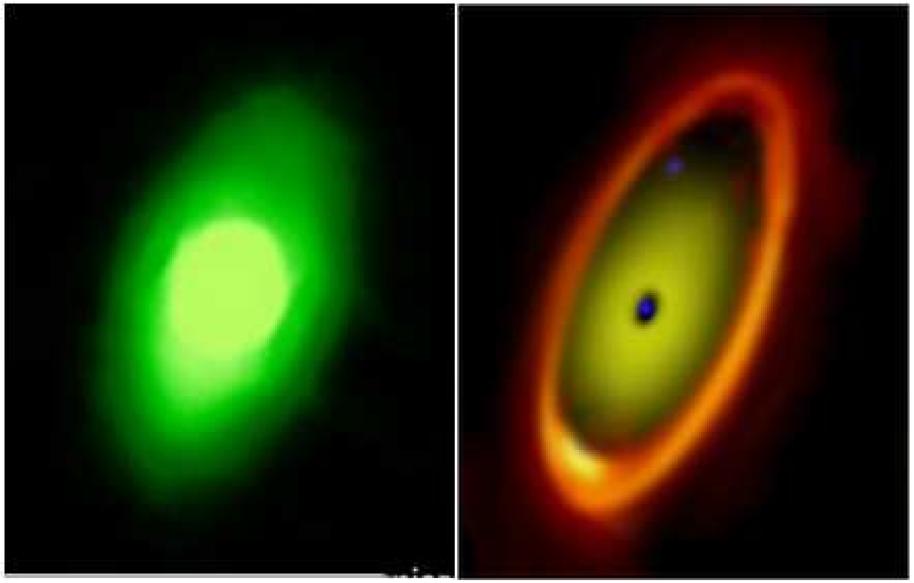
λ/D of 0.3 arcsec at 10microns; PFOV: 0.11 arcsec



For example, the image to the left shows the Spitzer/MIPS image of the debris disk around Fomalhaut at 24 microns, as released in the initial Spitzer press conference, compared with how the system might look to MIRI (right).
(from George Rieke http://ircamera.as.arizona.edu/MIRI/science.htm)

Target list for spectroscopic observations : 7 objects

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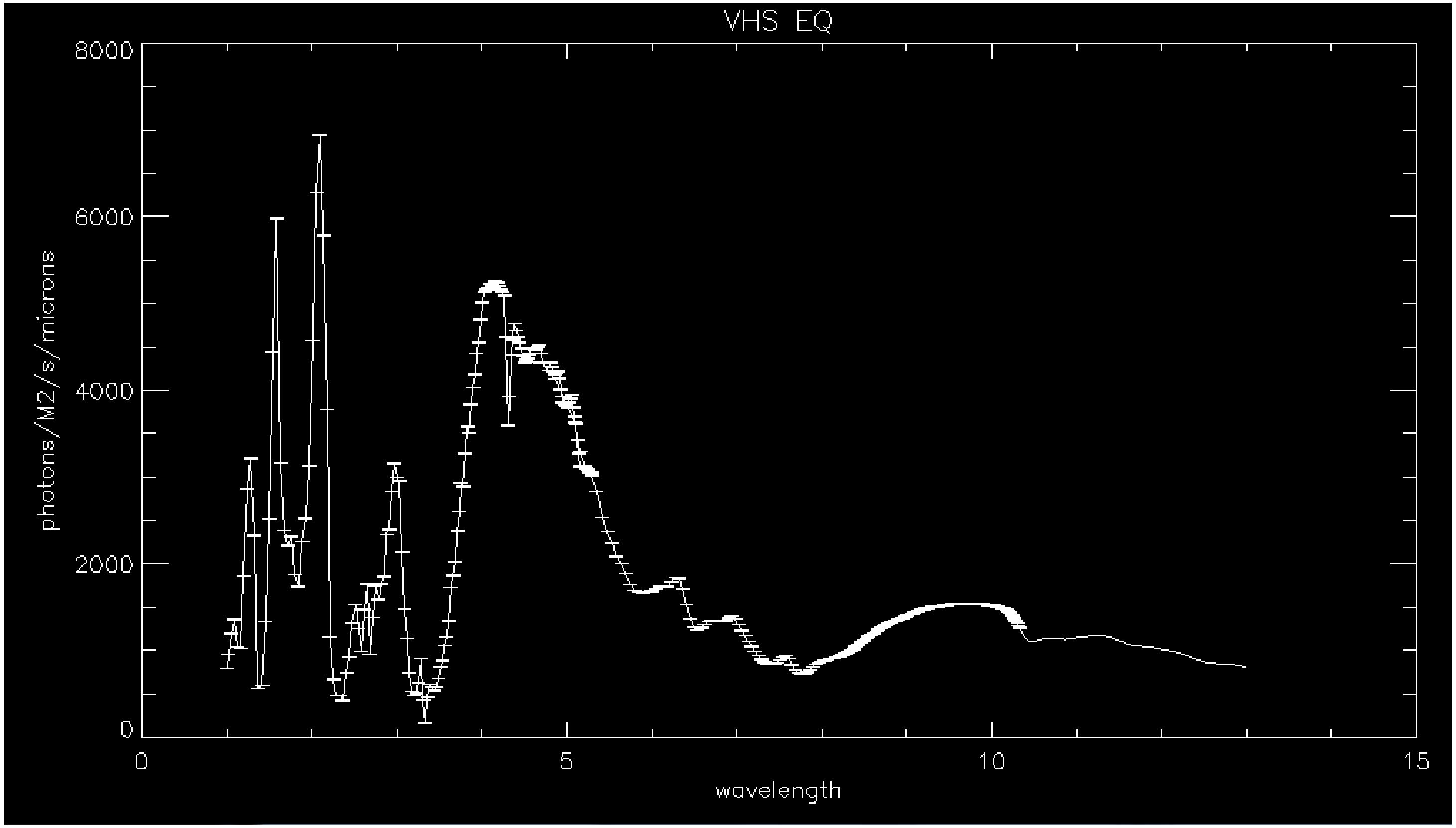
Instrument information		Main pointing information						Exposure information			
Instrument	Mode (Imaging, LRS, MRS, Coronography)	Main coordinates				Target of		Elements			Total Photon Collection time (hrs)
		Target Name or Optional ID	RA (J2000)	DEC (J2000)	Mosaicked or sub-arrayed Area	ToO? Y/N	Disruptive ToO? (Y/N)	Filter (imaging)	Channel (MRS)	Mask (Coronagraphy)	
MIRI	LRS	2MASSW J1207334-393254 b	12 07 33.5000	-39 32 54.40		N	N				0,494
MIRI	Imaging	2MASSW J1207334-393254 b	12 07 33.5000	-39 32 54.40	74"x113"	N	N	F1280W, F1500W, F1000W, F2100W			0,541
MIRI	LRS	2MASS J2236+4751 b	22 36 24.75	47 51 39.7		N	N				0,494
MIRI	MRS	ROSS 458 AB c	13 00 41.73	12 21 14.7		N	N		ALL		1,041
MIRI	LRS	GU Psc b	01 12 35.04	17 03 55.7		N	N				0,494
MIRI	Imaging	GU Psc b	01 12 35.04	17 03 55.7	74"x113"	N	N	F1280W, F1500W, F1000W, F2100W			0,541
MIRI	LRS	WD 0806-661B	08 07 14.675	-66 18 48.68		N	N				3,369
MIRI	Imaging	WD 0806-661B	08 07 14.675	-66 18 48.68	74"x113"	N	N	F1280W, F1500W, F1000W, F2100W			0,541
MIRI	LRS	PSO J318.5338-22.8603	21 14 08.026	-22 51 35.84		N	N				0,494
MIRI	Imaging	PSO J318.5338-22.8603	21 14 08.026	-22 51 35.84	74"x113"	N	N	F1280W, F1500W, F1000W, F2100W			0,541
MIRI	LRS	HD 106906 b	12 17 53.1	-55 58 31		N	N				0,494

Working together with NIRCAM, NIRSPEC to cover MIRI and NIRSPEC wavelengths

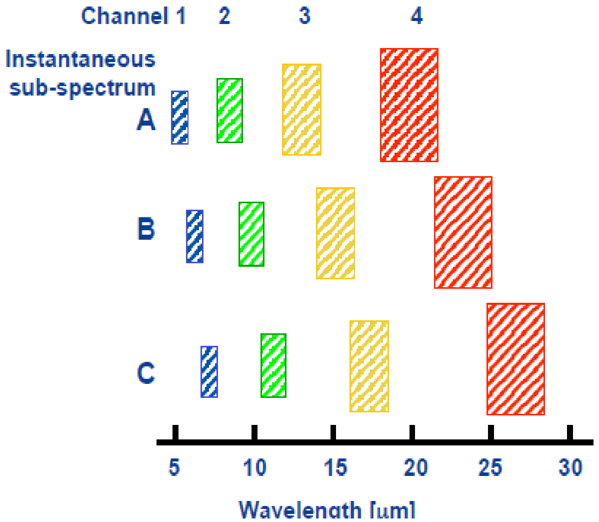
Amazing S/N to be reached



The reason of such S/N compared to transiting observations is that we are not dominated by the photon noise of the star but by the one of the planet

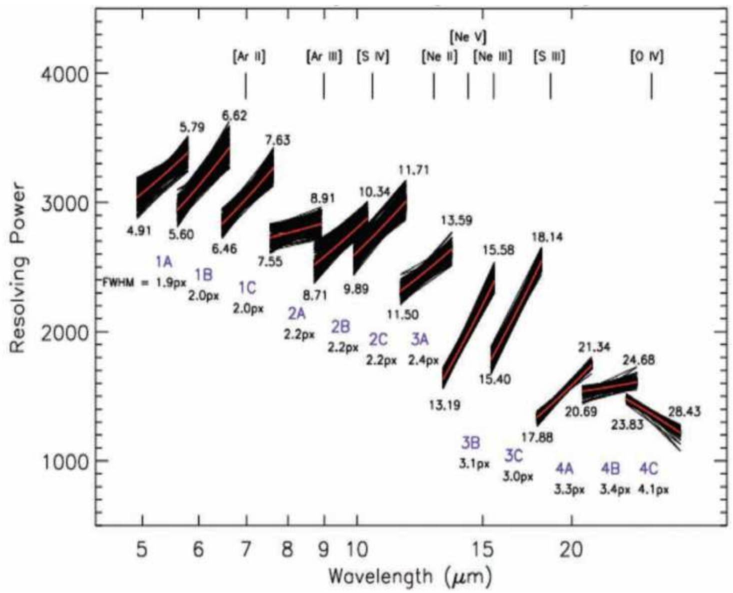
Three settings to get a full MRS spectra

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



Martyn Wells et al. PASP 2015

	Sub-band A			
μm	4.87 - 5.82	7.45 - 8.90	11.47 - 13.67	17.54 - 21.10
$\lambda/\Delta\lambda$	3320 - 3710	2990 - 3110	2530 - 2880	1460 - 1930
	Sub-band B			
μm	5.62 - 6.73	8.61 - 10.28	13.25 - 15.80	20.44 - 24.72
$\lambda/\Delta\lambda$	3190 - 3750	2750 - 3170	1790 - 2640	1680 - 1770
	Sub-band C			
μm	6.49 - 7.76	9.91 - 11.87	15.30 - 18.24	23.84 - 28.82
$\lambda/\Delta\lambda$	3100 - 3610	2860 - 3300	1980 - 2790	1630 - 1330



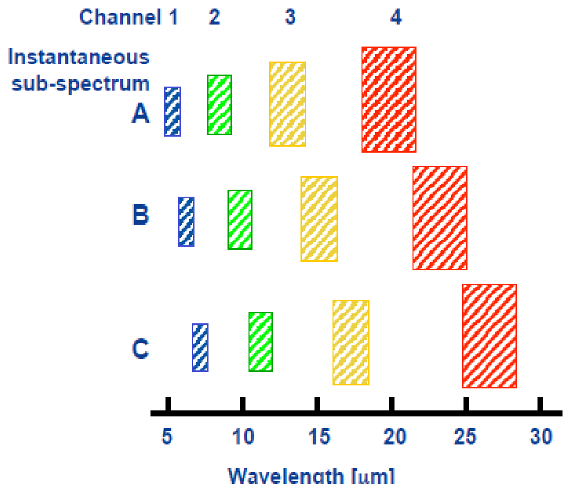
MEDIUM RESOLUTION SPECTROSCOPY

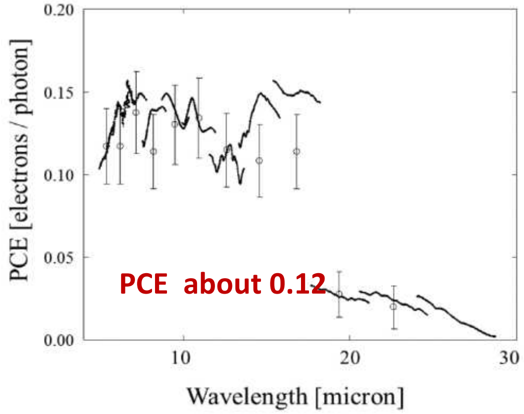
MIRI European Consortium

IFU MEDIUM RESOLUTION SPECTROSCOPY

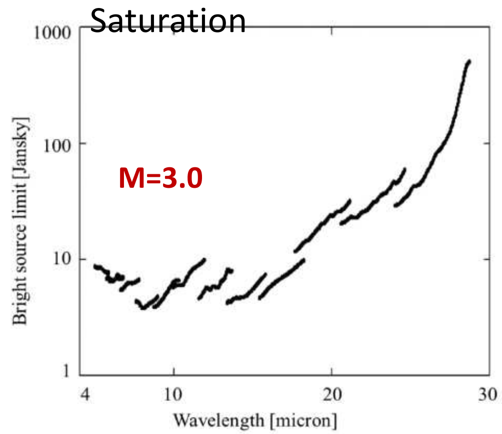
5-28.5 µm in 3 settings

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





For bright objects



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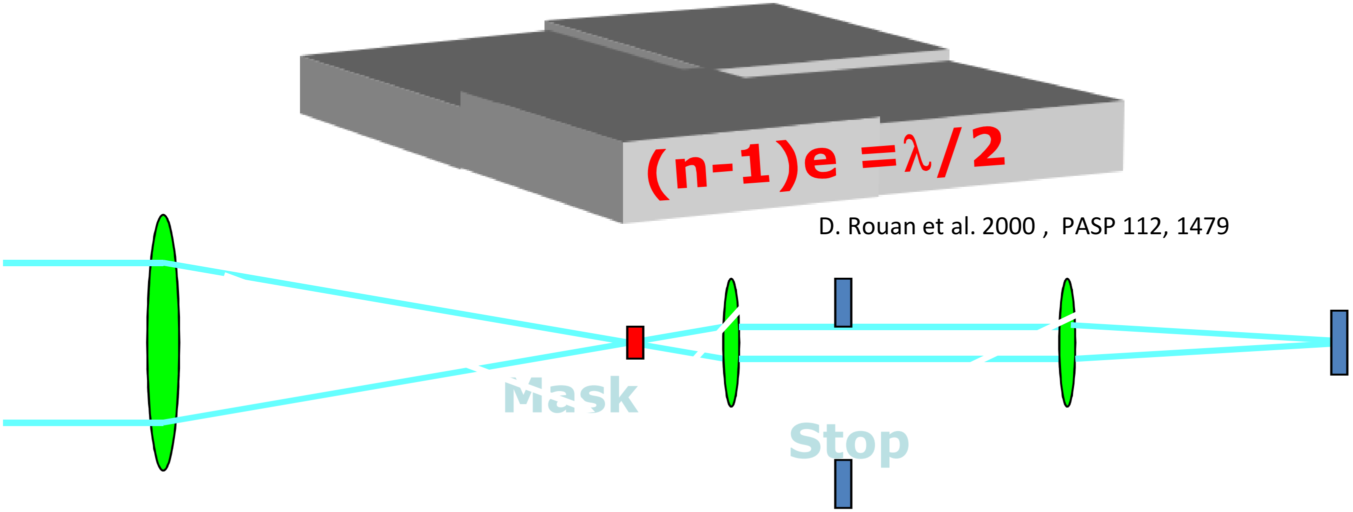
Target list for coronagraphic observations

MIRI European Consortium

Name	mass and incertainty (in Jup mass)	semi_major_axis (AU)	angular_distance (arcsec)	temperature in K	Contrast Planet/star	mag_K star
HR 8799 b	7 (-2/+4)	68	1,7	1000 (+/-100)	mag=8.09; 6x10^{-4}	5.24(+/-0.018)
HR 8799 c	10 (+/-3)	42,9	1,1	1000	Mag=7.97: 6.4 10-4	
HR 8799 d	10 (+/-3)	27	0,7	1000	Mag=8.14; 10-4	
(HR 8799 e)	9	14,5	0,4	1000		
HD95086 b	5 (+/- 2)	55.7	0.6	1050 (+/-450)	1.6x10^{-4}	6.79
~~HD131399 b~~	4 (+/-1)	80	0.83	850 (+/-50)	1x10-4	6.64
GJ 504 b	6 (+/-3) **but may also be 30**	43,5	2,48 en moyenne	544 (+/-10K)	3.6x10^{-3}	4.033
51 Eri b (GTO: G. Serabyn)	2 (+10)	13.2 (+/-0.2)	0,5	700 (+/- 100)	6.5x10^{-5}	4.54
βeta-Pic b; **not observable during 1st cycle with MIRI**	7(+4/-3)	9,2 (+0,4/-1,5)	0,42 max	1700; No NH3 expected; only 2 phase masks	1.4E-3; mag=7.15	3,48

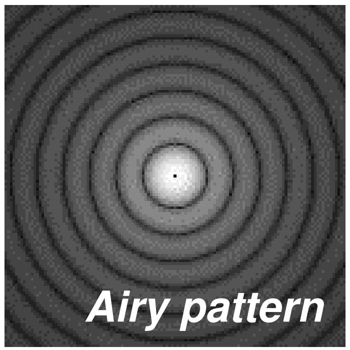
Same list as that of NIRCAM (C. Beichman)

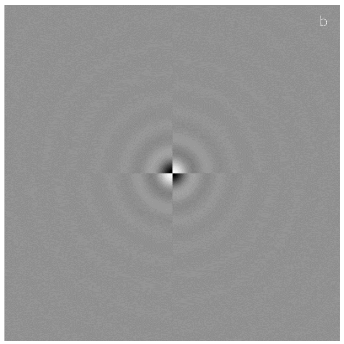
High constrats imaging : Phase mask coronography



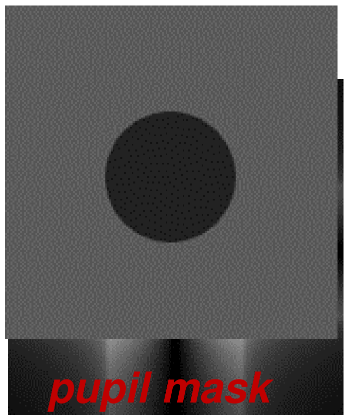
D. Rouan et al. 2000 , PASP 112, 1479

Each quadrant is 90° out-of-phase for interfering with the neighbouring one
➔full attenuation of the central star





focal plan mask



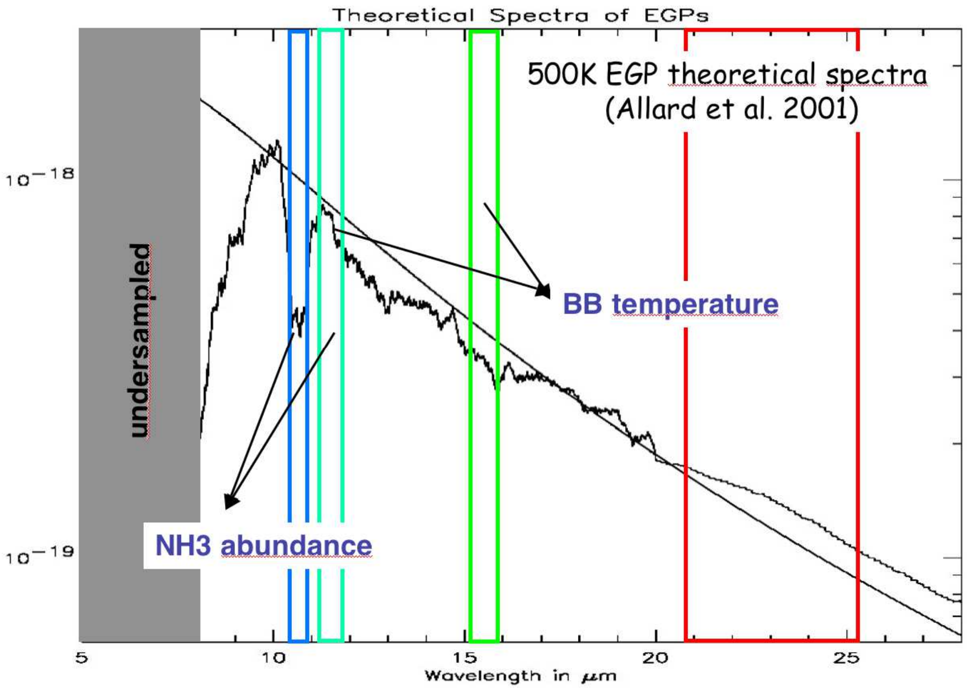
On-axis object is cancelled (for 1 λ)
Stellar residuals = 0

MIRI observing modes : I) Coronography

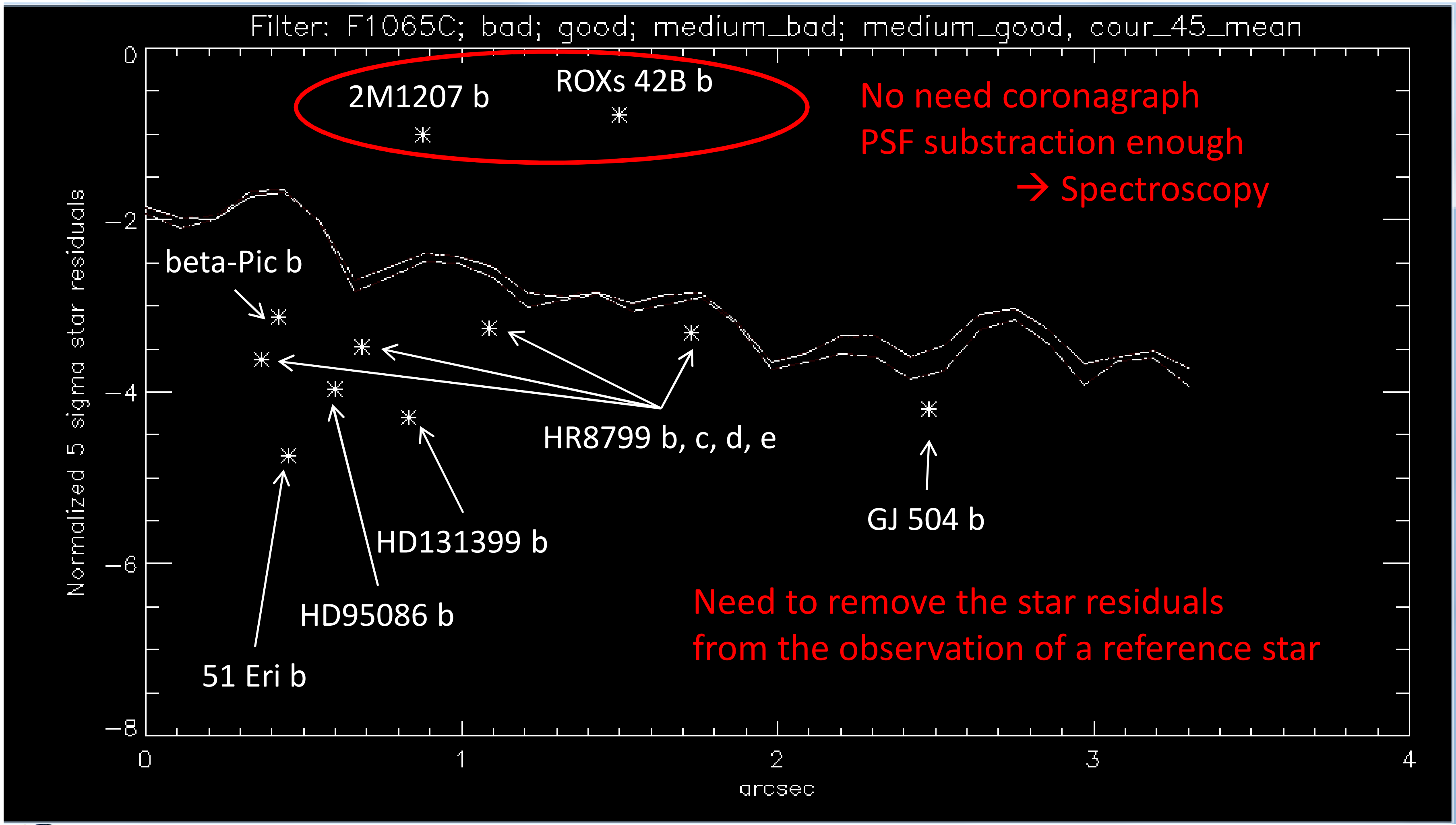
MIRI European Consortium

If the angular distance star – exoplanet is small and the constrast Star/planet large

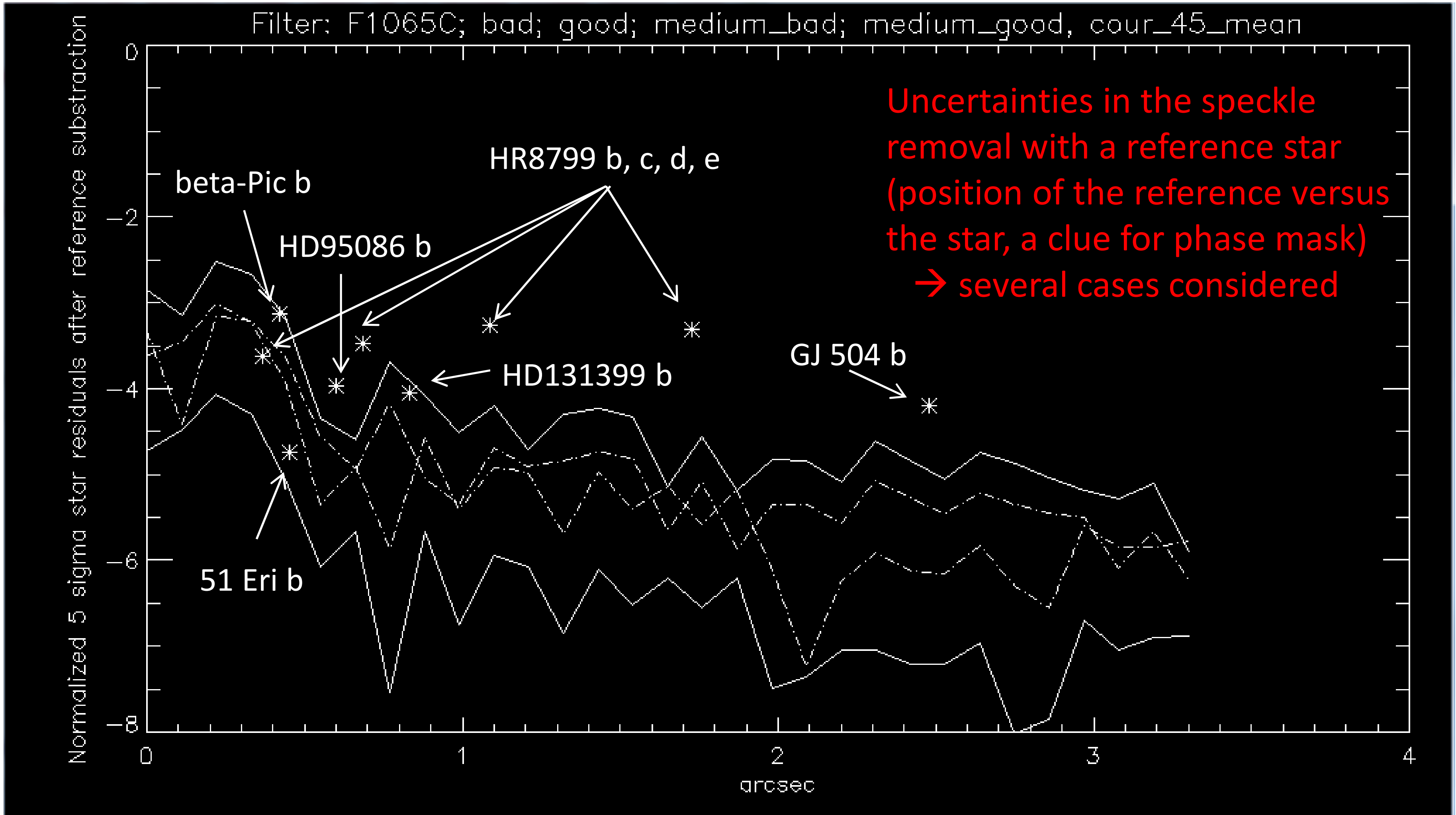
→ coronagraph imaging observations with the 3 phase masks optimized for the detection of the NH_3 feature : 10.65, 11.4, 15.5 μm



MIRI European Consortium

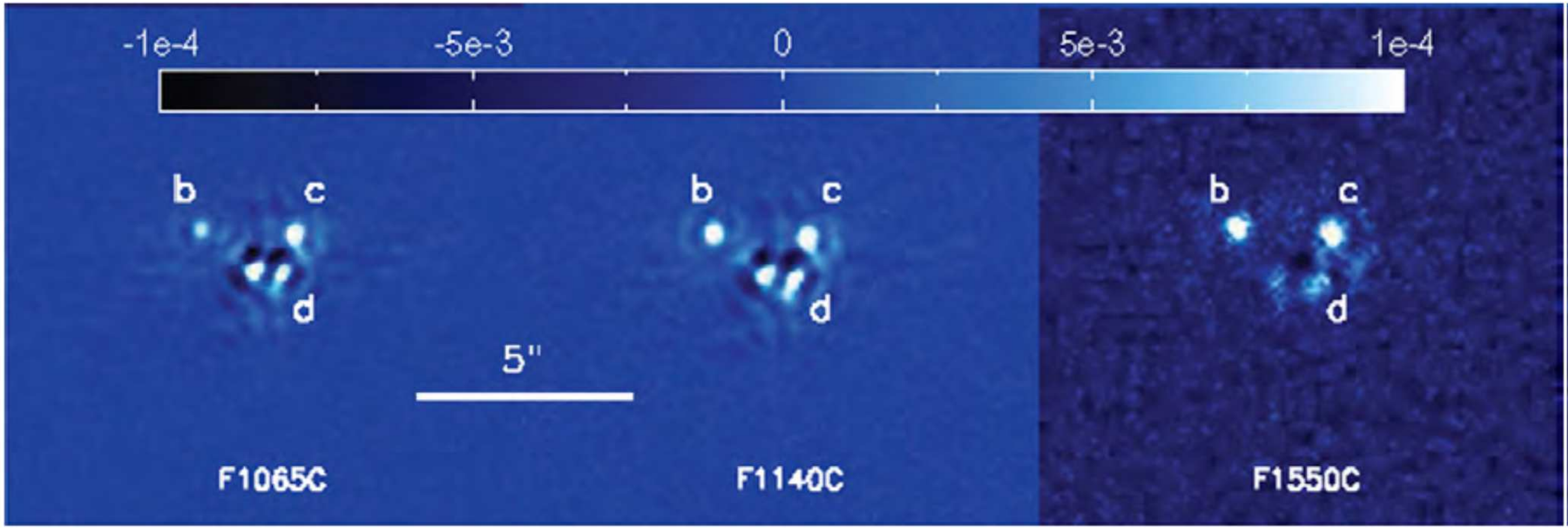


C. Danielski et al. in preparation



C. Danielski et al. in preparation

Simulation of coronagraphic observations of HR 8799 exoplanets

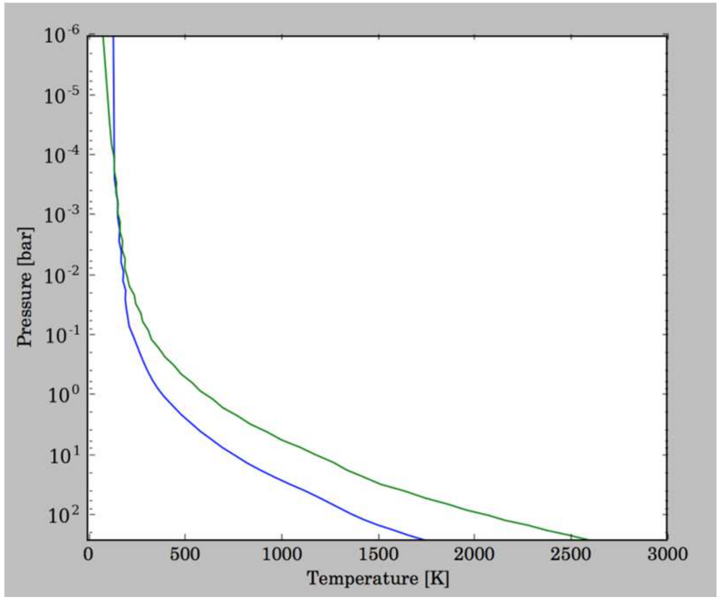


A. Boccaletti et al.

Brown Dwarfs program

Brown dwarfs observations is part of the exoplanet program as we aim at making the link between exoplanets and brown dwarfs

Influence of higher gravity (log(g))
→ different P-T profile; impact on



Lower gravitational settling in the Clouds; turbulence may also develop More efficiently at low gravity.

Green log(g)=4; Blue log(g)=5; Teff=500K.
P. Tremblin, private comunication

Summary GTO Observing plan MIRI

MIRI European Consortium

3 exoplanets (1 giant, 1 Neptune, 1 Earth) in transit (67 hours MIRI EC GTO)
+ 5 exoplanets in transit (77 hours MIRI Tom Greene GTO)
In collaboration with short wavelengths (NIRCAM GTO time; except Trappist 1b)

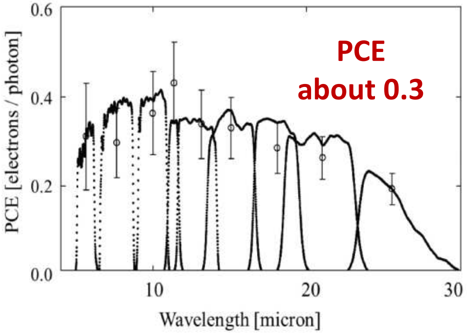
10 Exoplanets observed by direct imaging (40 hours MIRI EC GTO)
MIRI coronographic observations (3), LRS (6), MRS (1)
+ 3 exoplanets Gene Serabyn (20 hours MIRI JPL GTO)
In collaboration with short wavelengths (NIRCAM GTO time;
NIRSPEC GTO for MRS)

7 Brown Dwarfs (10 hours MIRI EC GTO)
MRS observations
In coordination/collaboration with NIRCAM, NIRSPEC, NIRISS GTO teams

All the observing modes of MIRI will be used for exoplanet charaterization

IMAGING, including coronagraphy

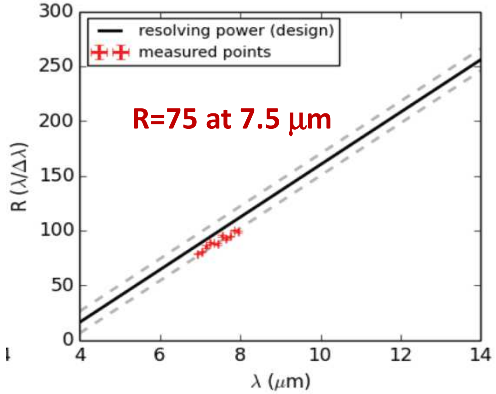
Filter name (and wavelength)	Pass band Δλ (μm)
F560W	1.2
F770W	2.2
F1000W	2.0
F1130W	0.7
F1280W	2.4
F1500W	3.0
F1800W	3.0
F2100W	5.0
F2550W	4.0

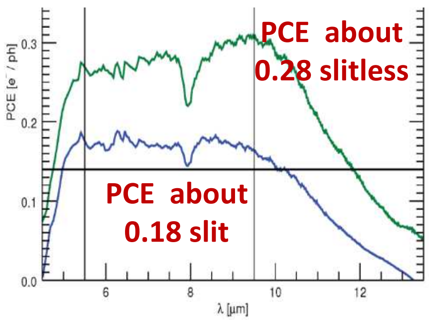


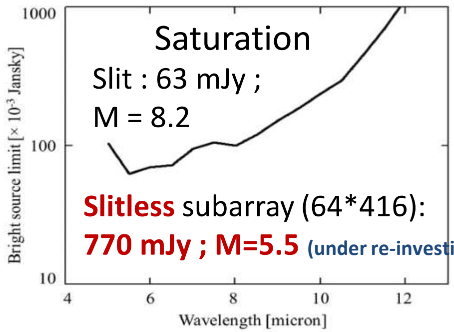
Saturation

Filter	Brt. Src. Limit (Jy) 64 × 64 subarray	
F560W	0.42	M=6.1
F770W	0.24	M=6.0
F1000W	0.52	M=4.7
F1130W	2.25	M=2.8
F1280W	0.95	M=3.5
F1500W	1.23	M=2.9
F1800W	2.2	M=1.9
F2100W	2.2	M=1.5
F2550W	6.4	M=0.

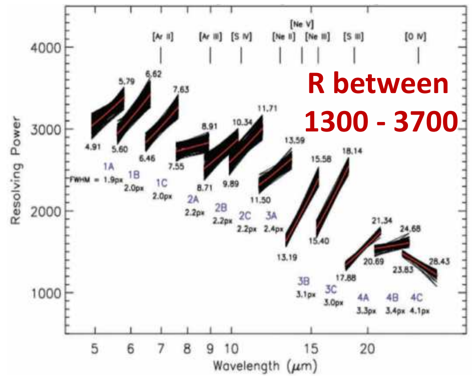
SLIT (5''*0.5 '') or SLITLESS LOW RESOLUTION SPECTROSCOPY 5-10 (→12) μm

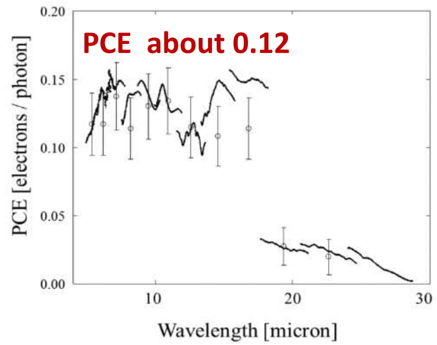


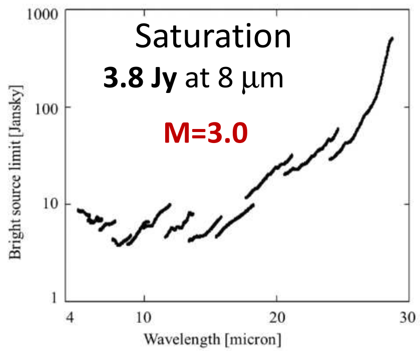




IFU MEDIUM RESOLUTION SPECTROSCOPY 5-28.5 μm in 3 settings







P. Bouchet et al. PASP; S. Kendrew et al. PASP; M. Wells et al. PASP; M. Ressler et al. PASP; A. Glasse et al. PASP

For more detailed information about MIRI capabilities:

MIRI European Consortium

Ten papers about MIRI in PASP 2015

I: Introduction, G. H. Rieke, G. S. Wright, T. Boker et al.

II: Design and Build, G. S. Wright , D. Wright, G. B. Goodson, et al.

III: MIRIM, the MIRI Imager, P. Bouchet, M. Gacia Marin, P.O. Lagage et al.

IV: The Low Resolution Spectrometer, S. Kendrew, S. Scheithauer, P. Bouchet et al.

V: Predicted Performance of the MIRI Coronagraphs A. Boccaletti, P.O. Lagage, P. Baudoz et al.

VI:The Medium Resolution Spectrometer, Martyn Wells, J.-W. Pel, A. Glasse et al.

VII: The MIRI Detectors, G. H. Rieke, M. E. Ressler, J. E. Morrison et al.

VIII: The MIRI Focal Plane System, M. E. Ressler, K. G. Sukhatme, B. R. Franklin et al.

IX: Predicted Sensitivity, A. Glasse, G. H. Rieke, E. Bauwens et al.

X: Operations and Data Reduction, K. D. Gordon, C. H. Chen, R. E. Anderson et al.

END

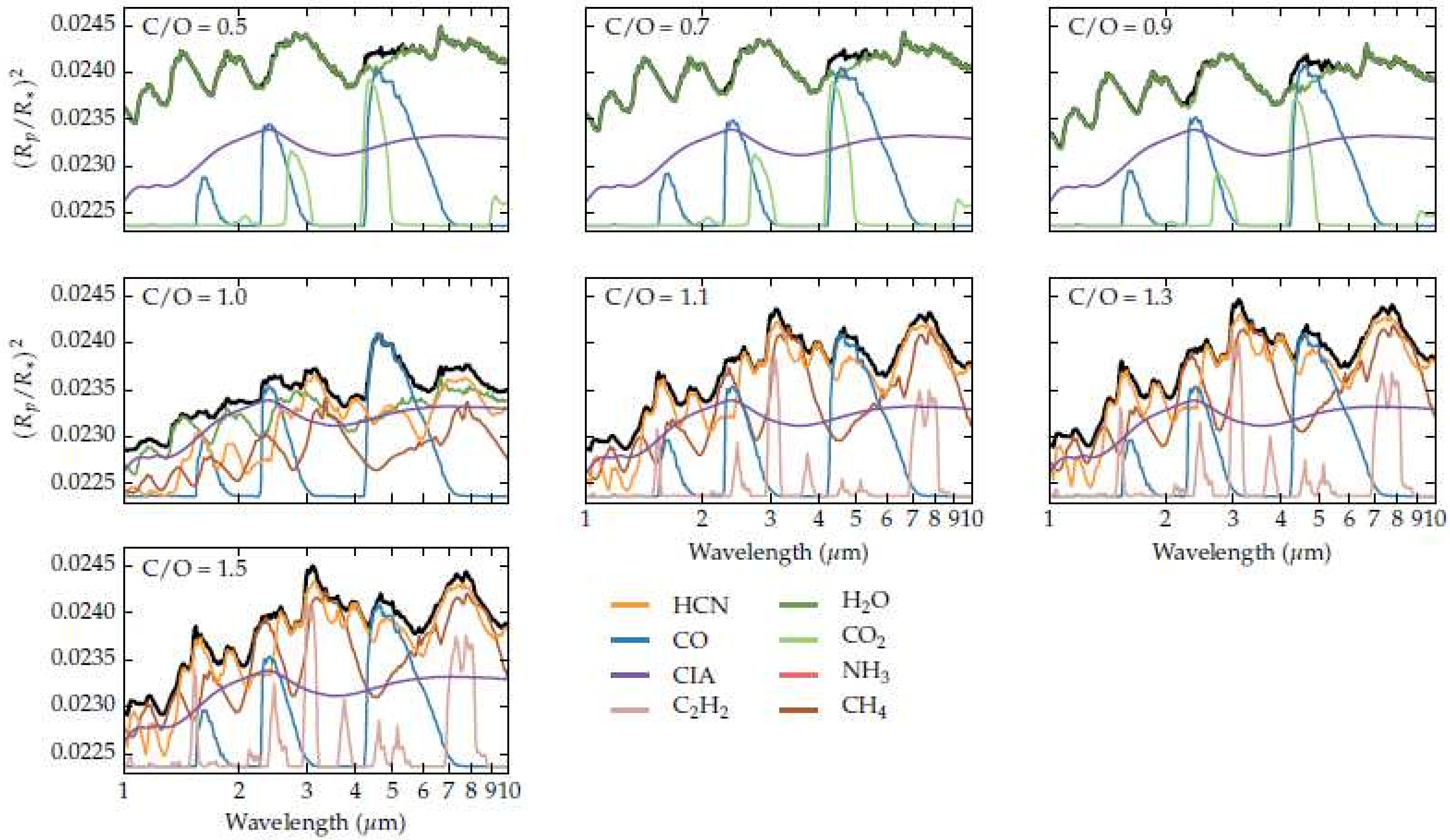


Figure 4. Synthetic transmission spectra (black lines) and contributions of the major opacity sources (colored lines, see legend) for the atmospheres whose chemistry is shown in Figure 3, for different C/O values. The opacity sources include the seven molecules considered in this study, and the collision induced absorption (CIA) from H_2–H_2 and H_2–He pairs. Note that for each plot we only show the major opacity contributors to the spectrum, and we hide the molecules that do not significantly contribute to the transmission spectrum features.

Medium Resolution Spectrometer

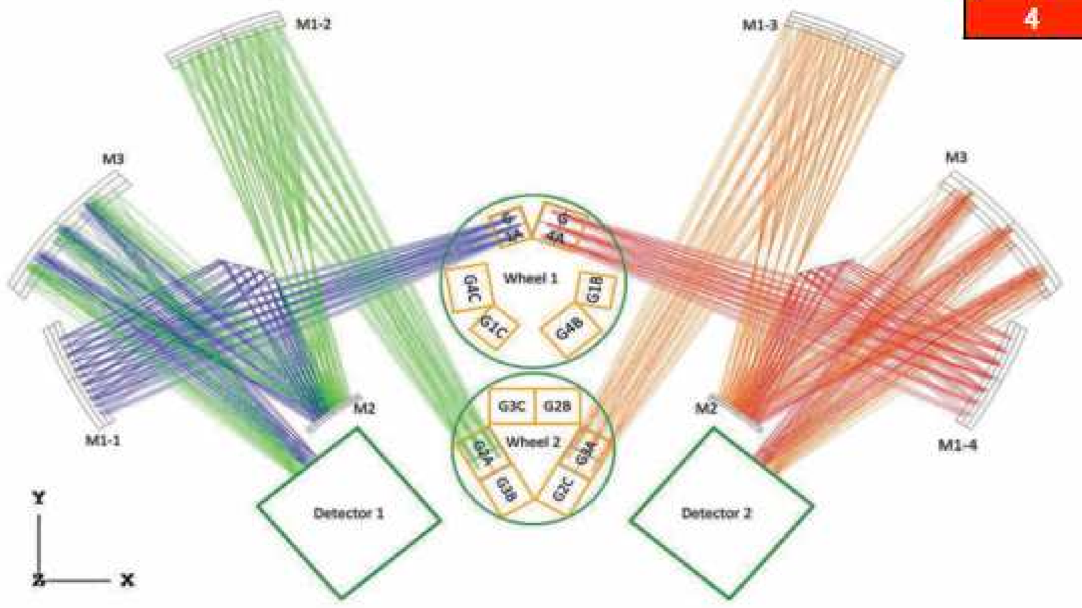
MIRI European Consortium

An Integral Field Unit Spectrometer

2 chan

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

Field of view across slices (arcsec)



M. Wells et al.: PASP, 2015

Too precise the JWST data ?

MIRI European Consortium

Table 1. *JWST* instrument modes

Instrument	Mode	Wavelength range (μm)
NIRISS	SOSS/GR700XD	1.0–2.5 μm
NIRCam	LW grism/F322W2	2.5–3.9 μm
NIRCam	LW grism/F444W	3.9–5.0 μm
MIRI	slitless/LRS prism	5.0–10.0 μm

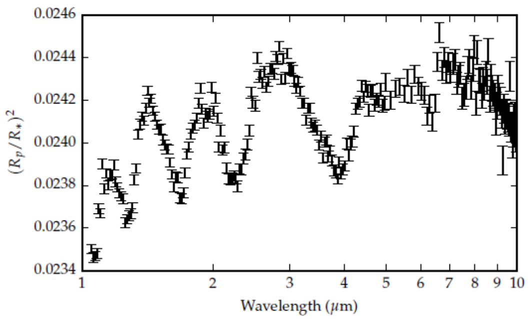


Figure 2. Simulated *JWST* observation for C/O = 0.5. The spectrum was obtained combining four separate synthetic observations obtained with NIRISS, NIRCam and MIRI to cover the 1–10 μm spectral range. This spectrum would therefore require observing a total of four transits.

Given the high precision of JWST observations over a large wavelength range

model assumptions, such as isothermal temperature, to retrieve transmissio spectra are no longer valid and

information on the P-T atmospheric profile can be retrieved from transmission spectra

EXPLORING BIASES OF ATMOSPHERIC RETRIEVALS IN SIMULATED *JWST* TRANSMISSION SPECTRA OF HOT JUPITERS

M. Rocchetto[1] , I. P. Waldmann[1], O. Venot[2], P.-O. Lagage[3,4], G. Tinetti[1]

[1] Department of Physics & Astronomy, University College London, Gower Street, WC1E6BT London, United Kingdom

[2] Instituut voor Sterrenkunde, Katholieke Universiteit Leuven, Celestijnenlaan 200D, 3001 Leuven, Belgium

[3] Irfu, CEA, Universit Paris-Saclay, F-9119 Gif-sur Yvette, France

and

[4] AIM, Universit Paris Diderot, F-91191 Gif-sur-Yvette, France

Accepted in ApJ

Various reasons to study the atmosphere of exoplanets

1) To learn about the nature of exoplanets and their diversity

2) To understand the physics and chemistry at work in atmospheres of exoplanets not present in the solar system (but some may be representative of the earlier planets of the solar system)

3) To constrain planet formation (metallicity, C/O ratio)

4) Ultimately to search for bio-signatures (e.g. O_3)

Too exquisite JWST data ?

MIRI European Consortium

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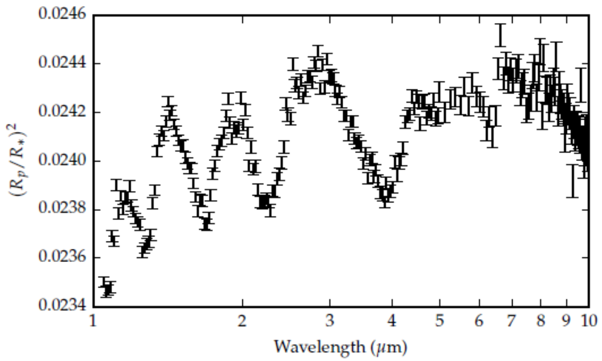

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[3] Irfu, CEA, Universit Paris-Saclay, F-9119 Gif-sur Yvette, France
and
[4] AIM, Universit Paris Diderot, F-91191 Gif-sur-Yvette, France

We have now spectra for all the exoplanets of GTO (and more)

MIRI European Consortium

P. Mollière et al.: Prime targets for JWST exoplanet observations 9

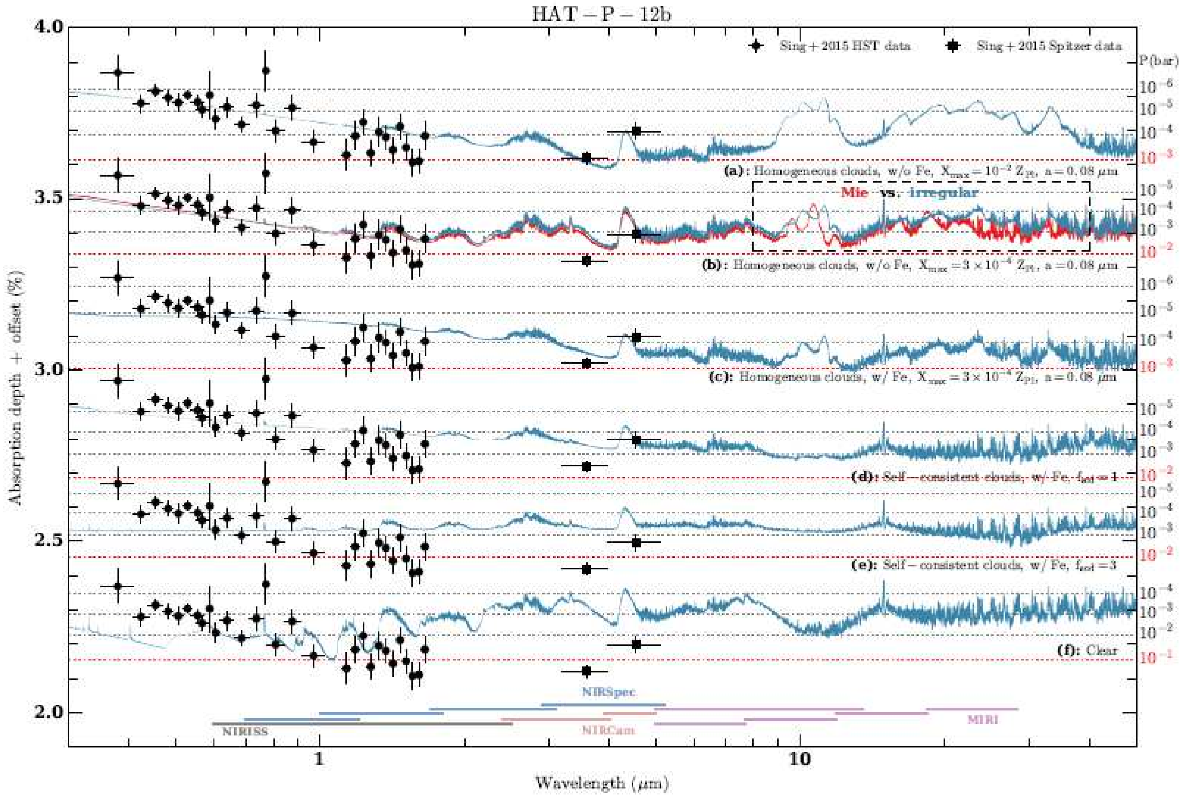

Fig. 2. Transmission spectra for the warm Saturn HAT-P-12b, along with the observational data taken from Sing et al. (2015a). For clarity a vertical offset has been applied to the various models. From top to bottom the following cases are plotted: (a): homogeneous clouds, a maximum cloud mass fraction of $X_{max} = 10^{-2} \cdot Z_{Pl}$ per species and a single cloud particle size of 0.08 μm. Iron clouds have been neglected; (b): like (a), but with $X_{max} = 3 \times 10^{-4} \cdot Z_{Pl}$, i.e. thinner clouds; (c): like (a), but including iron clouds; (d): self-consistent clouds using the Ackerman & Marley (2001) model with $f_{sed} = 1$, including iron clouds; (e): like (d), but using $f_{sed} = 3$; (f): clear, fiducial atmospheric model. All models plotted in teal assumed irregularly shaped cloud particles, using DHS theory. Models assuming homogeneous, spherical particles (using Mie theory) are shown in red. The different positions of the cloud resonance features in the MIR, when comparing irregular and homogeneous grains, have been highlighted by the dashed-line box for model (b). The colored bars at the bottom of the plot show the spectral range of the various *JWST* instrument modes. The dotted horizontal lines denote the pressure levels being probed by the transit spectra with the pressure values indicated on the right of the plot.