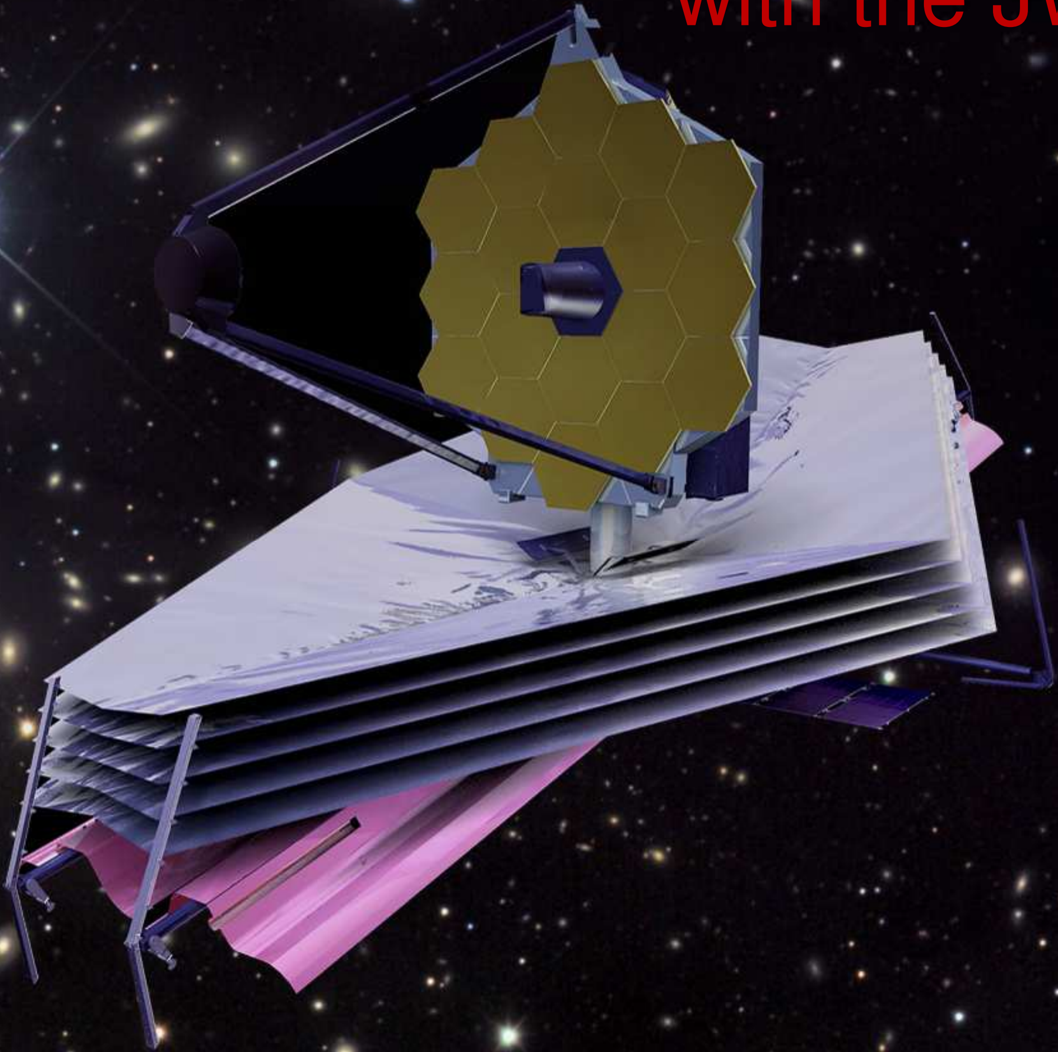
Characterization of exoplanet atmospheres with the JWST



MIRI GTO AIM

Pierre-Olivier Lagage
Pascal Tremblin
Dan Dicken
René Gastaud
Alain Coulais

JWST – Status - Hardware

The instruments are now installed at the back of the telescope.

From a telescope to a telescope with its instruments!

Integration of the payload module (ISIM) with the 4 JWST instruments

Instruments + telescope = **OTIS**

Credit for the images: NASA/Chris Gunn

Payload module at JSC

Credits: NASA/Chris Gunn

JWST's payload module (telescope + instruments = OTIS) just arrived to NASA's Johnson Space Center

JWST – From now to launch.

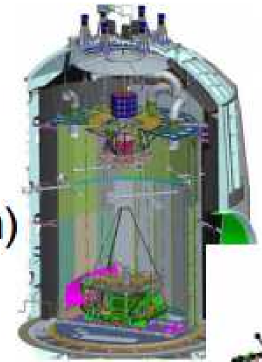
First half of 2017: testing of the telescope and the instruments together at the Johnson Space Center.

In parallel, the integration of the spacecraft and the sunshield continues at Northrop-Grumman's premises in California.

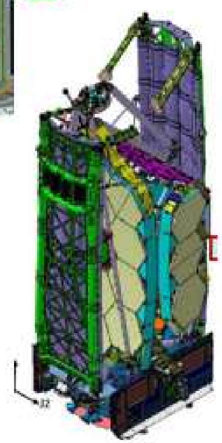
Forward Sunshield Unitized Pallet Structure Attached to the Spacecraft Bus (Northrop Grumman)

NEXT

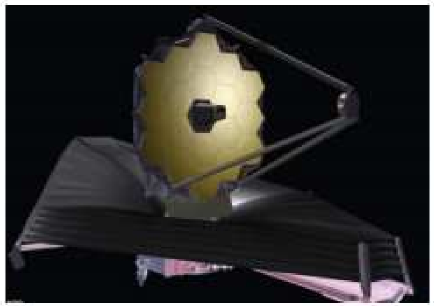
- Shipped for final “Space like” Thermal Cryo Vacuum tests early 2017 (@ JSC, Houston)



- Late 2017 shipped JSC to Space Park, California for final S/C integration

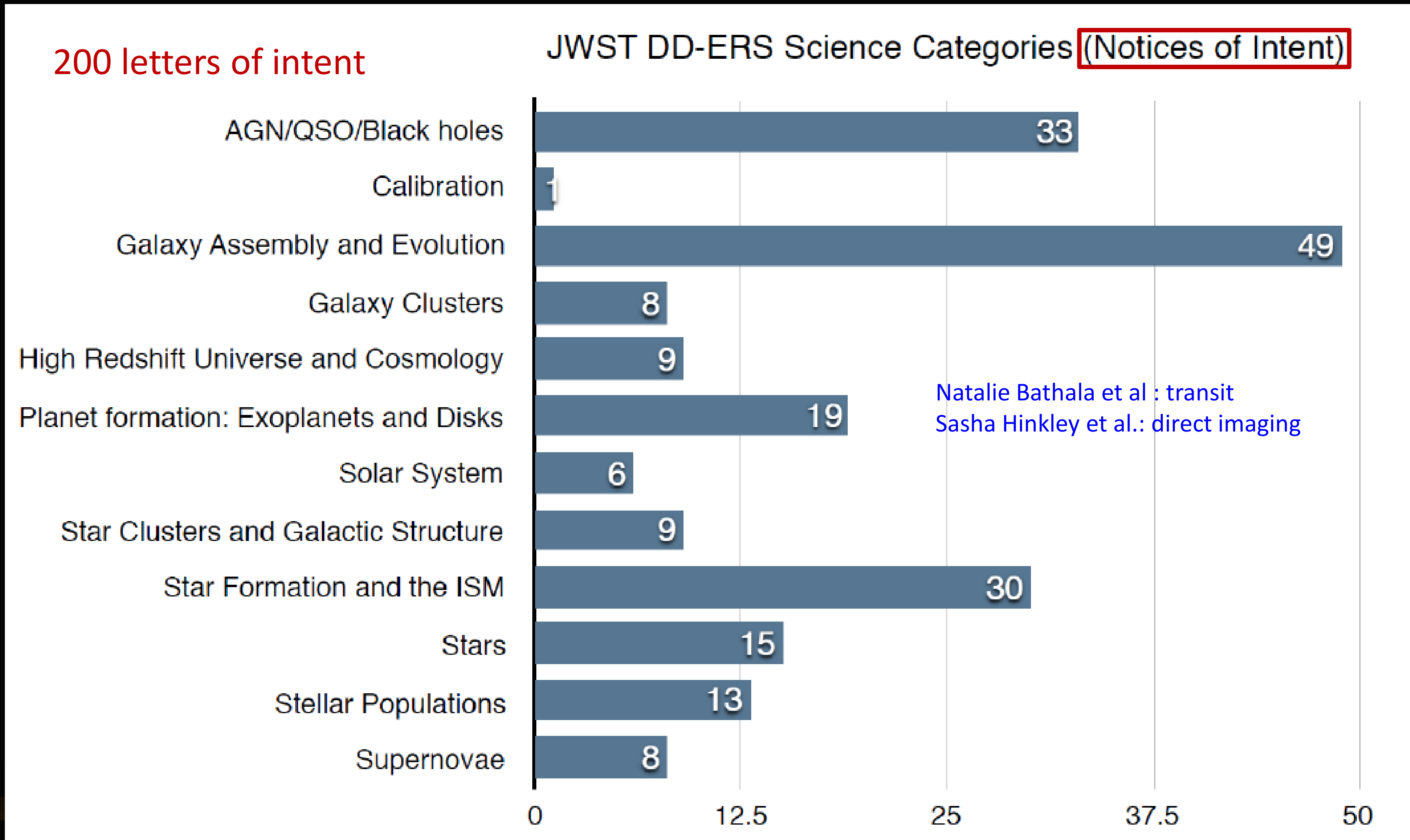


- Ship 2018 to Kourou for Ariane 5 Launch in Oct 2018.



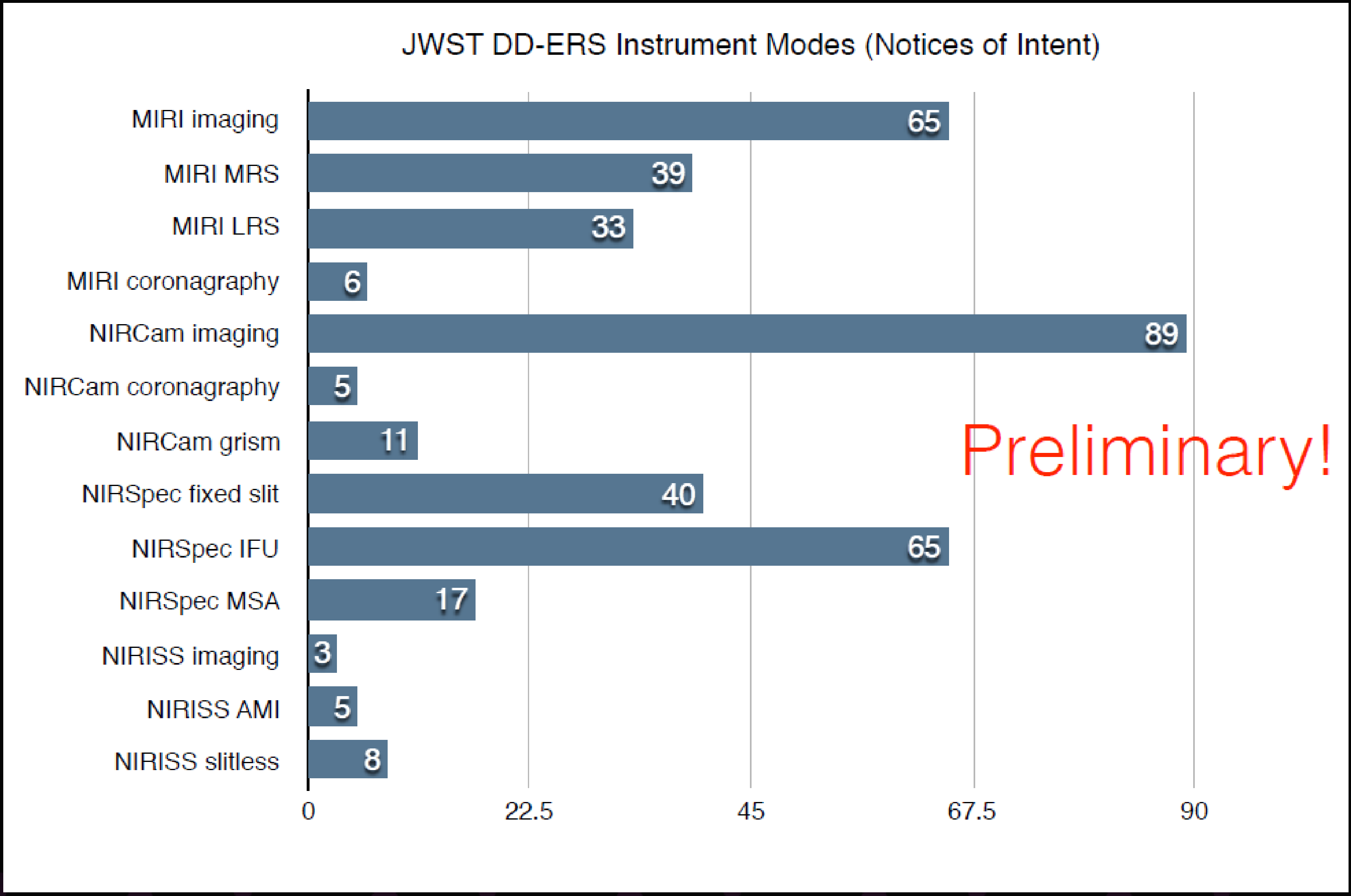

Still on track for a launch
mid October 2018
esa
ariane

The JWST Director's Discretionary Early Release Science (DD ERS) Program



From Nicole LEWIS STScI JWST project scientist

The JWST Director's Discretionary Early Release Science (DD ERS) Program



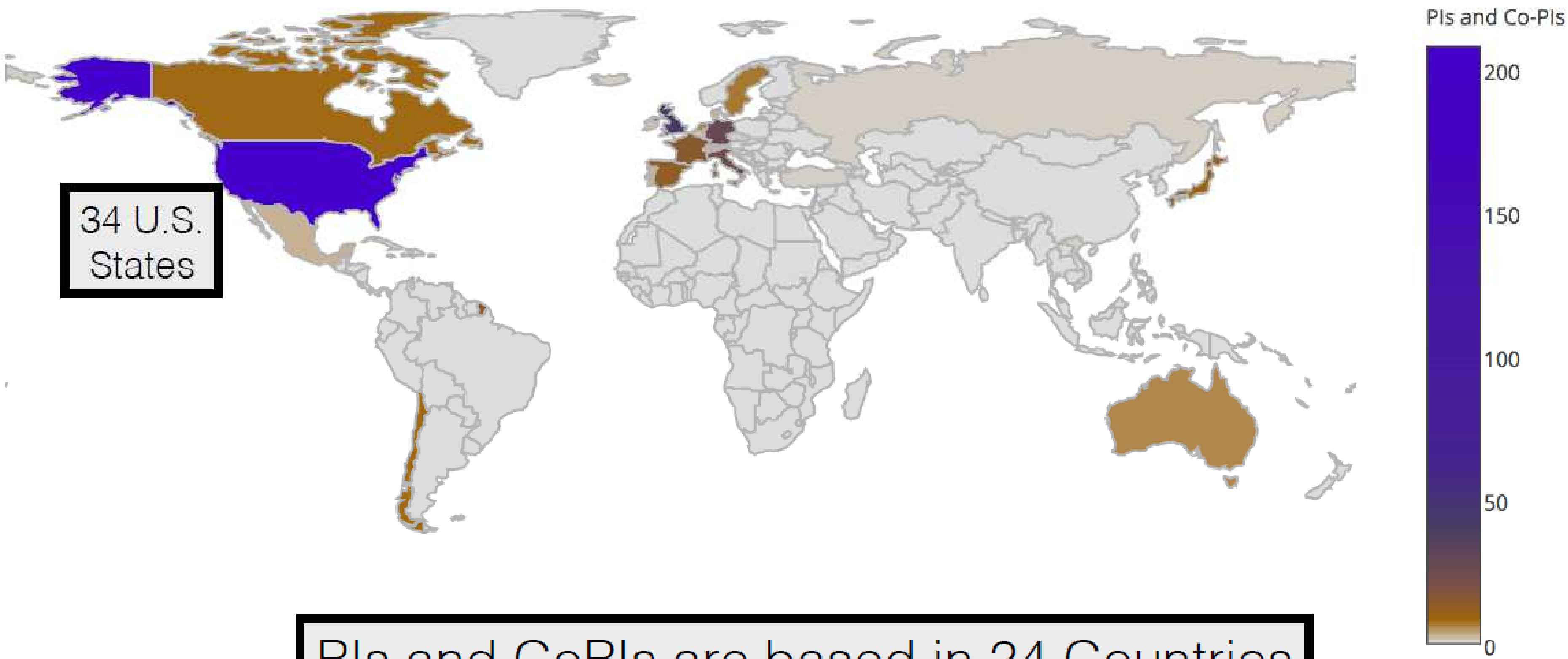
From Nicole LEWIS STScI JWST project scientist

The JWST Director's Discretionary Early Release Science (DD ERS) Program

Total of 3,665 Named Investigators/Collaborators
Average of 18 Scientists per Team
Largest Team is 119 Investigators
2,379 Unique Investigators/Collaborators
477 New User Investigators/Collaborators

The JWST Director's Discretionary Early Release Science (DD ERS) Program

JWST Director's Discretionary Early Release Science Program: Notice of Intent PIs and Co-PIs

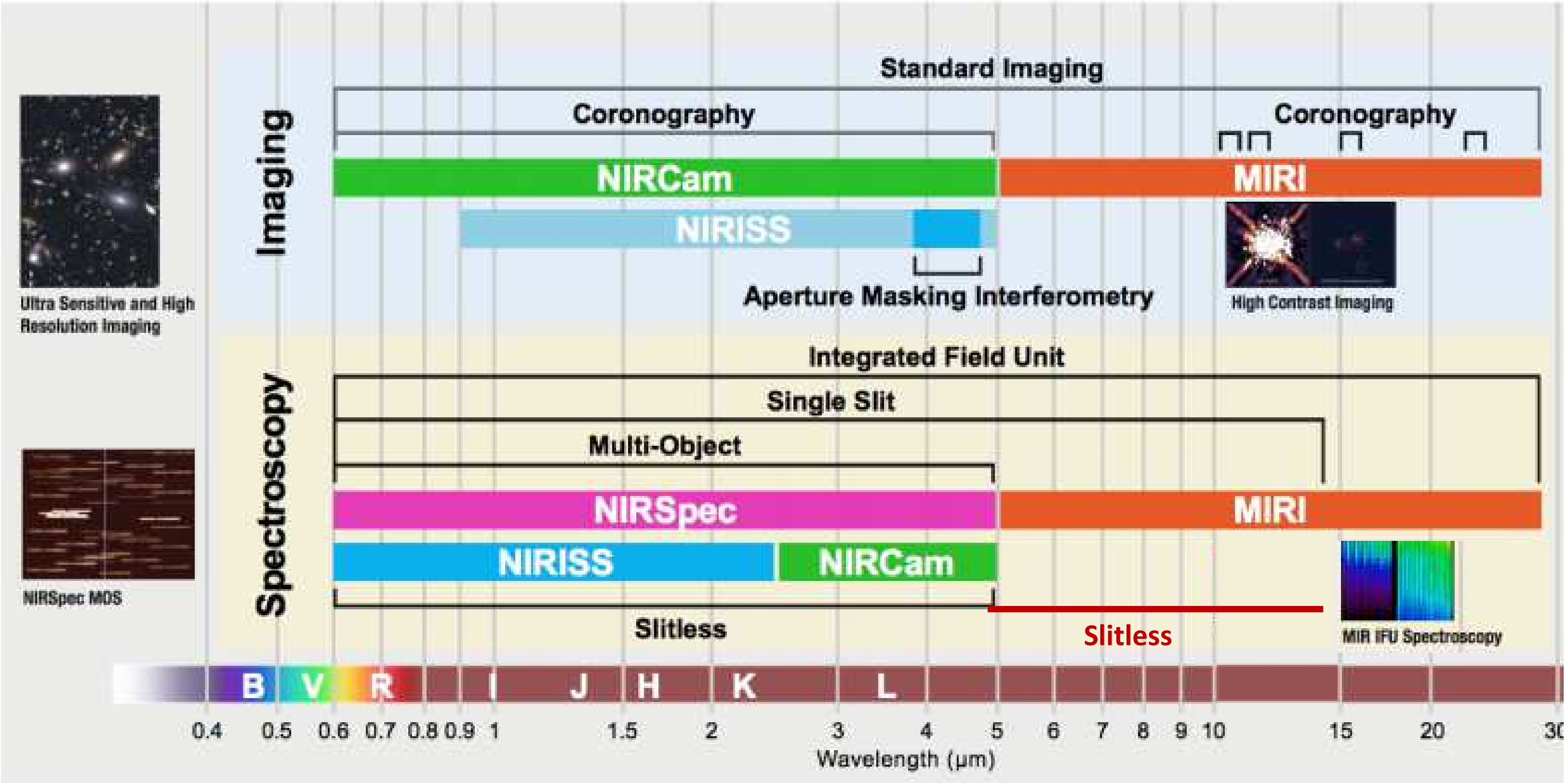


PIs and CoPIs are based in 24 Countries

Interactive Map: http://bit.ly/2m74cwX

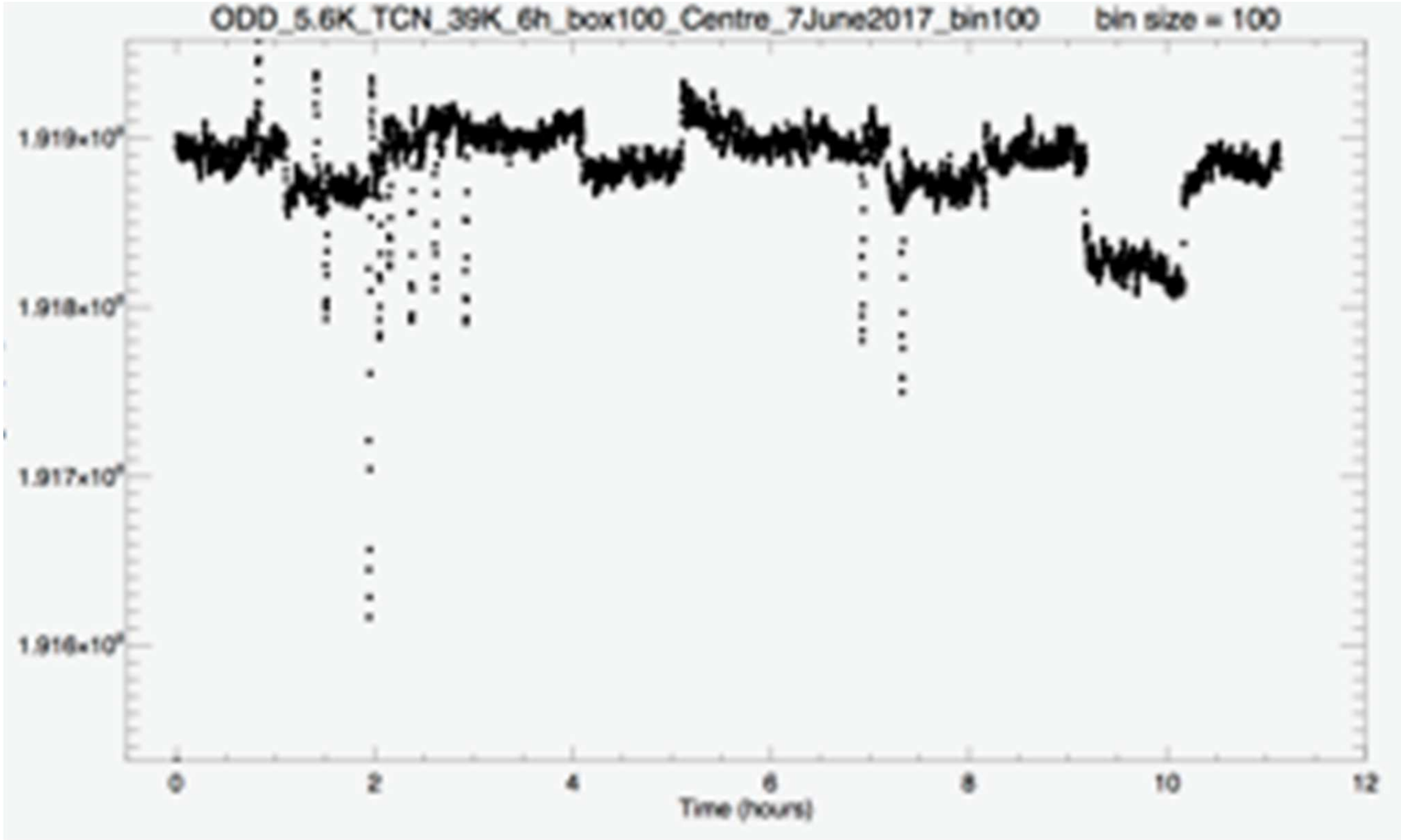
From Nicole LEWIS STScI JWST project scientist

MIRI THE JWST instrument covering the 5 – 28 microns range



Adapted from STScI

	WP2 : Preparation of JWST observations	Date	People in charge	Deliveries
1	Improvement of the MIRI observation simulator: - add simulated disk observations with the coronagraph - other improvements necessary for our programs	2016	R. Gastaud, P. Bouchet, A. Coulais, P.-O. Lagage, E. Pantin	Software + upgrade of the user manual
2	Data reduction pipeline (imager): - Providing data reduction algorithms to the STScI - Implement/test the STScI standard pipeline at Paris-Saclay - High level pipelines not implemented by STScI	2016 2017-2019 2016-2017	P. Bouchet, K. Dassas A. Abergel, A. Coulais, D. Dicken, R. Gastaud, P.-O. Lagage, E. Pantin, PhD + C. Coussou	Software, Documentation, Test reports Software & documentation
3	Exoplanet specifics: 1) MIRI Detector test campaings at JPL (one per year); Definition, participation, data reduction and interpretation. 2) Specific data pipeline • Member of the STScI WG to specify data pipeline for long observations (mainly exoplanet transit observations) 3) Data challenges: • data reduction, retrieval techniques benchmarking • pipeline Improvement following the data challenge results	2016-2018 2016-2017 2017-2018	D. Dicken, P. Bouchet, A. Coulais, R. Gastaud, P.-O. Lagage +collaboration with JPL and MPIA D. Dicken, P. Bouchet, A. Coulais, R. Gastaud, P.-O. Lagage. M. Ollivier +collab. (STScI and MPIA, SRON…) P.-O. Lagage P. Bouchet, A. Coulais, R. Gastaud, P. Tremblin, E. Pantin, PhD + STScI, MPIA, SRON, …	Test report Technical note Document with results 1 paper probably in PASP Software and associated documentation



Dan Dicken et al.

	Description	Date	People in charge	Deliveries
1	Benchmarking of atmospheric exoplanet models	2016	P. Tremblin , P-O. Lagage + MIRI consortium exoplanet modeling group	1 paper (ApJ)
2	Simulate the expected effects of composition variations (e.g., C/O ratio) for different scenarii of planet formation in disks, for direct imaging and for the exoplanets transiting	2016-2017	P. Tremblin, P.-O. Lagage + student at UCL	At least 2 papers (ApJ or A&A)
3	Implement of clouds in the ATMO model	2017-2018	P. Tremblin, postdoc	1 paper (ApJ or A&A)
4	Development of 3 D models from the dynamico code: Post-processing of 3D models with ATMO to produce 2D maps of the atmosphere transmission spectra, study of simple clouds prescriptions.	2016-2018	S. Fromang, P. Tremblin + postdoc	1 paper (ApJ or A&A)
5	Analysis of the first JWST exoplanet observations in ERS and in GTO	2019	P.O. Lagage, PhD (of WP2), S. Fromang, M. Ollivier, P. Tremblin and international collaborators	At least 1 paper (Nature or Science)

Requested funding : 1 postdoc for tasks 3 and 4 and a participation (63 K€) to a meso-machine

1 post-doc : Giuseppe Morello

6.4.1 WP2

PhD : "Exoplanet atmosphere characterization with the JWST" (2017-2020)

- 18 months: preparation to the exploitation of the observations of exoplanets with MIRI. During this first part, he/she will get familiar with the targets to be observed with MIRI (GTO and ERS), with the scientific objectives of the MIRI exoplanets observations, with the MIRI instrument itself (running the instrument simulator), with the data reduction. He/she will participate in exoplanet data challenges conducted prior to the JWST launch. He will participate in the 2018 detector test campaign and will reduce the data concerning exoplanets. Then, beginning of 2019, he/she will participate in the analysis of commissioning data. He/she will go to at least one conference a year and participate in summer schools.
- 18 months: scientific exploitation of JWST: data reduction and interpretation (retrieval) of observations of the exoplanet atmospheres available from the Early Release Science program and for the MIRI Guaranteed time Observations. He/she will especially be in charge of the measurement of the C/O ratio in relation with the planet formation in disk (making the link between exoplanets and disks). He will write papers and show the results in conferences. He/she will also participate in the preparation of open time proposals.

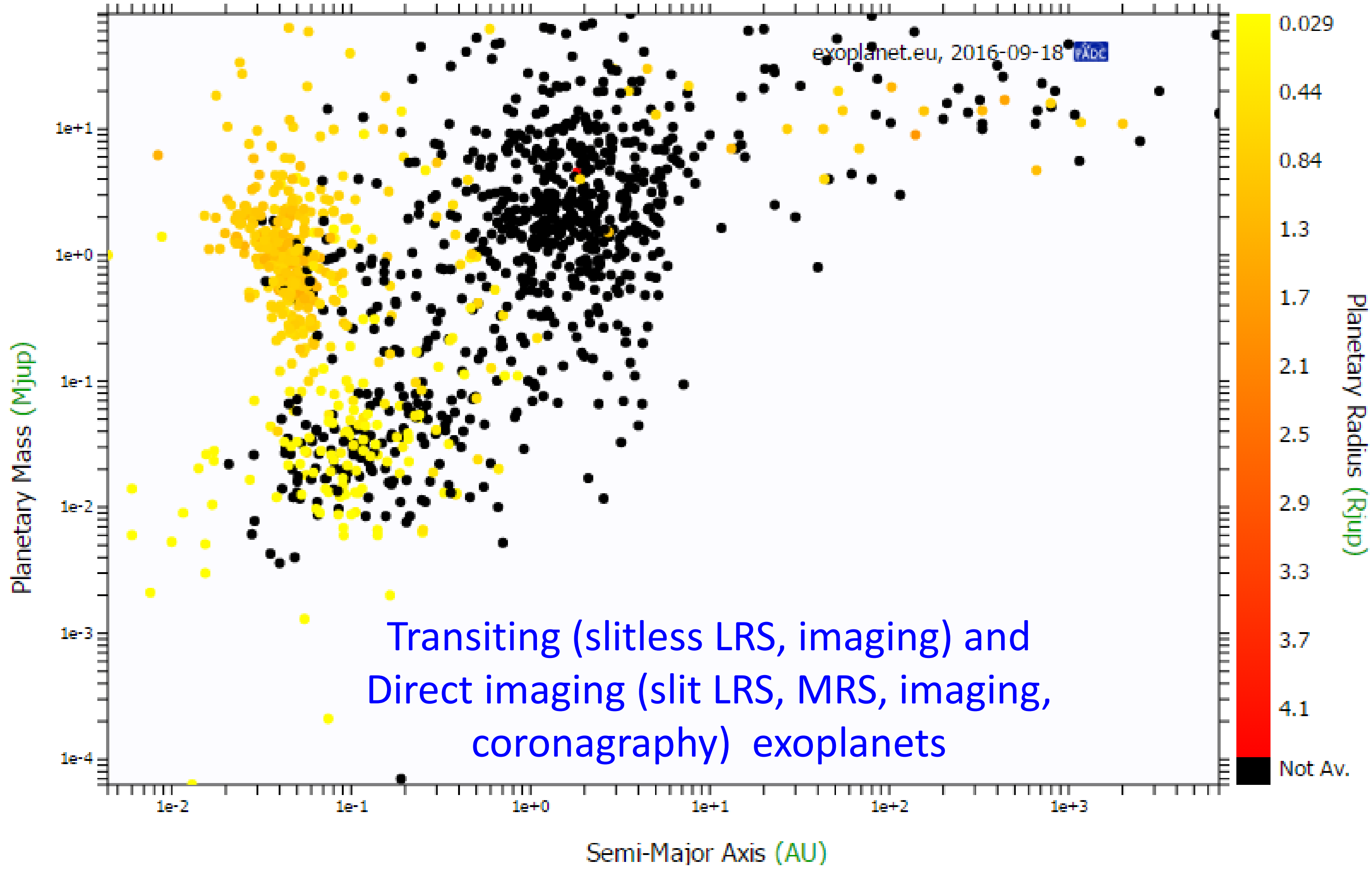
The PhD student, supervised by P.-O. Lagage (SAp) and M. Ollivier (IAS), will be based at SAp but will frequently go to IAS. He/she will benefit from an excellent environment with, next door, MIRI instrument specialists, MIRI data reduction specialists, next building, exoplanet modeling specialists and at IAS, specialists in dust and disk modeling, in exoplanet and data reduction. He/she will be member of the exoplanet working group of the MIRI European consortium, where he/she will find complementary expertise to that present at Paris-Saclay, especially for the use of the medium resolution spectrometer (SRON, MPIA Heidelberg, ATC UK). He/she will also be integrated in the network of collaborators with who we are coordinating the exoplanet GTO observations (T. Green (NASA Ames); C. Beichman (IPAC, US); R. Doyon (Canada); R. Soummer (STSCI, Baltimore), …).

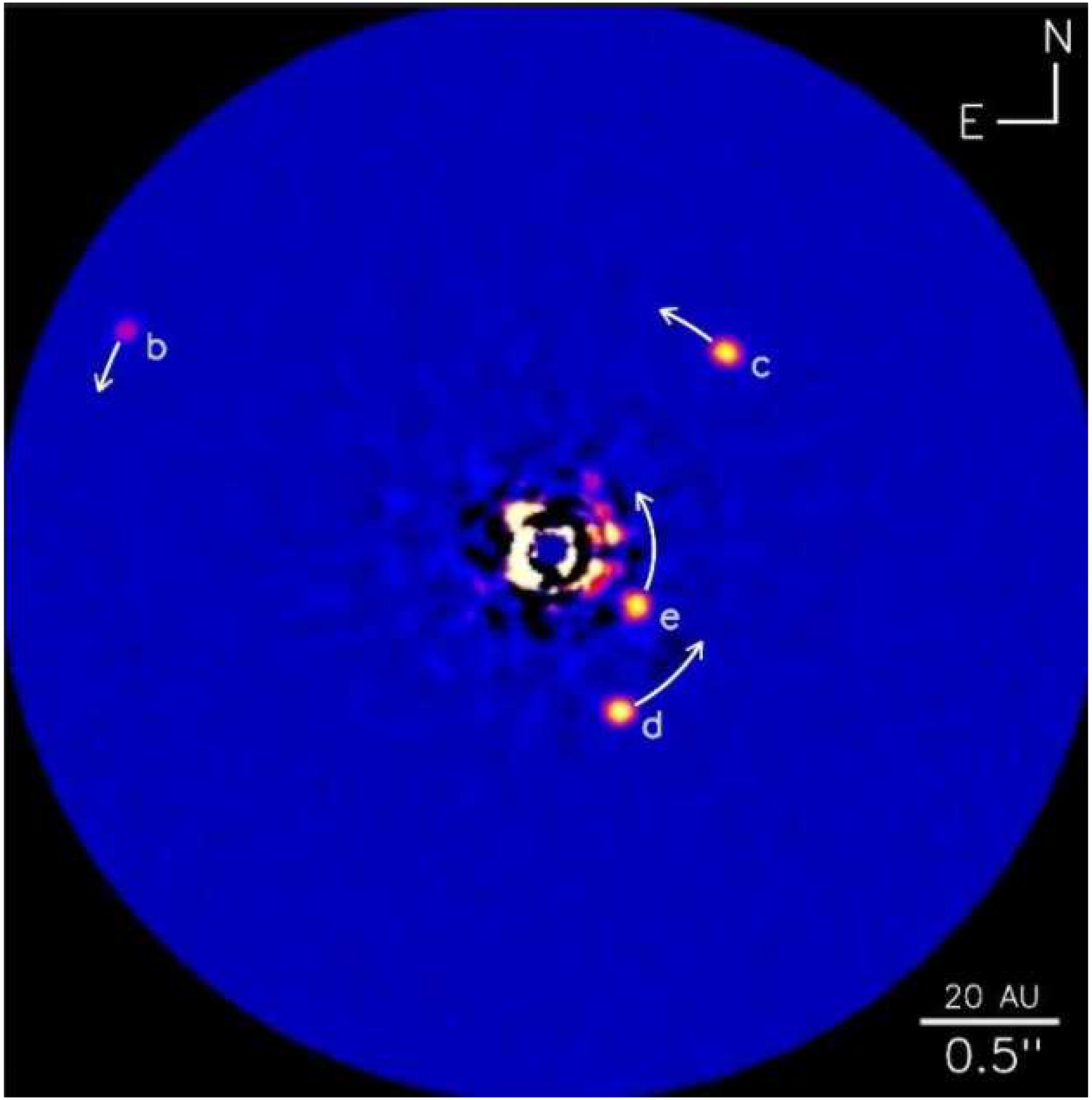
Marine Martin-Lagarde

GTO MIRI : large program of characterization of exoplanet atmosphere : 115 h.

All the modes will be used for exoplanets observations in GTO

MIRI European Consortium




N
E
b
c
e
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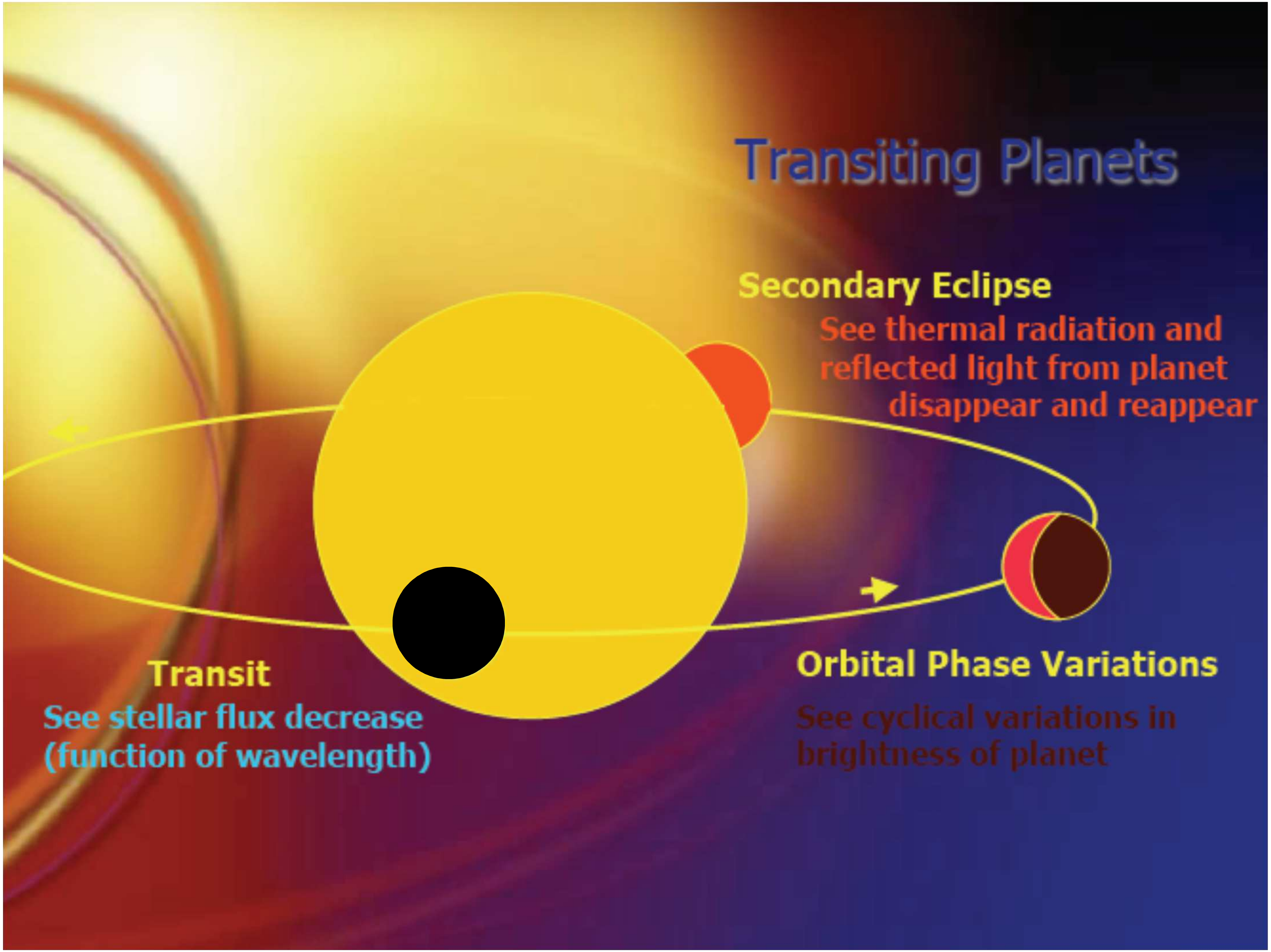
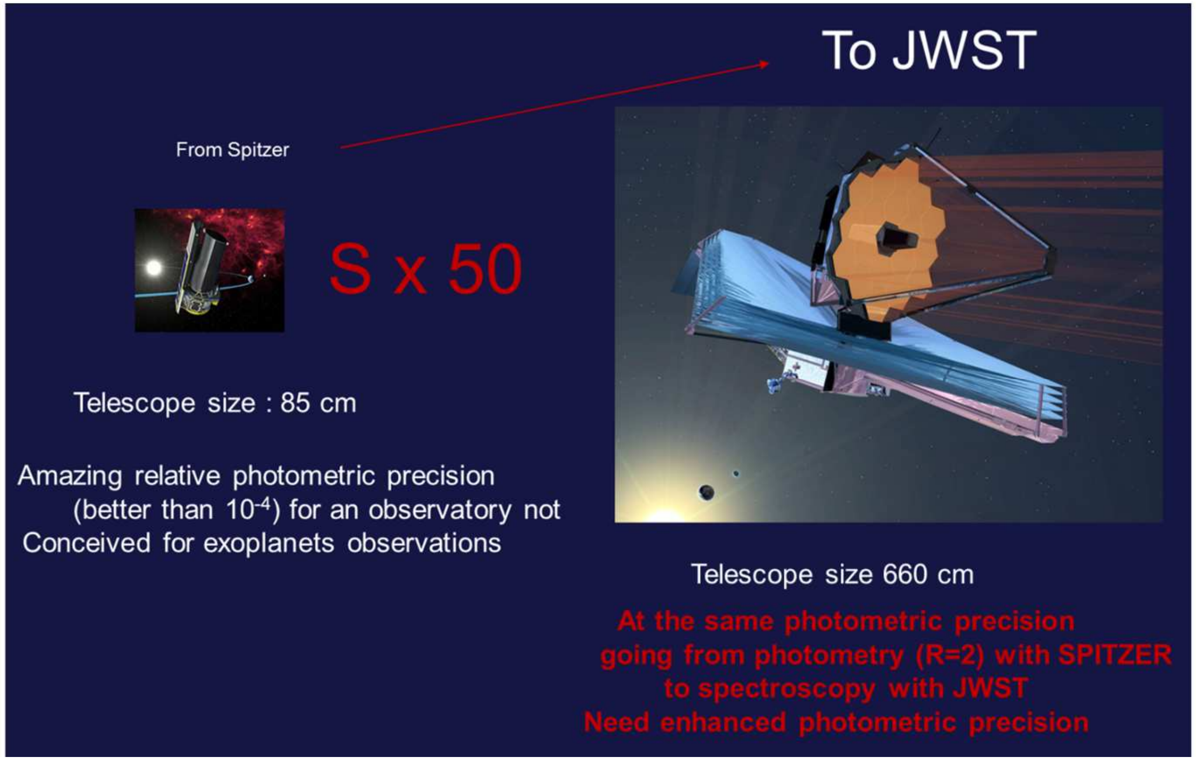
20 AU
0.5''


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

Selection sources: Giant exoplanets

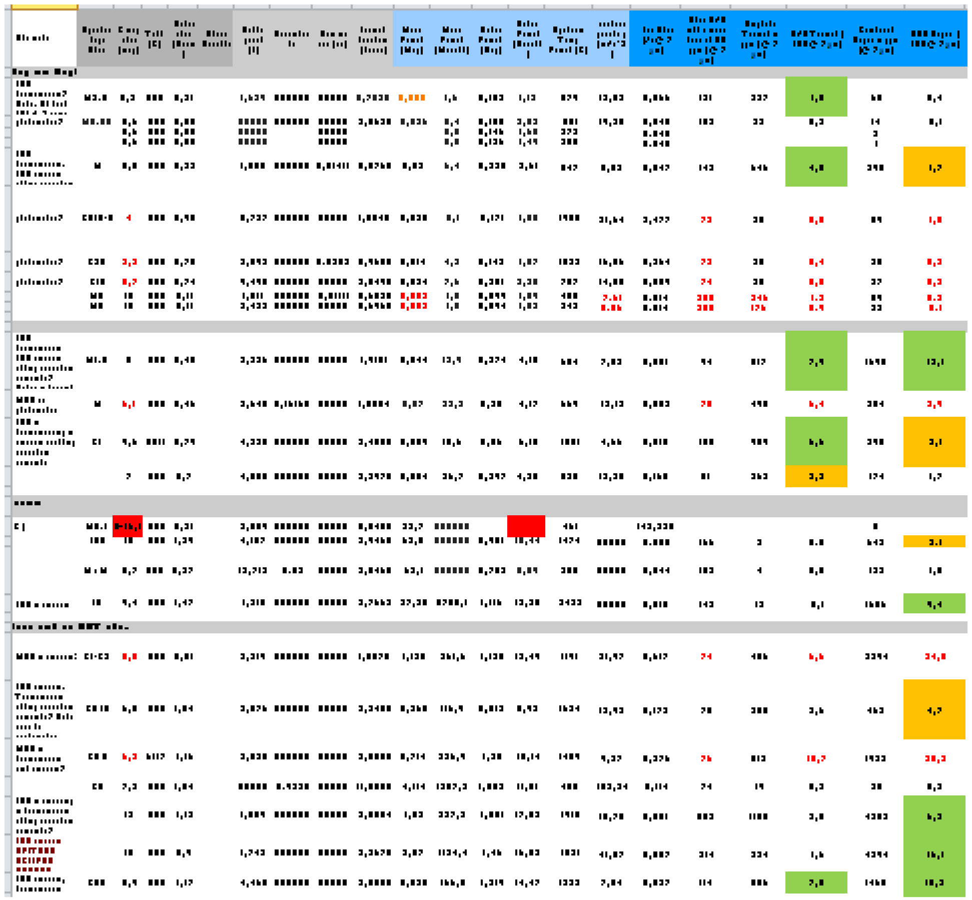
Three criteria:

- 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.



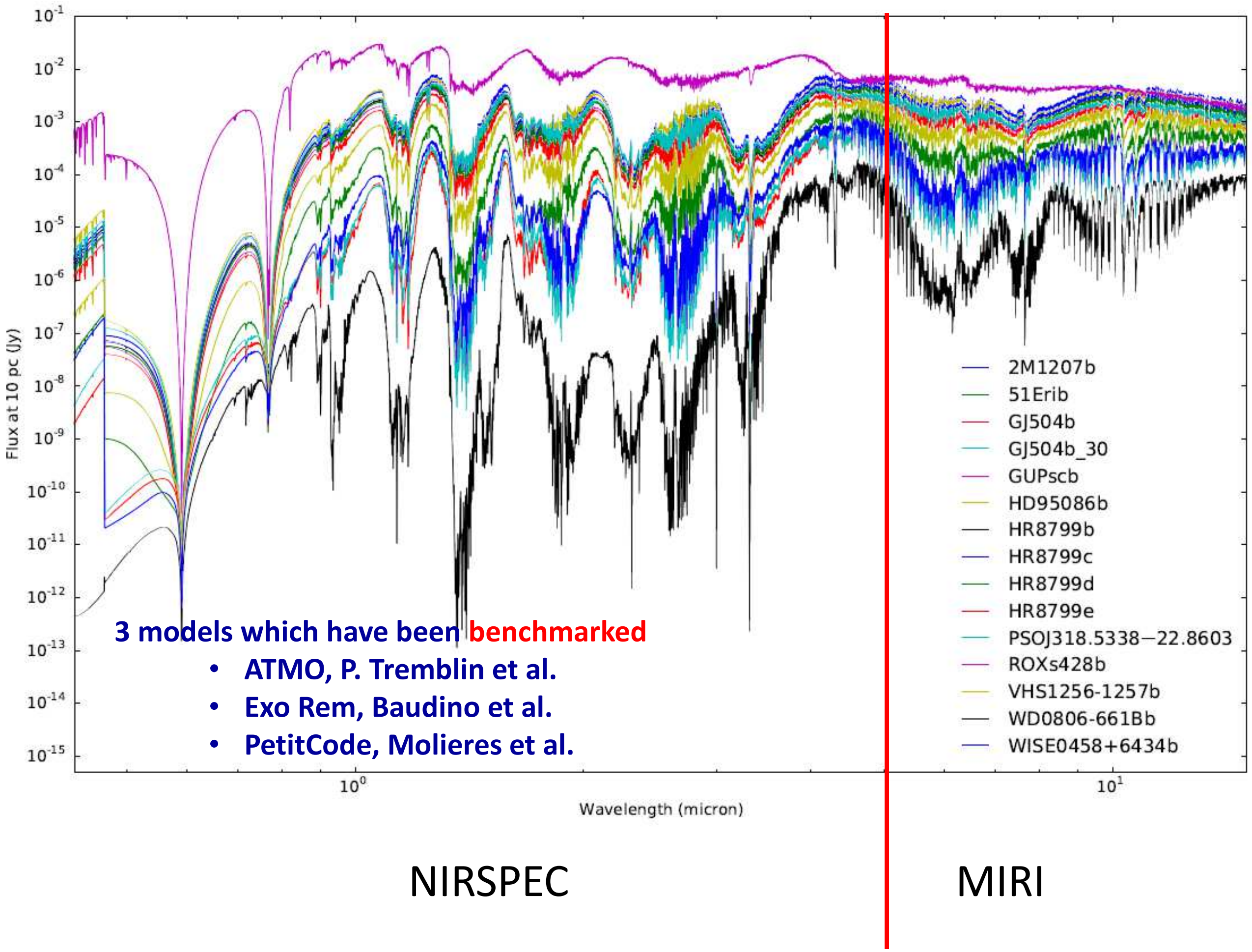
Fifty sources met the criteria when observed **in emission**

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



Selecting exoplanets with Teff < 1000K

MIRI European Consortium

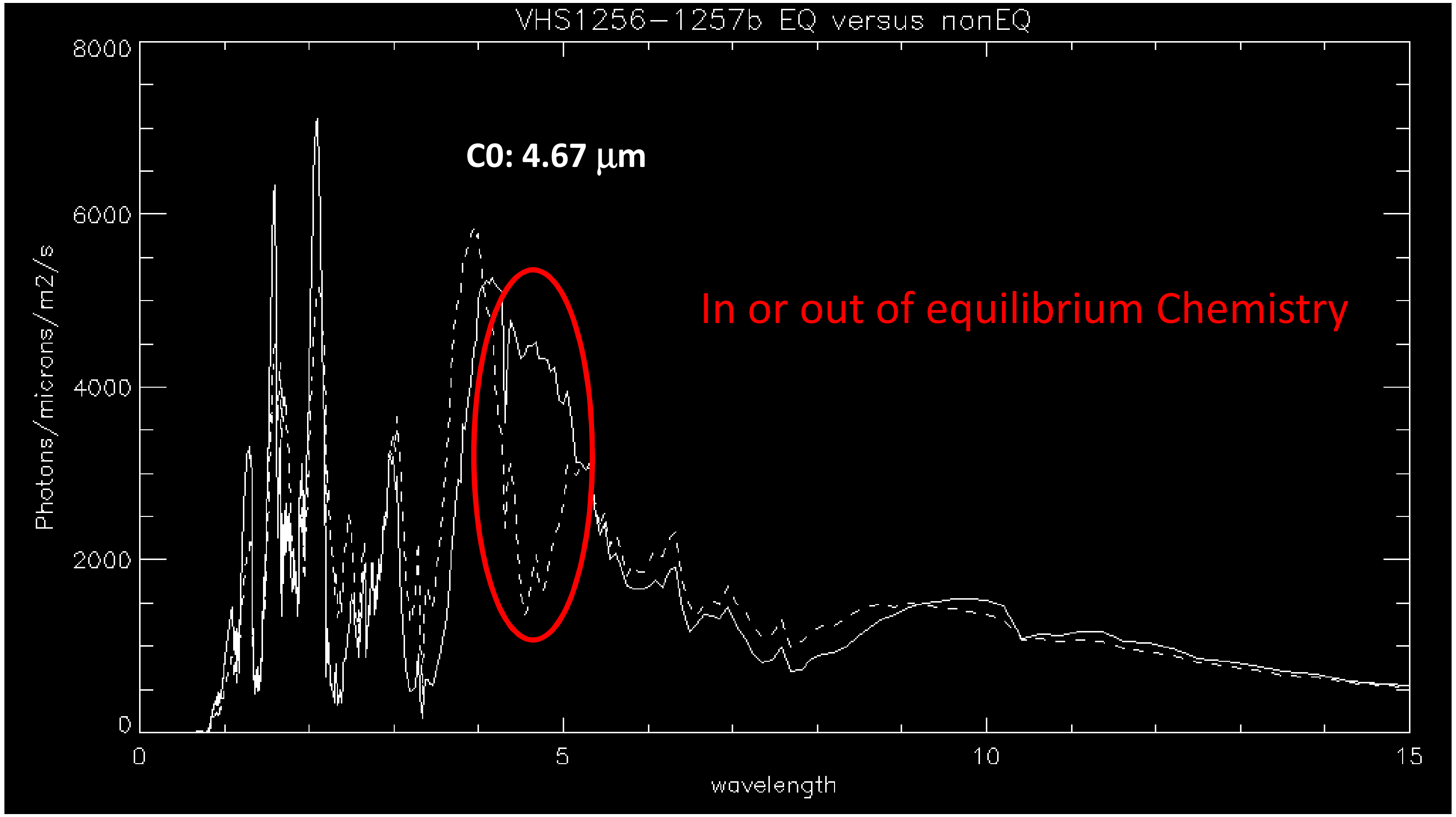


3 models which have been benchmarked

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

Important to have a broad wavelength coverage

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.

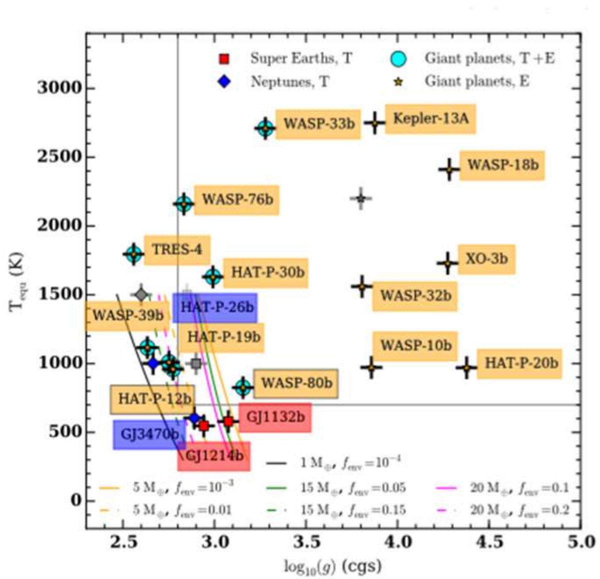
And 2 Neptune mass

HAT-P-26 b, GJ 3470b

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

mass : 38 Earth masses

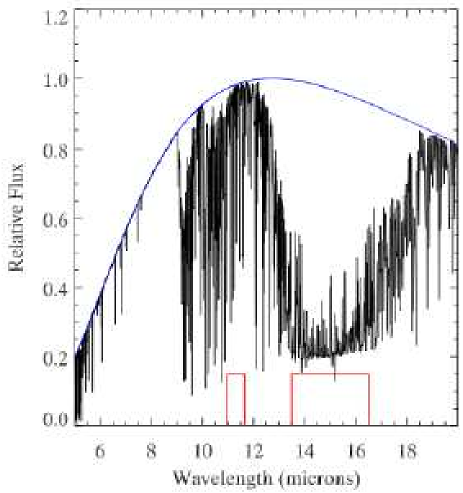
(intermediate Giant, Neptune mass)



Paul Molliere et al. ApJ

Imaging observations for Super-Earth and Earth mass planets

MIRI European Consortium



Deming et al. 2009

Feasible for GJ 1214 b

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

for filters F1130W to F2550W

Filter name (and wavelength)	Pass band $\Delta\lambda$ (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

For **GJ 1132 b**

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

But time of the eclipse?

GTO Imaging observations of Trappist 1 b

MIRI European Consortium

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

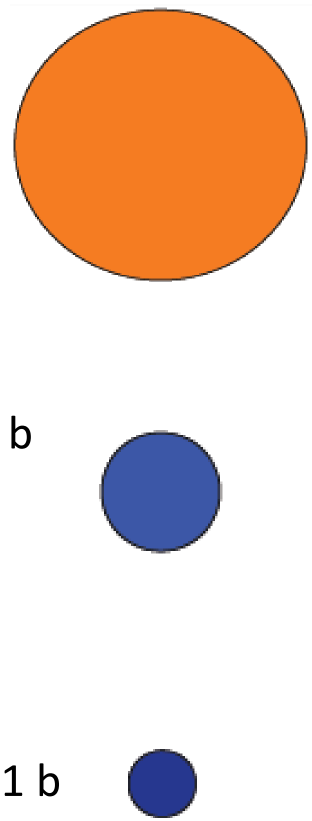
Search for therma emission of Trappist b (400 K) by looking for 5 transits with the 12.80 microns filter

S/B of 5 expected

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

12.07s, 14,50

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

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, + 1h time constrain)

Characterisation of exoplanets detected by direct imaging

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

MIRI European Consortium

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

→ spectroscopic observations

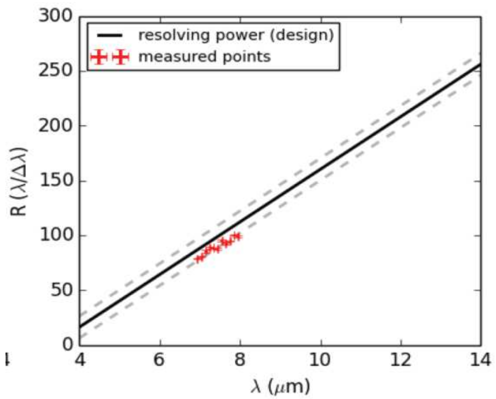
either

MIRI Low resolution Spectrometer (LRS)

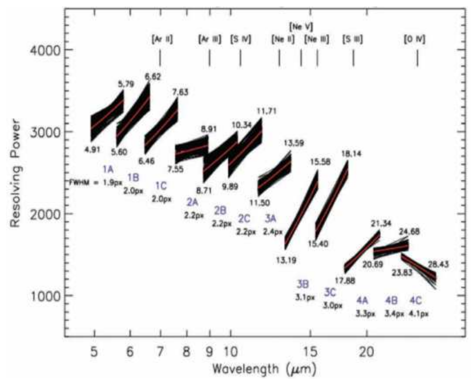
or bright enough exoplanet

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



Target list for spectroscopic observations : 7 objects

MIRI European Consortium

Instrument information		Main pointing information						Exposure information			
Instrument	Mode (Imaging, LRS, MRS, Coronography)	Main coordinates: Target Name or Optional ID	RA (J2000)	DEC (J2000)	Mosaicked or sub-arrayed Area	ToO? Y/N	Target of Disruptive ToO? (Y/N)	Elements: Filter (imaging)	Channel (MRS)	Mask (Coronagraphy)	Total Photon Collection time (hrs)
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

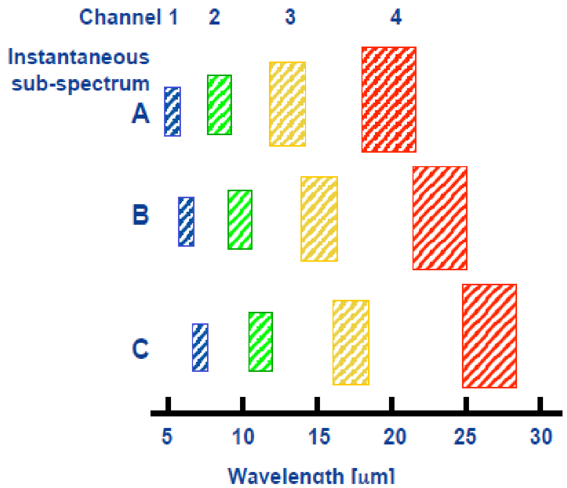
Working together with NIRCAM, NIRSPEC to cover MIRI and NIRSPEC wavelengths

MEDIUM RESOLUTION SPECTROSCOPY

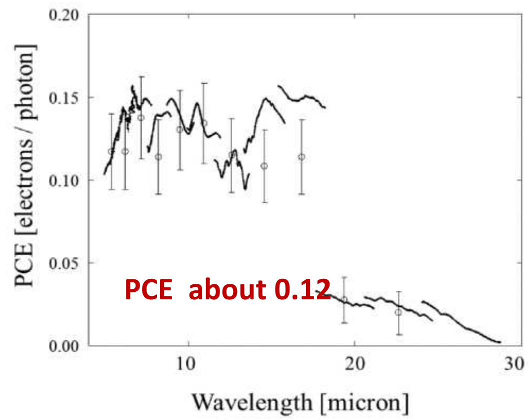
IFU MEDIUM RESOLUTION SPECTROSCOPY

5-28.5 µm in 3 settings

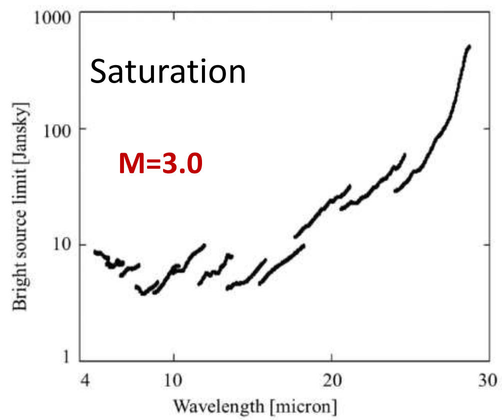
- 3 mechanism selected sub-spectra per channel with dedicated dichroic and gratings



	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



For bright objects



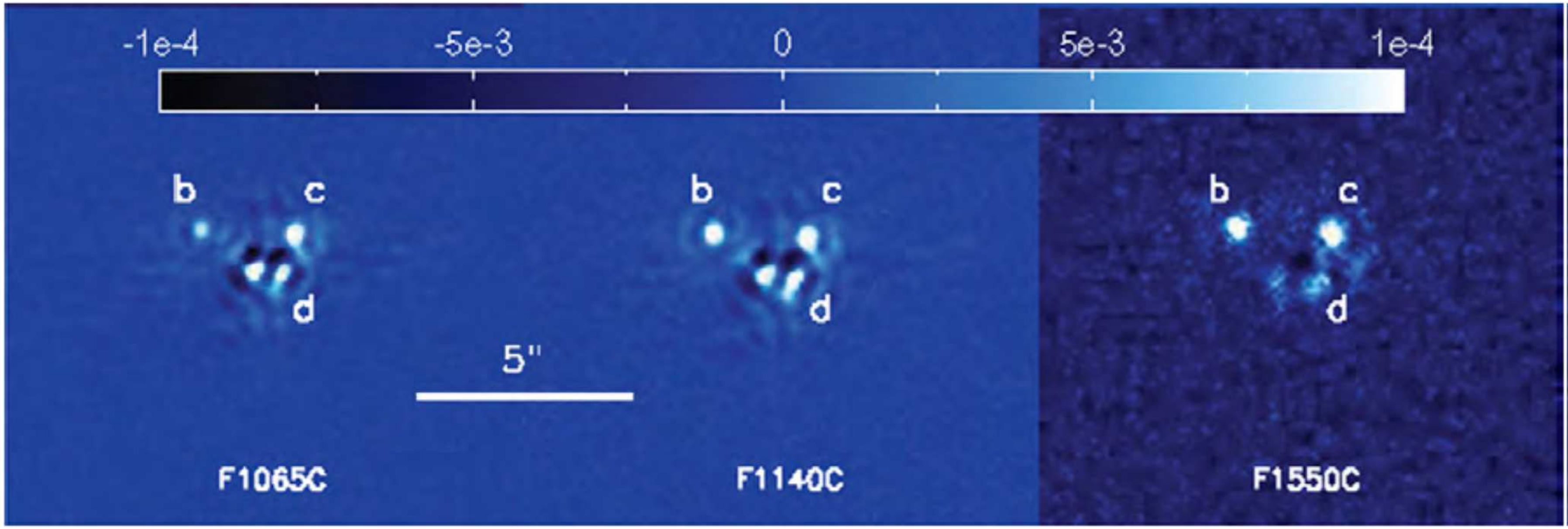
Target list for coronagraphic observations

MIRI European Consortium

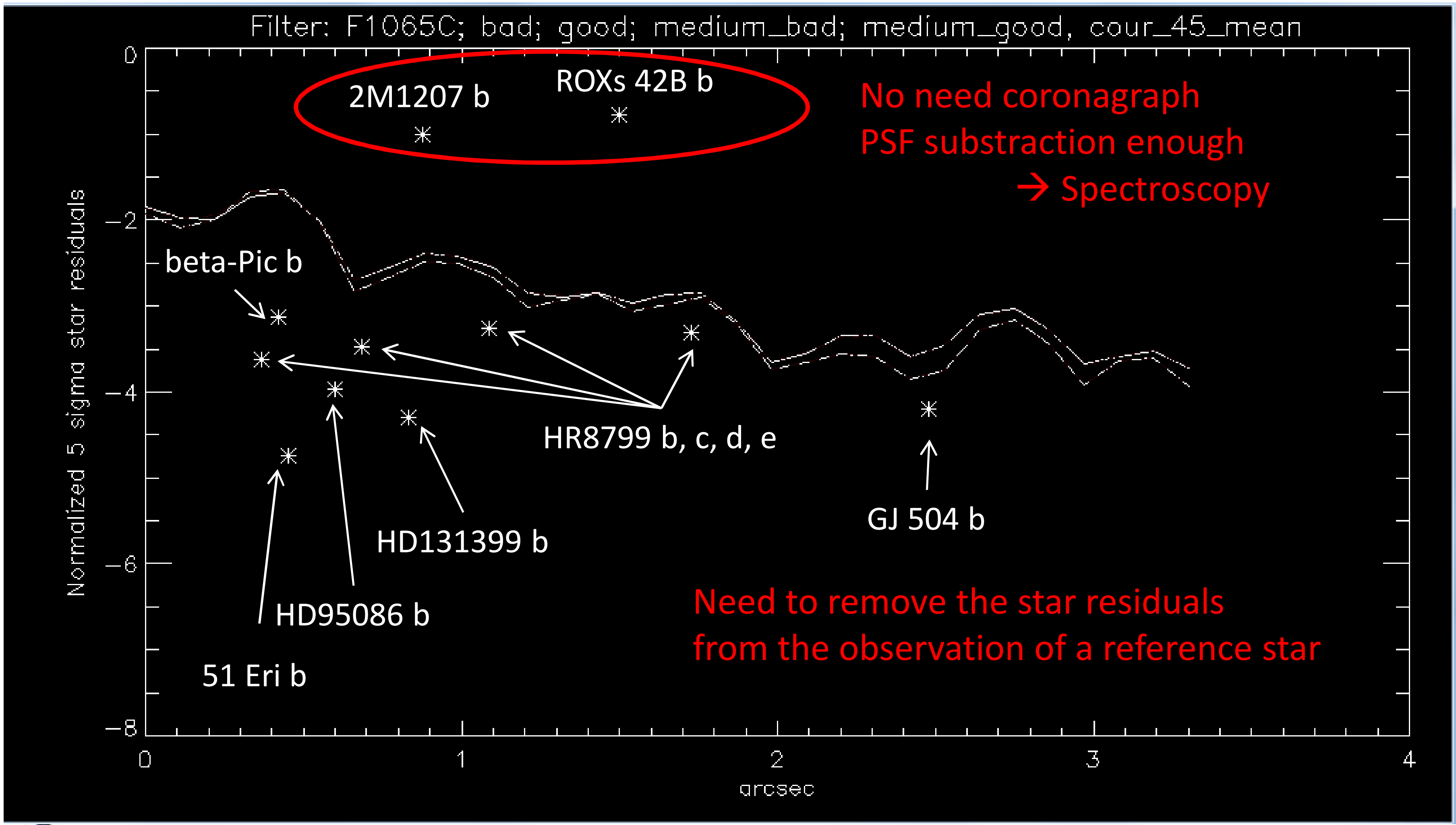
# name	Observing mode	Collaboration	mass and incertainty (in Jup mass)	radius (in Jupiter radius)	semi_major_axis (AU)	angular_distance (arcsec)	temperature
HR 8799 b	MIRI Coronagraph; 10,65; 11,40; 15.50 microns + Lyot 23 microns	Chas Beichman NIRCAM coranagraphic obs.	7 (-2/+4)	1,2 (+/-0.1)	68	1,725888	1000 (+/-100)
HR 8799 c			10 (+/-3)	1,3	42,9	1,088832	1000
HR 8799 d			10 (+/-3)	1,2	27	0,685279	1000
HR 8799 e	MIRI Coronagraph	NO MIRI EC time; MIRI JPL time (Gene); STSCI : NIRCAM	9		14,5	0,36802	1000
HD95086 b	MIRI Coronagraph; 10,65; 11,40; 15.50 microns + Lyot 23 microns	Chas Beichman NIRCAM coranagraphic obs.	5 (+/- 2)	1,3	55.7	0.6	1050 (+/-450)
GJ 504 b	MIRI Coronagraph; 10,65; 11,40; 15.50 microns		6 (+/-3) **but may also be 30**. In discussion with Rafael Garcia to better	0.96(+/-0.07)	43,5	2,48 en moyenne	544 +/-10K
51 Eri b	MIRI Coronagraph	NO MIRI EC time; MIRI JPL time (Gene); STSCI : NIRCAM	2 (+10)	1	**13.2** (+/-0.2)	0,45	700 (+/- 100)
HD 106906, disk	MIRI Coronagraph; 11,40; 15.50 microns	Chas Beichman NIRCAM coranagraphic obs.		1 assumed	650		

Simulation of coronagraphic observations of HR 8799 exoplanets

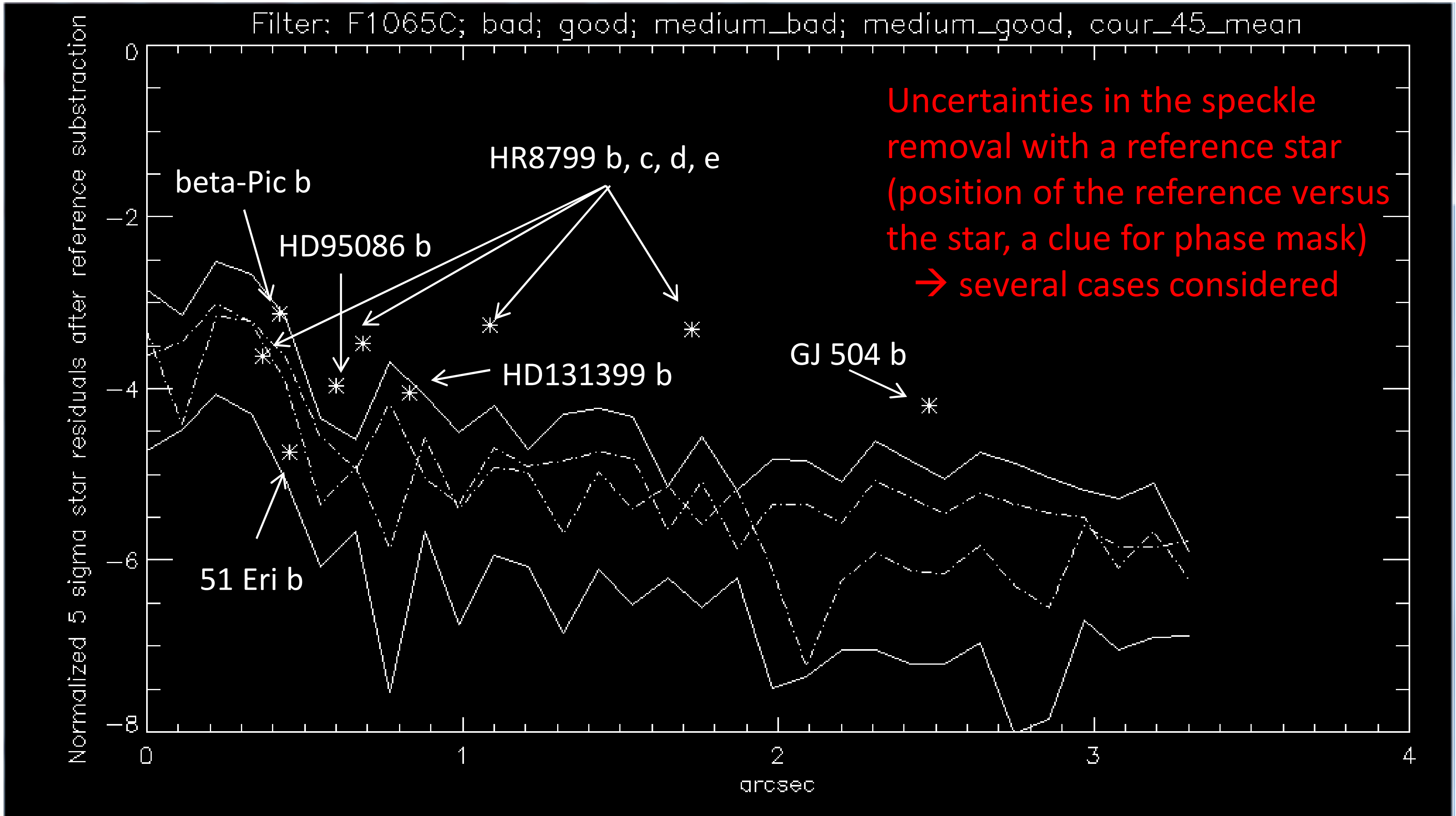
MIRI European Consortium



A. Boccaletti et al.



C. Danielski et al. in preparation



C. Danielski et al. in preparation

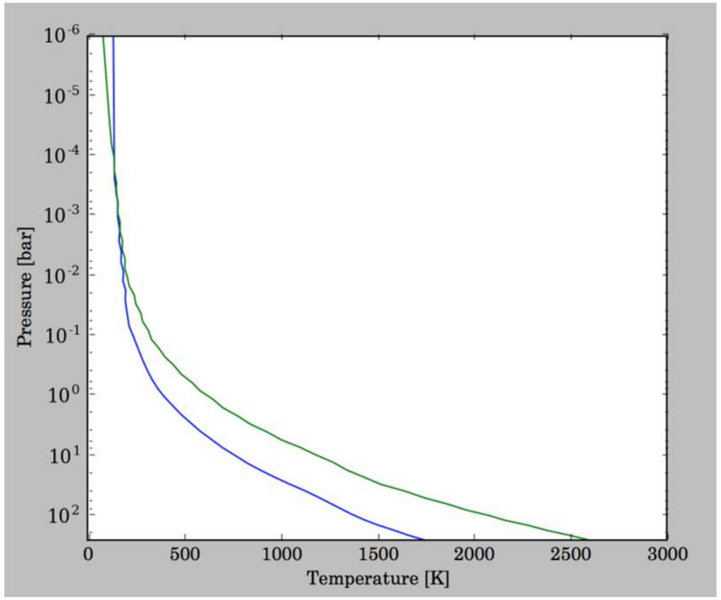
Brown Dwarfs program

MIRI European Consortium

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

3 exoplanets (1 Giant gaseous, 1 intermediate Giant gaseous, 1 Earth mass) in transit
(67 hours MIRI EC GTO; in coordination with Tom Greene for two of them)
(+ 5 exoplanets in transit (77 hours MIRI Tom Greene GTO))

12 Exoplanets observed by direct imaging (40 hours MIRI EC GTO)
MIRI coronographic observations (5), LRS (6), MRS (1)
+ 3 exoplanets Gene Serabyn (20 hours MIRI JPL GTO, corono)
In coordination with short wavelengths obs (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