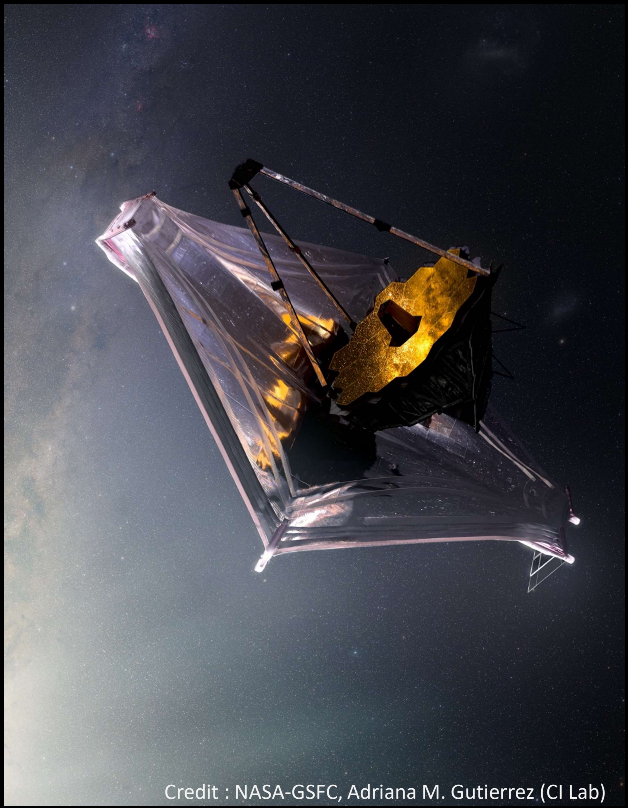
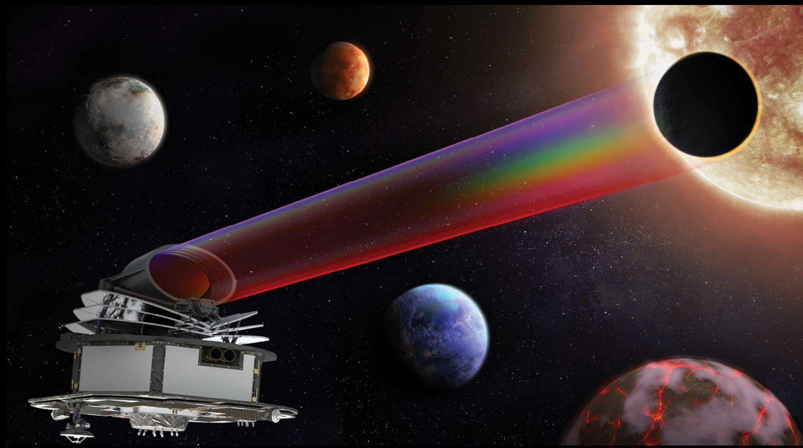
Charactérisation des atmosphères d’exoplanétes avec le JWST et Ariel



Credit : NASA-GSFC, Adriana M. Gutierrez (CI Lab)

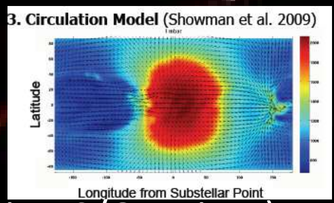
Pierre-Olivier Lagage



https://www.esa.int/ESA_Multimedia/Images/2024/07/Ariel_key_visual

Why studying exoplanet atmospheres ?

- Constraining atmospheric models in conditions not present in the Solar system
(Physical, Chemical processes at work, clouds formation, atmosphere structure, dynamics, climate…)



- Constraining the formation and evolution of exoplanets
(from the molecular composition of the atmosphere, metallicity, C/O ratio..;)

- Constraining the interior of exoplanets
(Models of exoplanet Internal structure can be degenated when only constrainted by mean density)

- Searching for secondary atmosphere around rocky planets and then characterizing
(Ultimately searching for biosignatures)

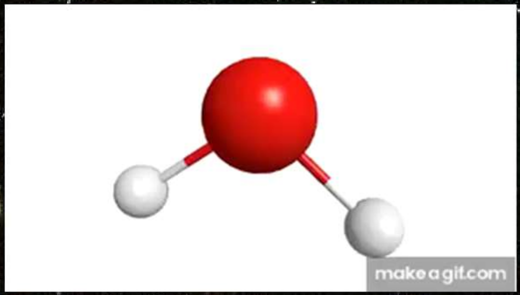
2

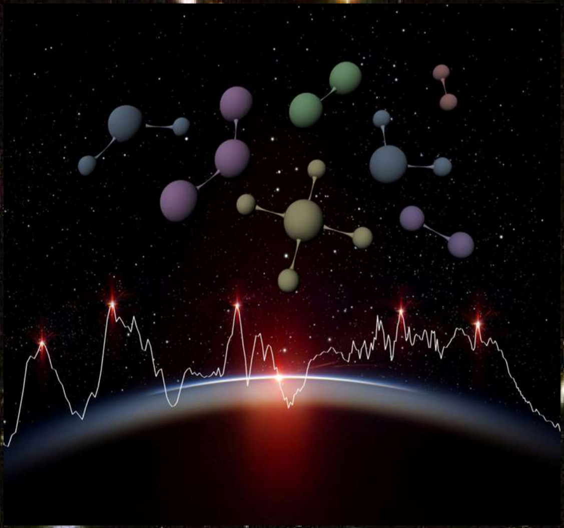
Molecular vibration in the Infrared

Exoplanet atmosphere
(Protostellar disks
Protoplanetary disks)

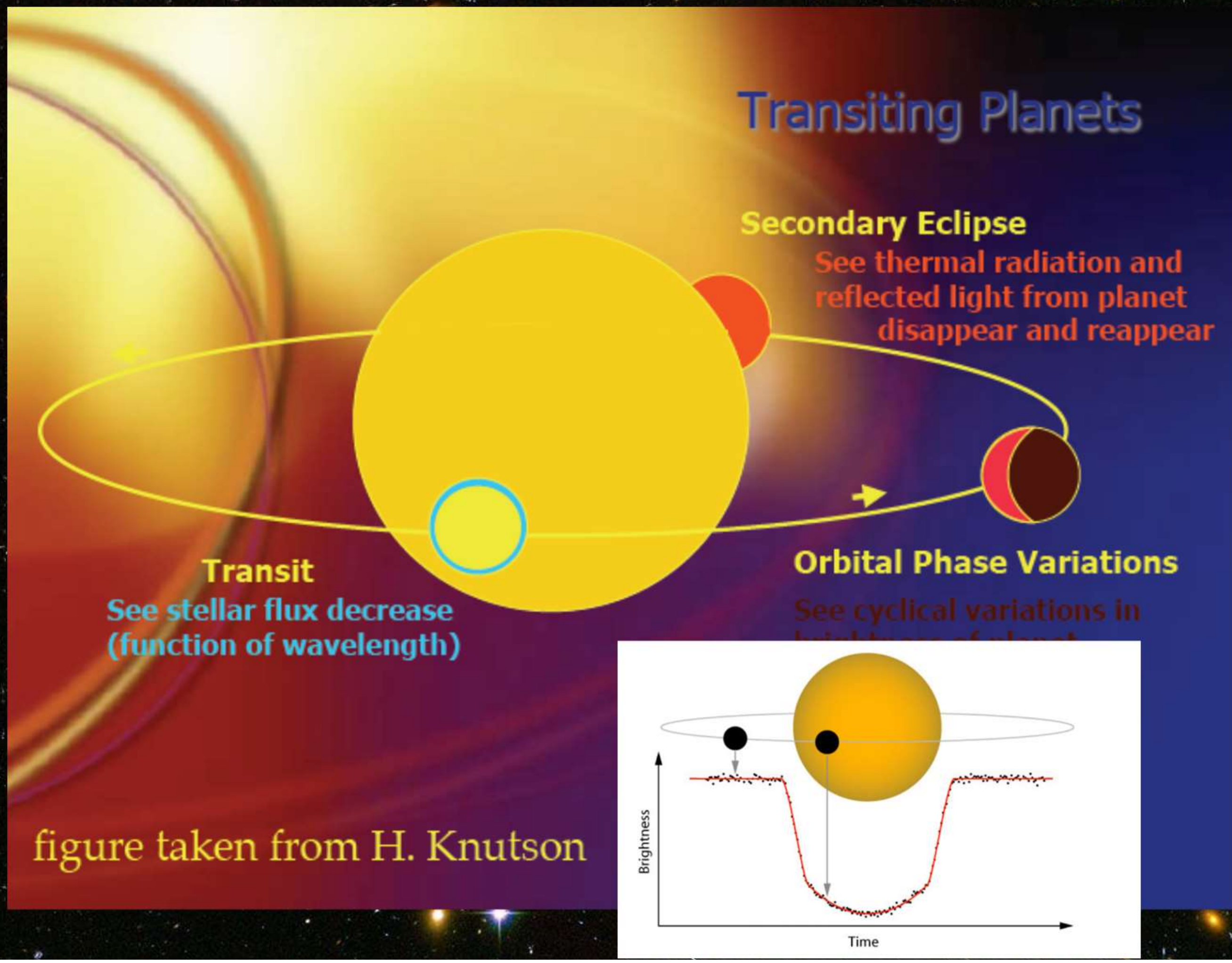
Molecule	λ (S_{max}) 2–5 μm	S_{max} cm^{-2} am^{-1}	λ (S_{max}) 5–16 μm	S_{max} cm^{-2} am^{-1}
H_2O	2.69 (ν_1, ν_3)		6.27 (ν_2)	
HDO	3.67 (ν_1, $2\nu_2$)		7.13 (ν_2)	
CH_4	3.31 (ν_3)		7.66 (ν_4)	
CH_3D	4.54 (ν_2)		8.66 (ν_6)	
NH_3	2.90 (ν_3)		10.33	
	3.00 (ν_1)		10.72 (ν_2)	
PH_3	4.30 (ν_1, ν_3)		8.94 (ν_4)	
			10.08 (ν_2)	
CO	4.67 (1-0)			
CO_2	4.25 (ν_1)		14.99 (ν_2)	
HCN	3.02 (ν_3)		14.04 (ν_2)	
C_2H_2	3.03 (ν_3)		13.7 (ν_5)	
C_2H_6	3.35 (ν_7)		12.16 (ν_{12})	
O_3			9.60 (ν_3)	

Tinetti et al.

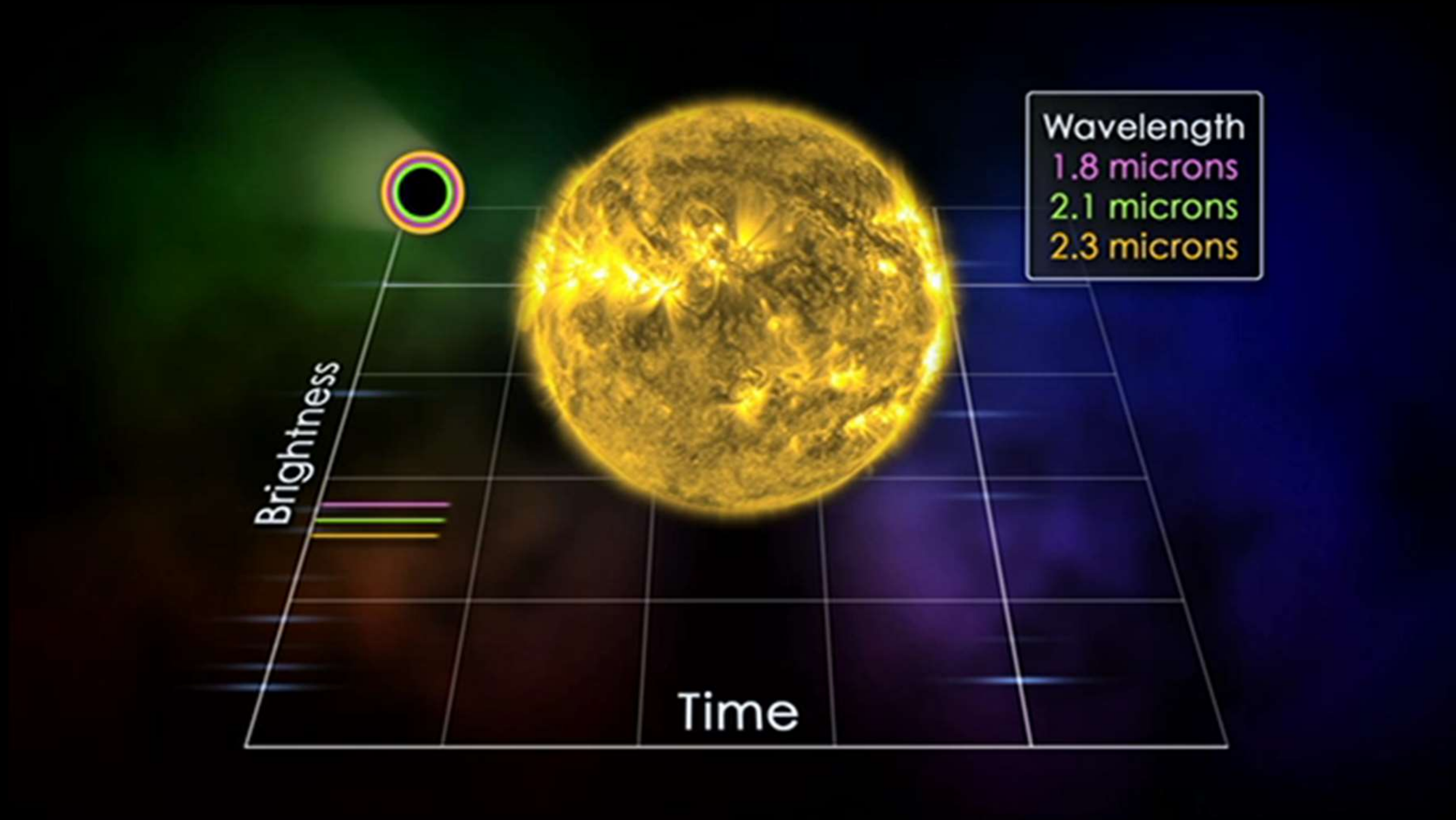




Méthode des transits : des géantes aux rocheuses

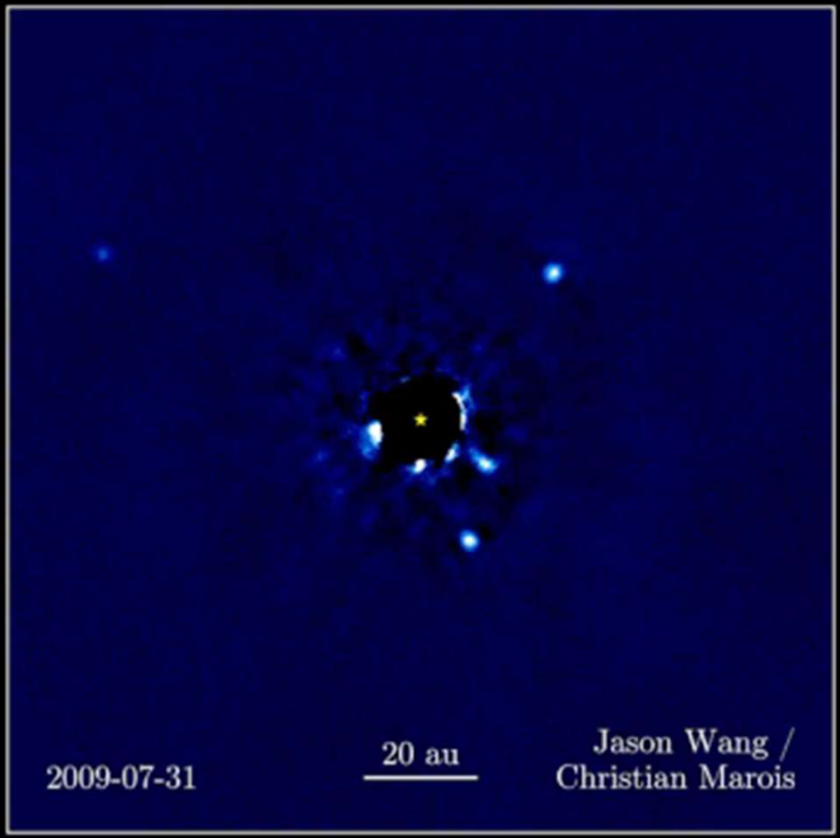


We need to perform **spectroscopic observations** of exoplanet transits



https://svs.gsfc.nasa.gov/11428/

Imagerie directe



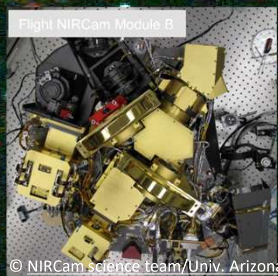
JWST (NASA led)

In operation (launched on the 25th of December 2021)

Ariel (ESA led)

To be launched in 2031
PI G. Tinetti

4 instruments complexes au foyer du télescope



© NIRCam science team/Univ. Arizona

NIRCAM


•CREDIT EADS Astrium

NIRSPEC


•CREDIT CSA

NIRISS

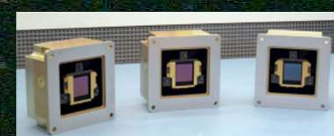
Collaboration Europe-US (JPL)

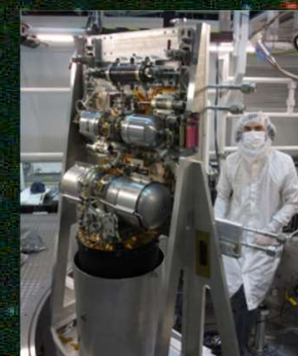
EC PI : Gillian Wright ROE ; POL F Co-PI
US PI : George Rieke (Arizona University)


Credit: STFC RAL Space

MIRI

Focal plan and cryocoolers by JPL (Mike Ressler)

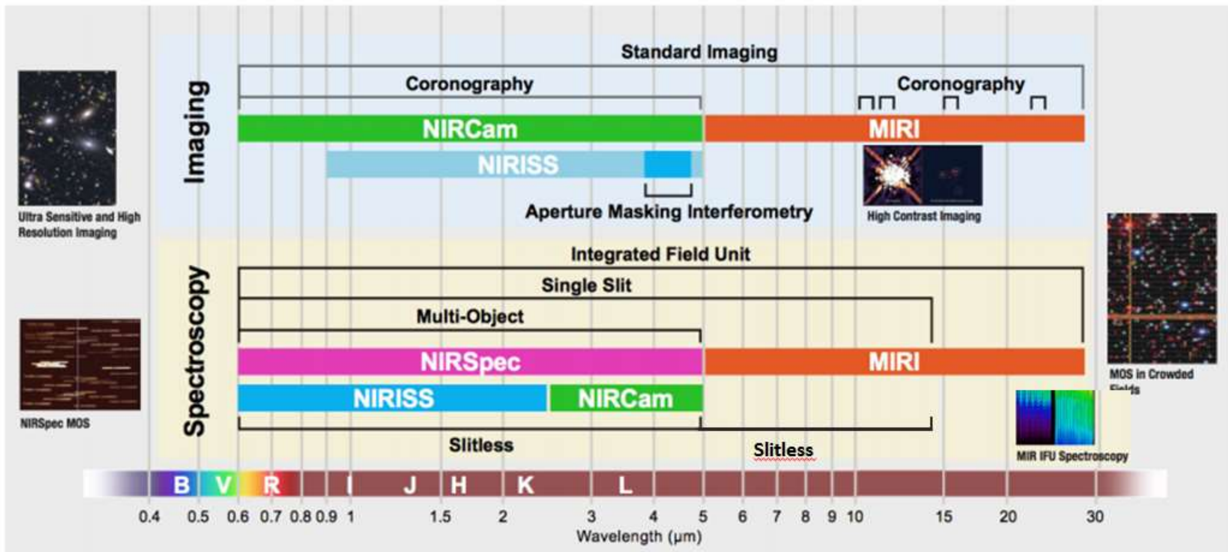




The Cryocooler Compressor Assembly..
Image: NASA/JPL-Caltech

crédit NASA

10 of the 17 observing modes dedicated to exoplanet observations (one issue is avoiding saturation)



lapted from STScI

Transiting

- NIRISS Single Object Slitless Spectroscopy (SOSS)
- NIRCam Time-Series Imaging
- NIRCam Grism Time Series
- NIRSpec Bright Object Time-Series Spectroscopy (BOTS)
- MIRI Imaging TSOs
- MIRI Low Resolution Spectroscopy (LRS)
- MIRI Medium Resolution Spectroscopy (MRS)

Direct imaging

MIRI Coronagraphic Imaging

NIRCam Coronagraphic Imaging

NIRISS Aperture Masking Interferometry

Atelier de travail préparation réponse appel à propositions JWST cycle 6

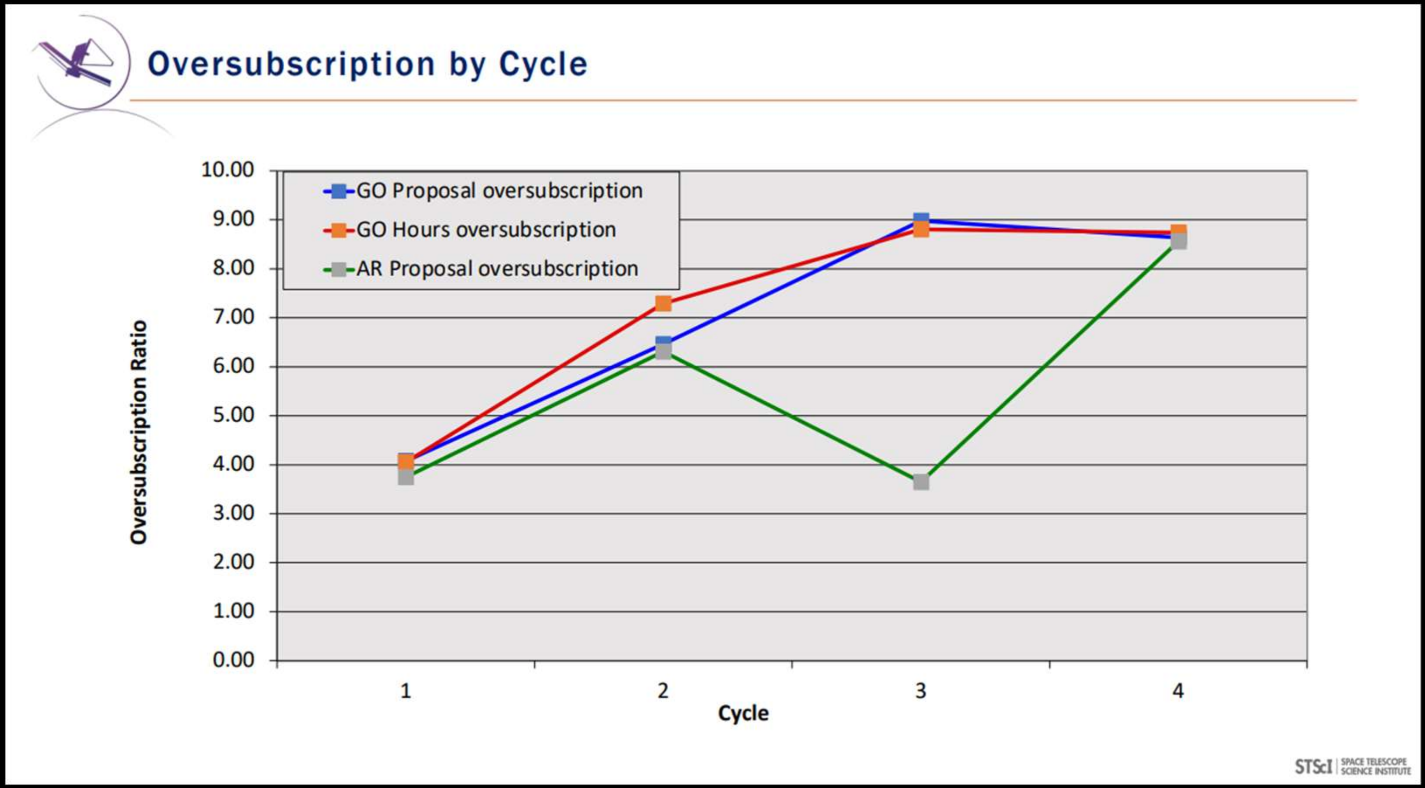
Nice du 16 au 18 juin

V. Parmentier et al.

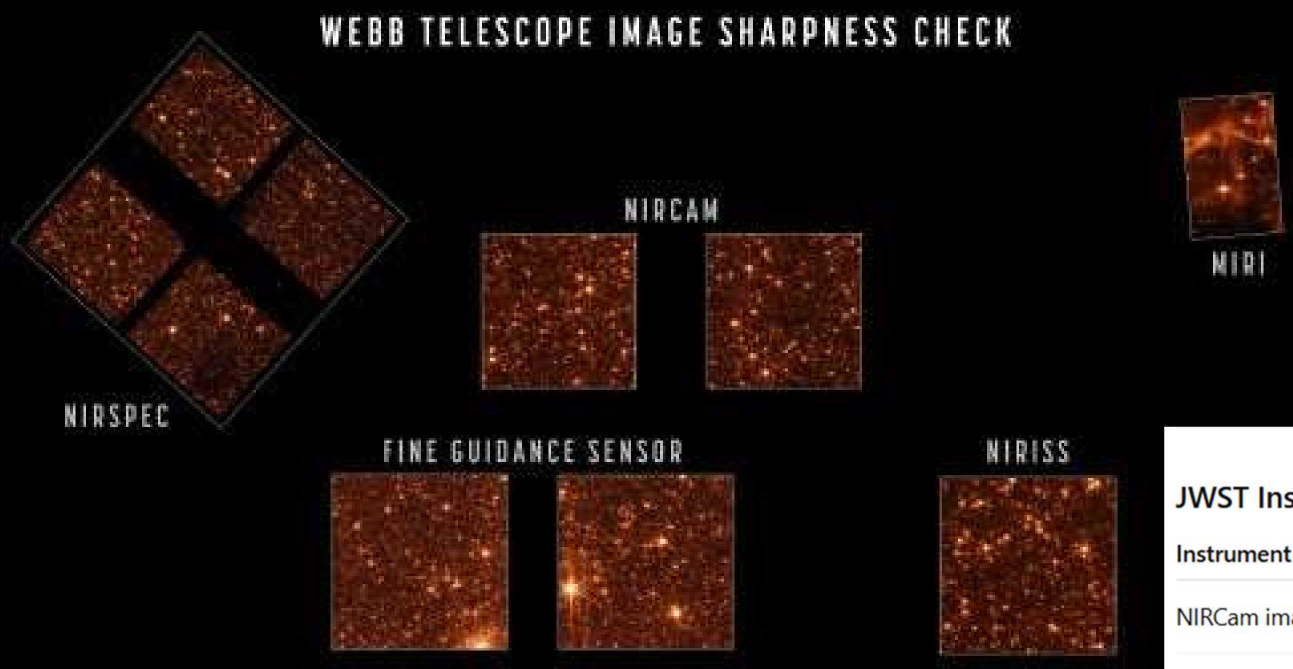
JEPP C5 - JWST Exosystems Proposal Preparation Workshop, Cycle 5

18-19 juin 2025 Marseille (France)

Très forte pression pour avoir du temps d'observation!



The instruments do not see the same field



Approximate usable field of view: 20 arcmin × 10 arcmin

Table — Pixel Size / Pixel Scale

Instrument / Mode	Pixel Scale
NIRCam short-wave	~0.031″ / pixel
NIRCam long-wave	~0.063″ / pixel
NIRISS imaging	~0.066″ / pixel
MIRI imaging	~0.11″ / pixel
NIRSpec MOS/IFU	~0.1″ / pixel (approx)

JWST Instrument Field of View (FoV)

Instrument / Mode	FoV
NIRCam imaging (each module)	2.2′ × 4.4′
NIRISS imaging	2.2′ × 2.2′
MIRI imaging	74″ × 113″
NIRSpec MOS	~9.7 arcmin^2

Des performances exceptionnelles

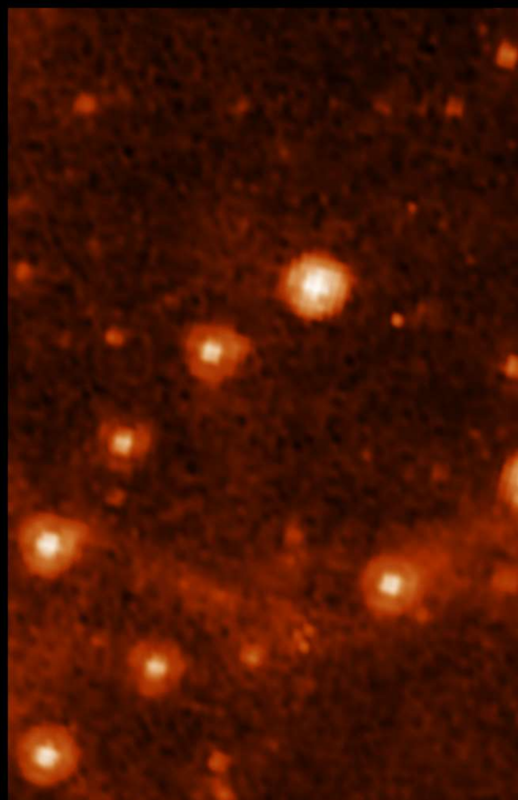
La qualité image est meilleure que spécifiée (limite de diffraction à 1 micron au lieu de 2)

La transmission est meilleure que spécifiée

La stabilité du telescope est meilleure que spécifiée (< 1 mas alors que la specification était de 4 mas)

→ Sensibilité environ 2 fois meilleure qu'annoncé

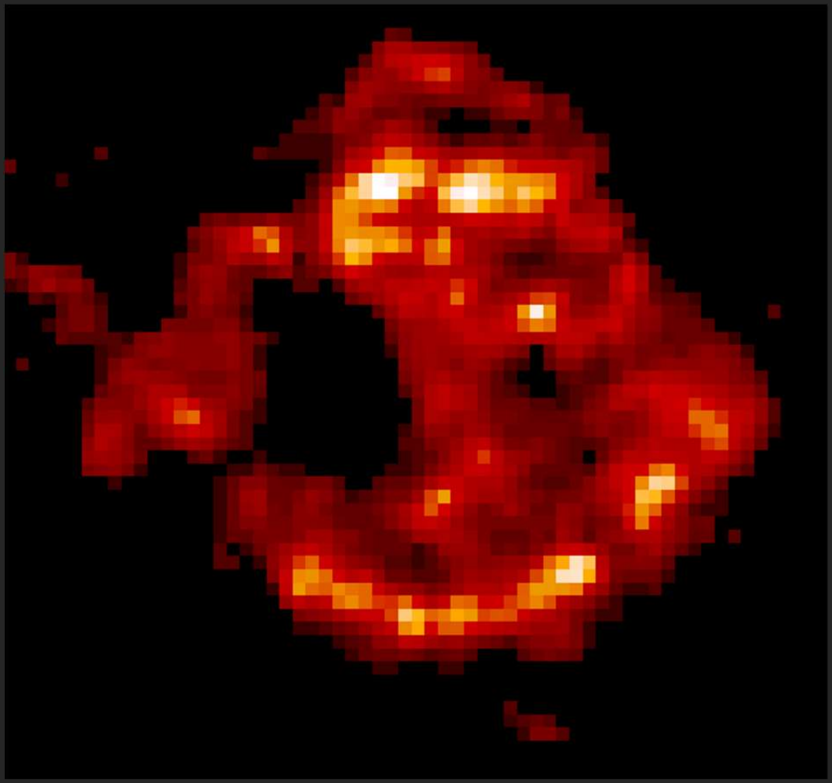
Diffraction pattern : λ/D



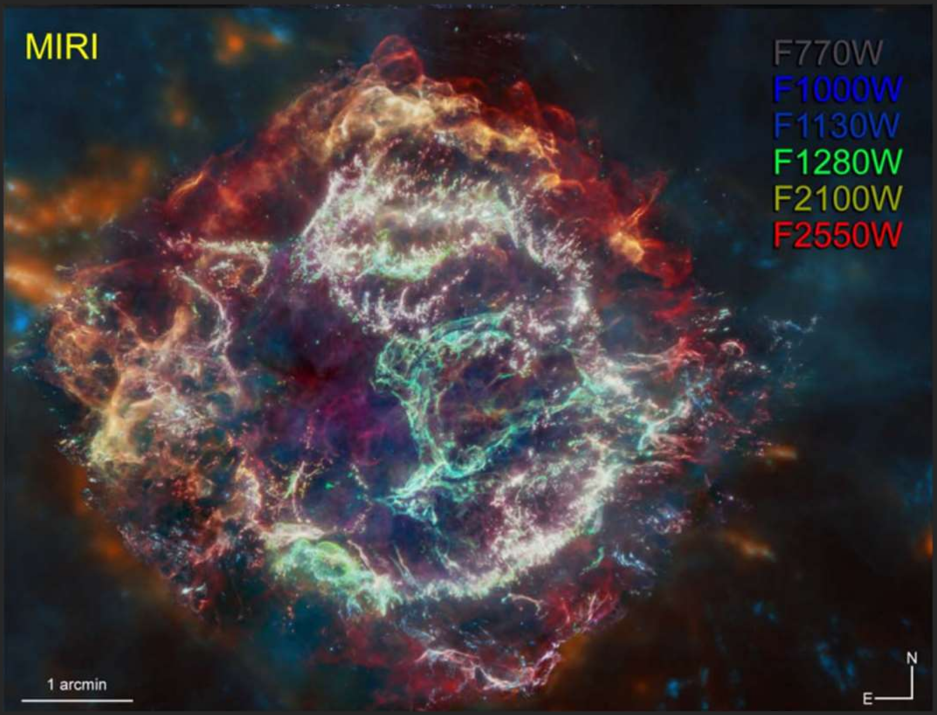
SPITZER IRAC 8.0μ

WEBB MIRI 7.7μ

CREDIT; Spitzer: NASA/JPL-Caltech; MIRI: NASA/ESA/CSA/STScI

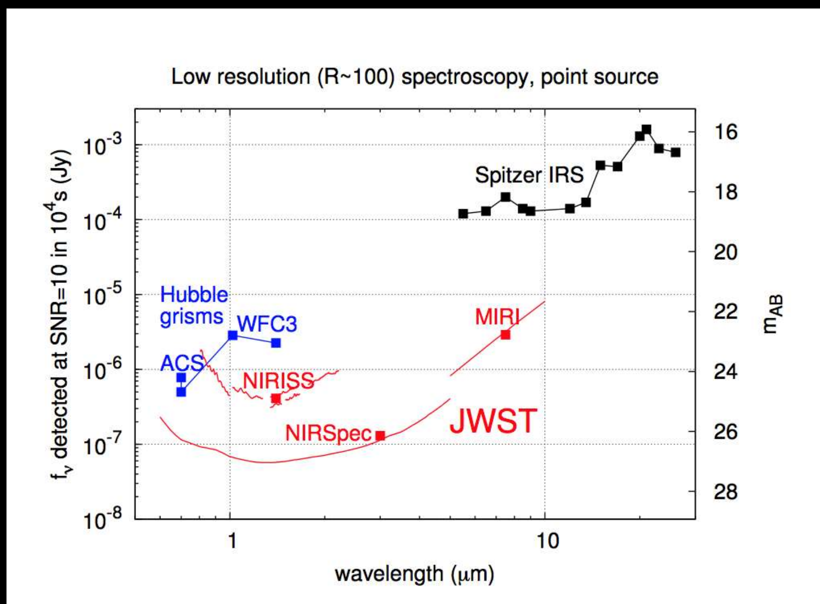


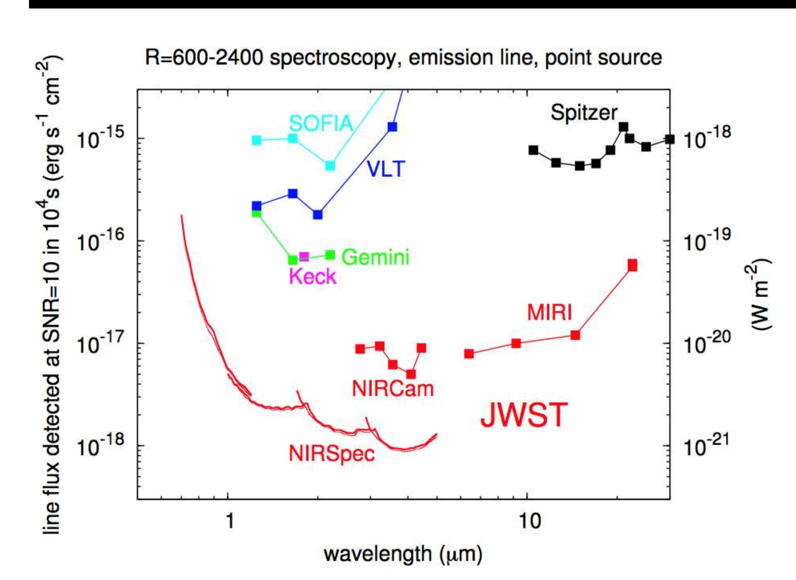
ISOCAM : 10.7 – 12 microns
(P.-O. Lagage et al. 1996)



MIRI composite image
(Dan Milisavljevic et al. 2024)

Sensibility





From www.stci.edu/jwst/science/sensitivity

Environ 200 observées exoplanetes

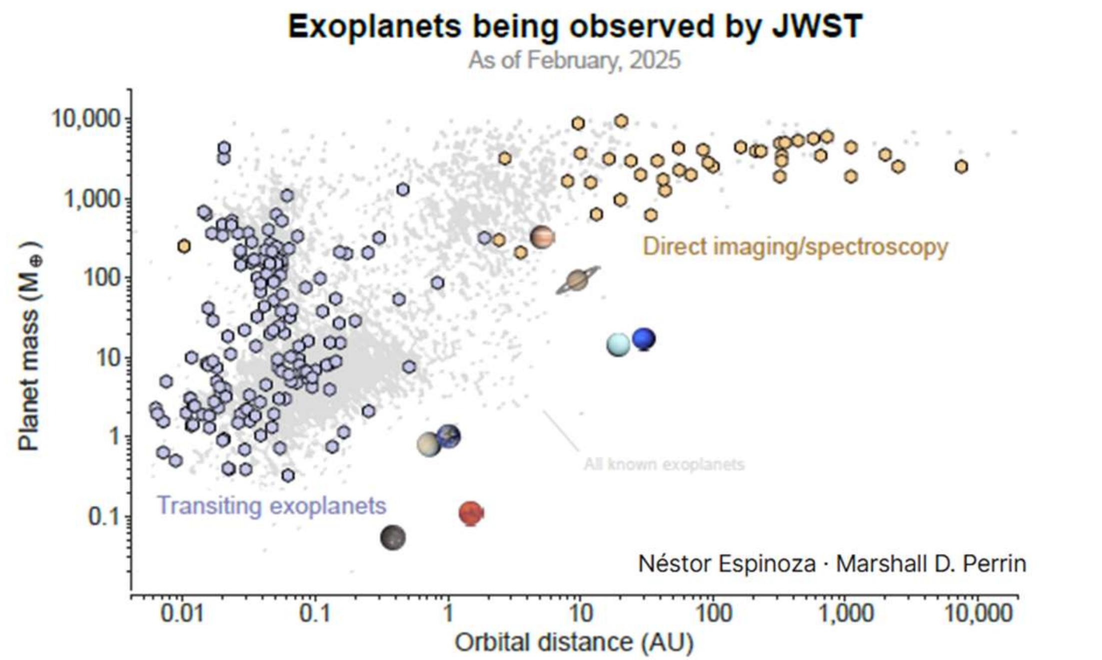


Fig. 2 Exoplanets being observed by JWST as of February 2025. Orbital distance in Astronomical Units (AU) versus planetary mass (in Earth's units) of known exoplanets being observed by JWST through February 2025 (hexagons). This includes Guaranteed Time Observations (GTO), Director's Discretionary Time (DDT), Early Release Observations (ERO), Early Release Science (ERS) and General Observer (GO) observations from Cycles 1, 2 and 3. Yellow hexagons represent JWST direct imaging/spectroscopy exoplanet observations, while purple hexagon represent transiting exoplanet observations with JWST. Grey points represent all known confirmed exoplanets. Images of Solar System planets are embedded for reference.

https://www.stsci.edu/~nnikolov/TrExoLiSTS/JWST/trexolists.html

TrExoLiSTS: Transiting Exoplanets List of Space Telescope Spectroscopy

Welcome to TrExoLiSTS! This table details archived and planned JWST NIRSpec, NIRISS, NIRCam and MIRI observations of transiting exoplanets and flares of red dwarfs. Complementary physical, orbital and observational properties are provided for the stars and planets identified in the "NASA Exoplanet Archive".

Usage: Please click on the table headers and use the filter boxes to sort or filter the table, respectively. The search bar on the right can be employed to look for targets, observations, instrument modes, etc., that may have already been observed or employed by a previous program.

Table download: CSV

Documentation: Research Note to the AAS and STScI Instrument Science Report

Last update: 2026-04-01 01:16:13

For questions, or to report issues, please contact Nikolay Nikolov at: nnikolov@stsci.edu

Show 25 entries　　　　Search:

Star name	Planet letter	Event	Program	Cycle	Obs.	Visit status*	Observing Mode	Subarray	Readout pattern	Groups	Start UT decimal	Start UT YYYY-m hh:mm:
Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter
WASP-96	b	Transit	COM 2734	0	2	Archived	NIRISS SOSS	SUBSTRIP256	NISRAPID	14.0	2022.469	2022-06
L 168-9	b	Transit	COM 1033	0	5	Archived	MIRI LRS	SLITLESSPRISM	FASTR1	9.0	2022.406	2022-05
K2-34	b	Transit	COM 1541	0	3	Withdrawn	NIRISS SOSS	SUBSTRIP256	NISRAPID	16.0	n/a	n/a
HAT-P-14	b	Transit	COM 1442	0	1	Archived	NIRCam GRISMR+F322W2	SUBGRISM128	BRIGHT2	20.0	2022.332	2022-05

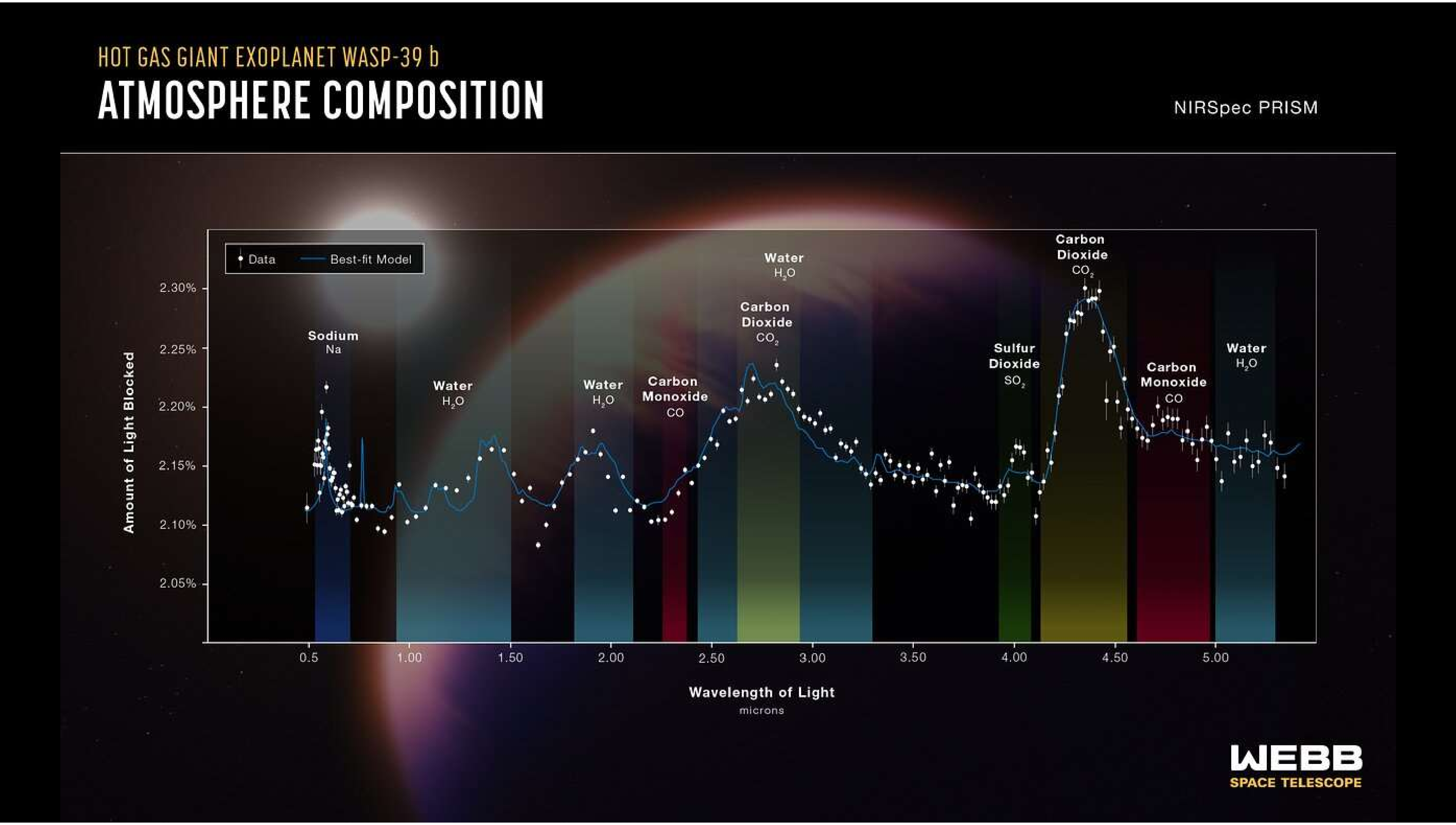
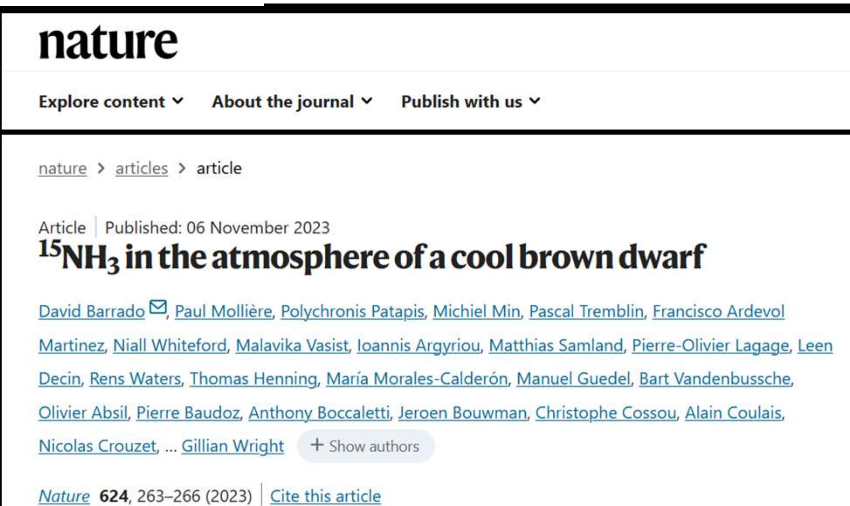

HOT GAS GIANT EXOPLANET WASP-39 b
ATMOSPHERE COMPOSITION
NIRSpec PRISM
Data
Best-fit Model
Sodium
Na
Water
H_2O
Water
H_2O
Carbon Monoxide
CO
Carbon Dioxide
CO_2
Water
H_2O
Sulfur Dioxide
SO_2
Carbon Dioxide
CO_2
Carbon Monoxide
CO
Water
H_2O
Amount of Light Blocked
2.30%
2.25%
2.20%
2.15%
2.10%
2.05%
0.5
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Wavelength of Light
microns
WEBB
SPACE TELESCOPE

Illustration of results from MIRI in the framework of GTO time

2) MRS observations of J1828, a Brown Dwarf at 380 K


nature

Explore content About the journal Publish with us

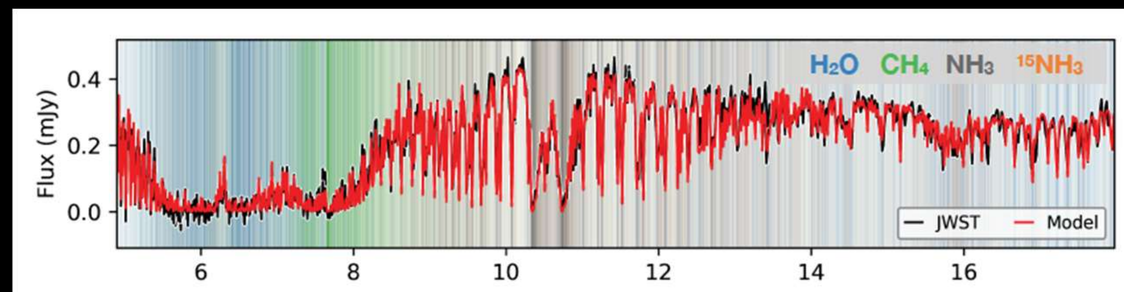
nature > articles > article

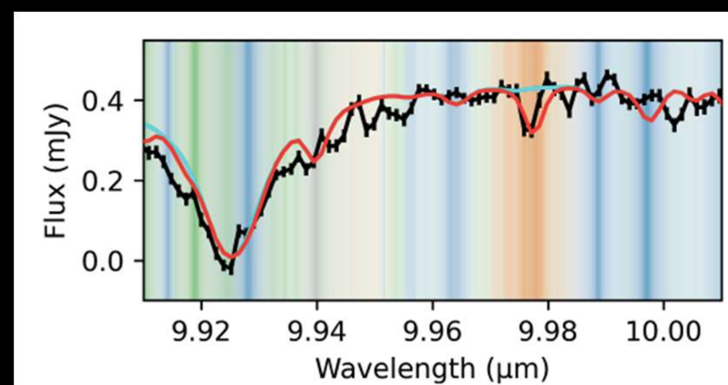
Article | Published: 06 November 2023

$^{15}NH_3$ in the atmosphere of a cool brown dwarf

David Barrado, Paul Mollière, Polychronis Patapis, Michiel Min, Pascal Tremblin, Francisco Ardevol Martinez, Niall Whiteford, Malavika Vasist, Ioannis Argyriou, Matthias Samland, Pierre-Olivier Lagage, Leen Decin, Rens Waters, Thomas Henning, María Morales-Calderón, Manuel Guedel, Bart Vandenbussche, Olivier Absil, Pierre Baudoz, Anthony Boccaletti, Jeroen Bouwman, Christophe Cossou, Alain Coulais, Nicolas Crouzet, ... Gillian Wright + Show authors

Nature 624, 263–266 (2023) | Cite this article





Detection Of $^{15}NH_3$, isotopologue de $^{14}NH_3$

Disques protoplanétaires

nature astronomy

Explore content ⌄ About the journal ⌄ Publish with us ⌄ Subscribe

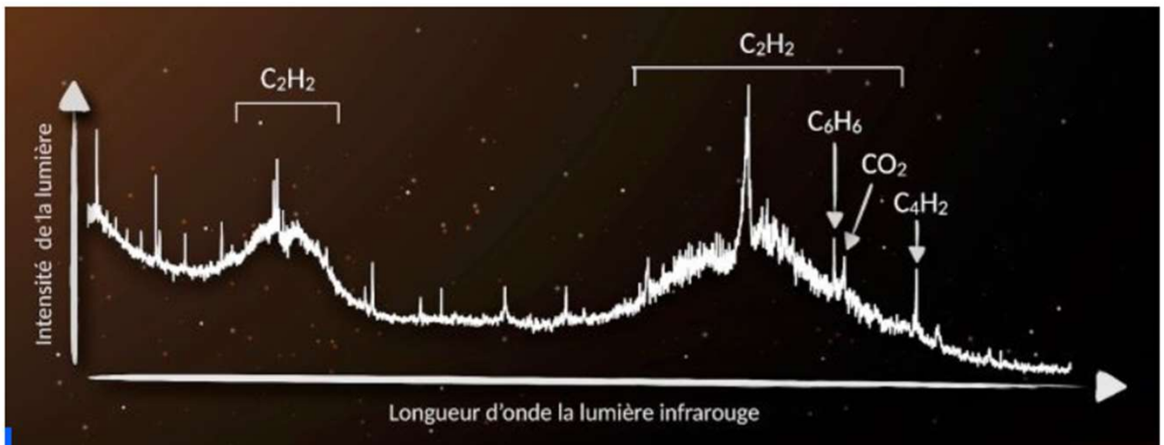
nature › nature astronomy › articles › article

Article | Published: 11 May 2023

A rich hydrocarbon chemistry and high C to O ratio in the inner disk around a very low-mass star

B. Tabone, G. Bettoni, E. F. van Dishoeck, A. M. Arabhavi, S. Grant, D. Gasman, Th. Henning, I. Kamp, M. Güdel, P. O. Lagage, T. Ray, B. Vandenbussche, A. Abergel, O. Absil, I. Argyriou, D. Barrado, A. Boccaletti, J. Bouwman, A. Caratti o Garatti, V. Geers, A. M. Glauser, K. Justannont, F. Lahuis, M. Mueller, ... G. Wright

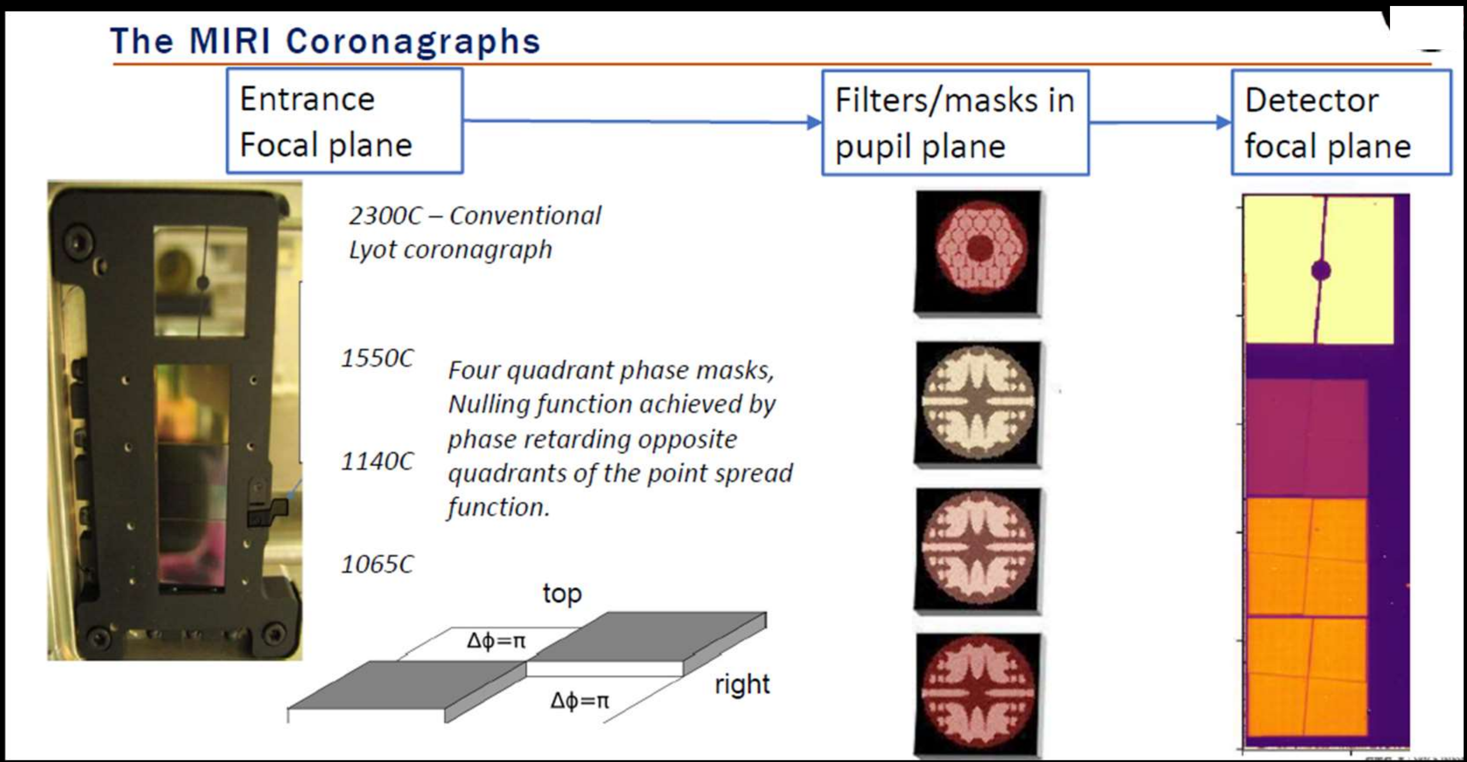
+ Show authors



The MIRI spectrum of star J160532. Emission lines for benzene (C2H6), diacetylene (C4H2), and carbon dioxide (CO2) appear as narrow peaks in the spectrum. Acetylene is so abundant that it produces two large humps in the spectrum. This reflects the predominance of hydrocarbons in the disc. Emissions from water, commonly observed in other discs, are weak or absent.

© Benoît Tabone/MINDS consortium/NASA/ESA

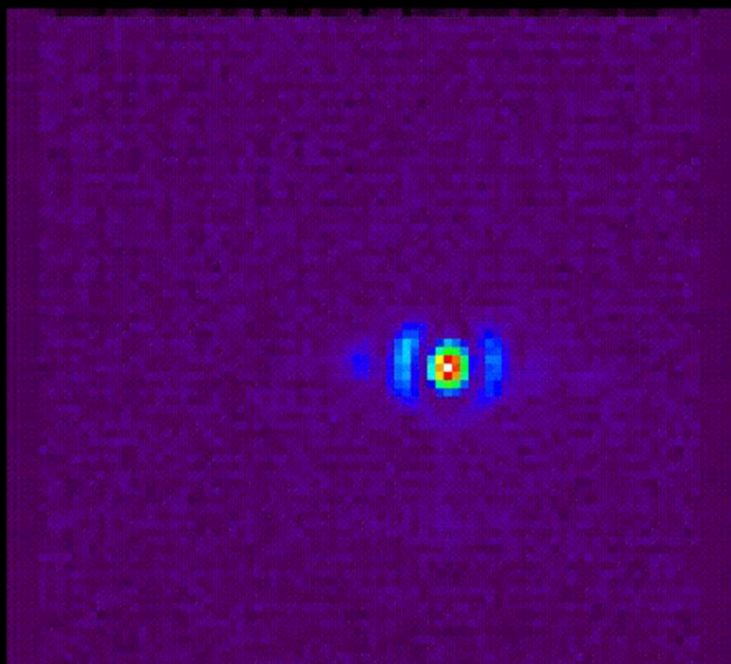
Direct imaging with JWST : coronographic observations

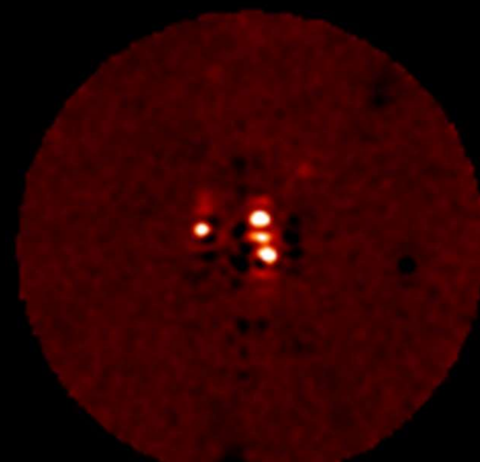


Placing the target at the center of the coronagraph within 5-10 mas for the phase masks and 20 mas for the lyot mask **is key**

Advantage → λ / D ; same performance as NIRCAM coronagraph

Coronographie





Méthode limitée aux exoplanètes géantes et jeunes

JWST (NASA led)

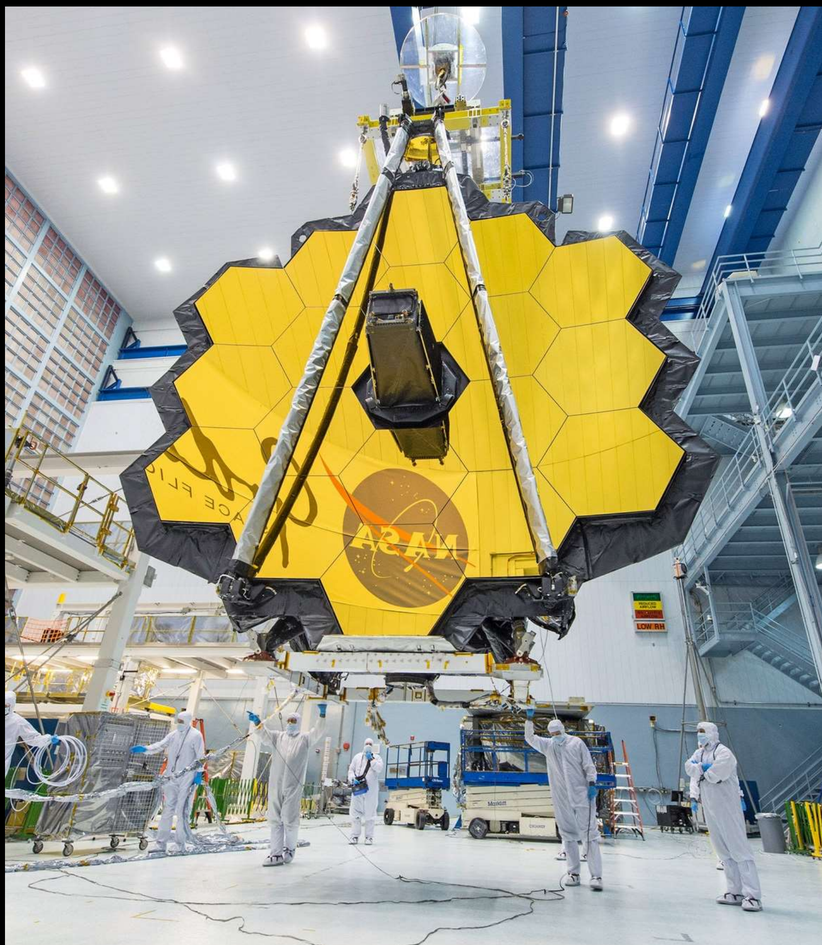
In operation (launched on the 25th of December 2021)

© ESA

Ariel (ESA led)

To be launched in 2031
PI G. Tinetti

JWST **25 m^2**



Ariel **0.6 m^2**

Ariel peut être plus efficace que JWST !

Méthode des transits

On observe des sources proches et brillantes; problème de saturation des détecteurs JWST

Spectro-Photométrie relative , il faut une ligne de base
→ temps d'observation incompressible

Telescope size :

D = 6.5 m

D ~ 1 m

- For transit

S/N depends on f(planet(r,H))*D*$(F_{star}*t_{obs})^{1/2}$

$t_{obs\ min}$ = T_transit

brighter the star is, better the S/N is

Ariel can observe brighter targets than JWST (detector Saturation)

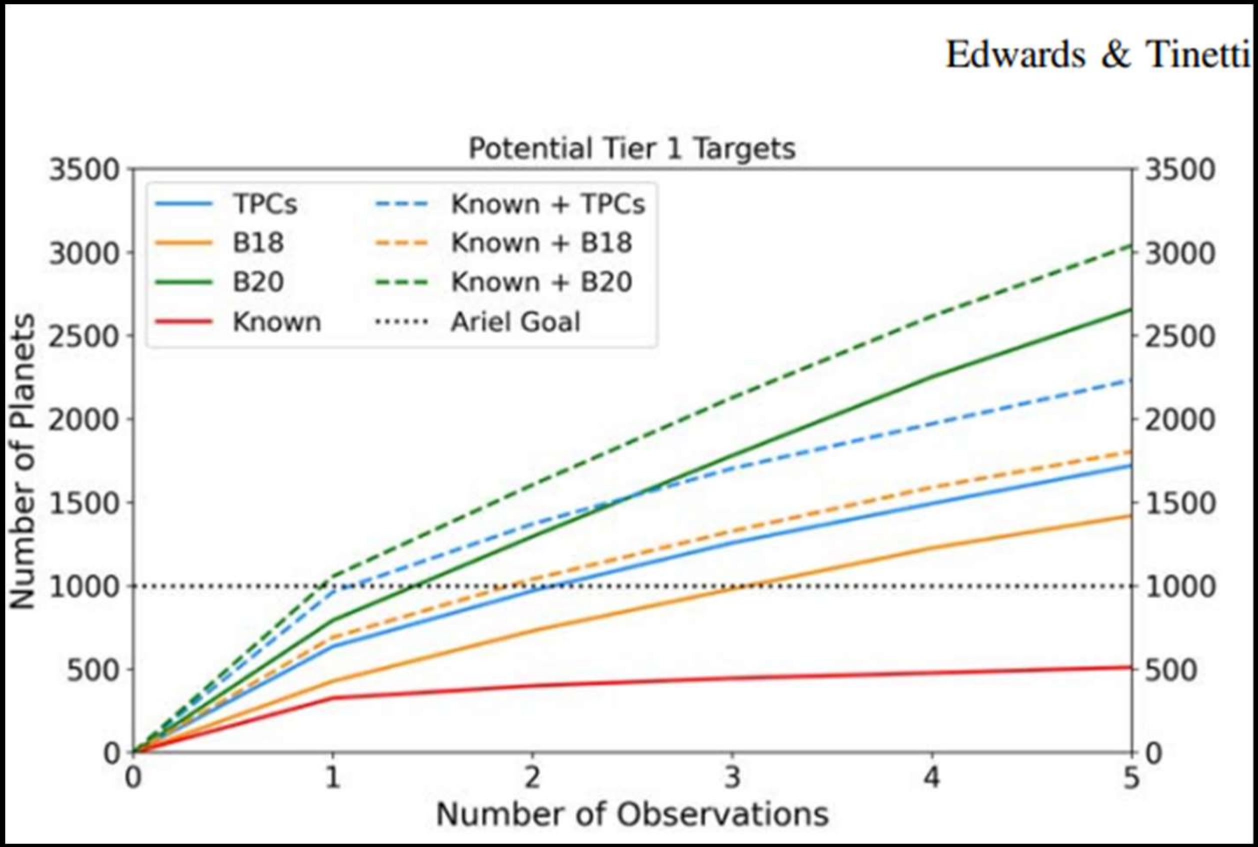
For Eclipse and the detection of planet emission

S/N depends on f(planet(r, T))*D*$t_{obs})^{1/2}$ / $(F_{star})^{1/}$

faintest the star is, better the S/N is

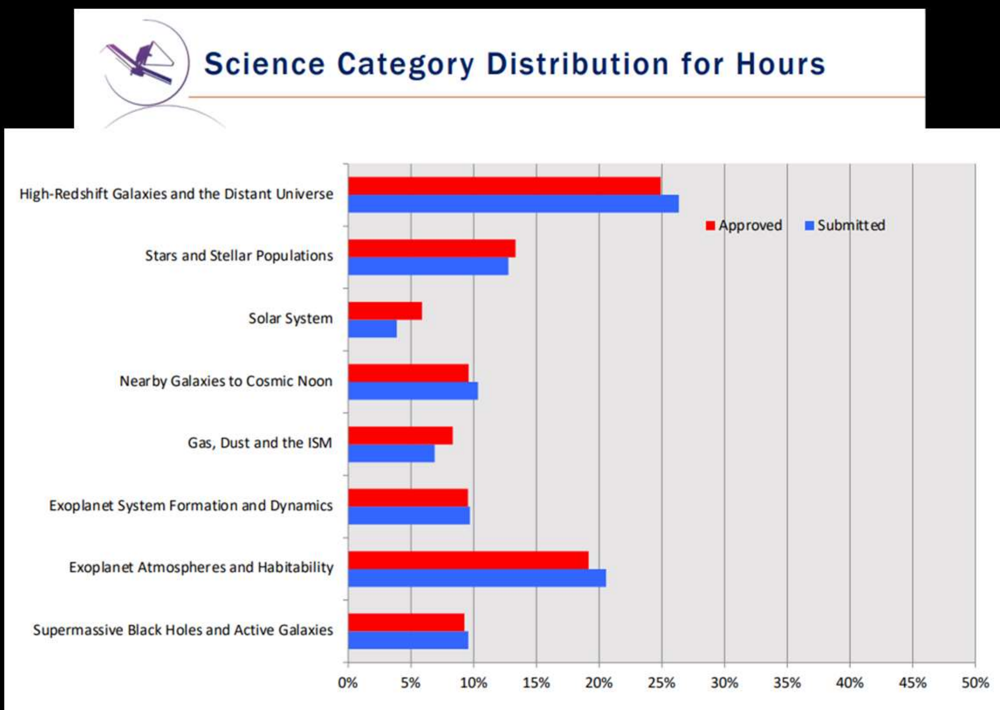
JWST Higher S/N means detecting smaller stars or at a lower temperature

Ariel peut être plus efficace que JWST !



JWST

Seulement 25% du temps d'observation consacré aux exoplanètes



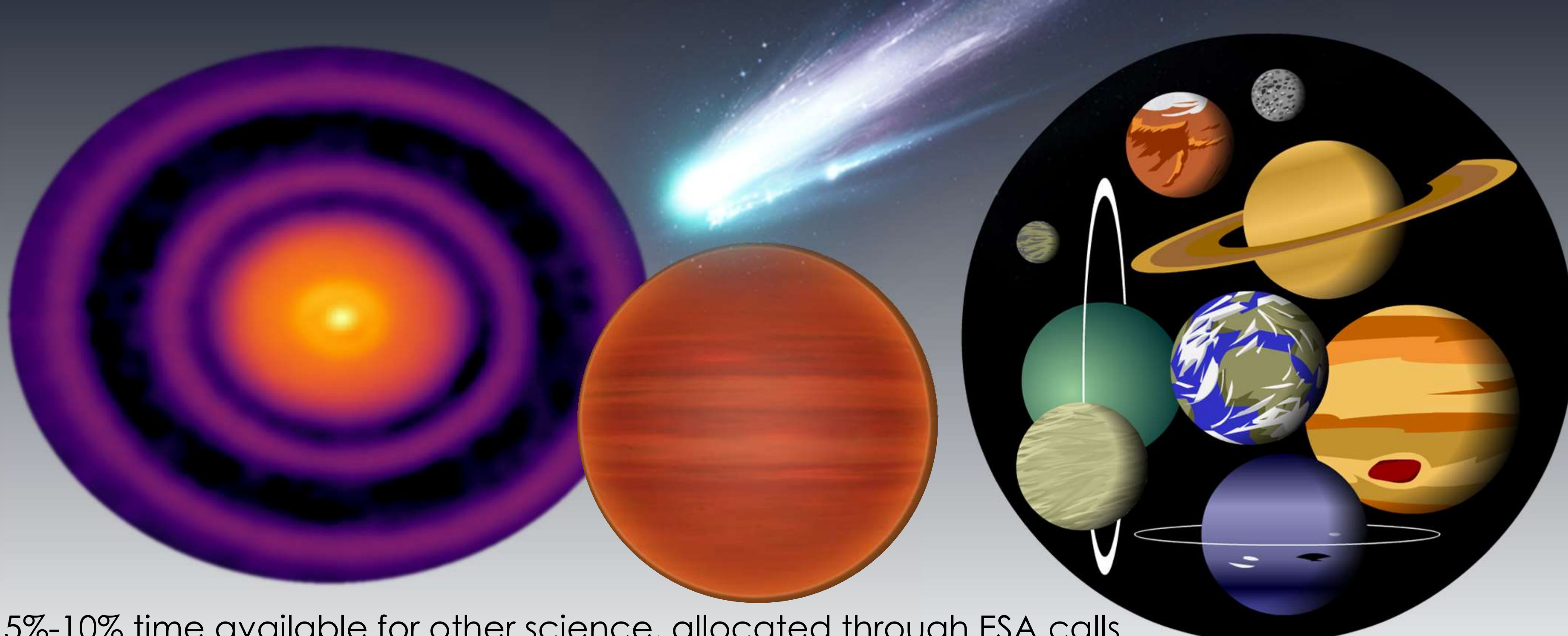
Ariel

Dédié à la caractérisation de l'atmosphère d'exoplanéte

90 à 95 % du temps d'obs

Complementary science with Ariel

It is important to understand Ariel performances for science beyond exoplanets



- 5%-10% time available for other science, allocated through ESA calls
- Proprietary to the proposers for 6 months

Spacecraft & mission

S/c studied by Airbus and Ariel Consortium (PLM)

PI consortium: G. Tinetti

Responsable Scientifique ESA:
Theresa Lueftiger

Instruments

- Spectrometers (3 bands)
  - NIRSpec: 1.1-1.95 μm R>15
  - AIRS0: 1.95-3.9 μm R>100
  - AIRS1: 3.9-7.8 μm R>30
- Photometers (3 bands)
  - VISPhot, FGS1/2: 0.5-0.6, 0.6-0.8, 0.8-1.1 μm

Telescope

- Off-axis Cassegrain
- 1.1 x 0.7 m aperture (0.6 m^2 collecting area)

Spacecraft & mission

- Payload module (PLM) passively cooled
- Some detectors actively cooled
- Dual A62 launch, launch mass ~1.4 ton
- Large halo-orbit around L2
- Nominal lifetime 4 years, extended 6 years

Observation de **1000** exoplanètes de façon homogène et simultanément sur la gamme de 0.5 à 7.8 microns

Different approaches and focus.

JWST Cycle 1-4 trends (STScI Strategy report, Redfield+2024):

Community focus on small planets (from GO, DDT 500h).

Potential 30k hours by Cycle 20 (15 years).

Science programs of < 50h (S), < 130h (M), and > 130h (L).

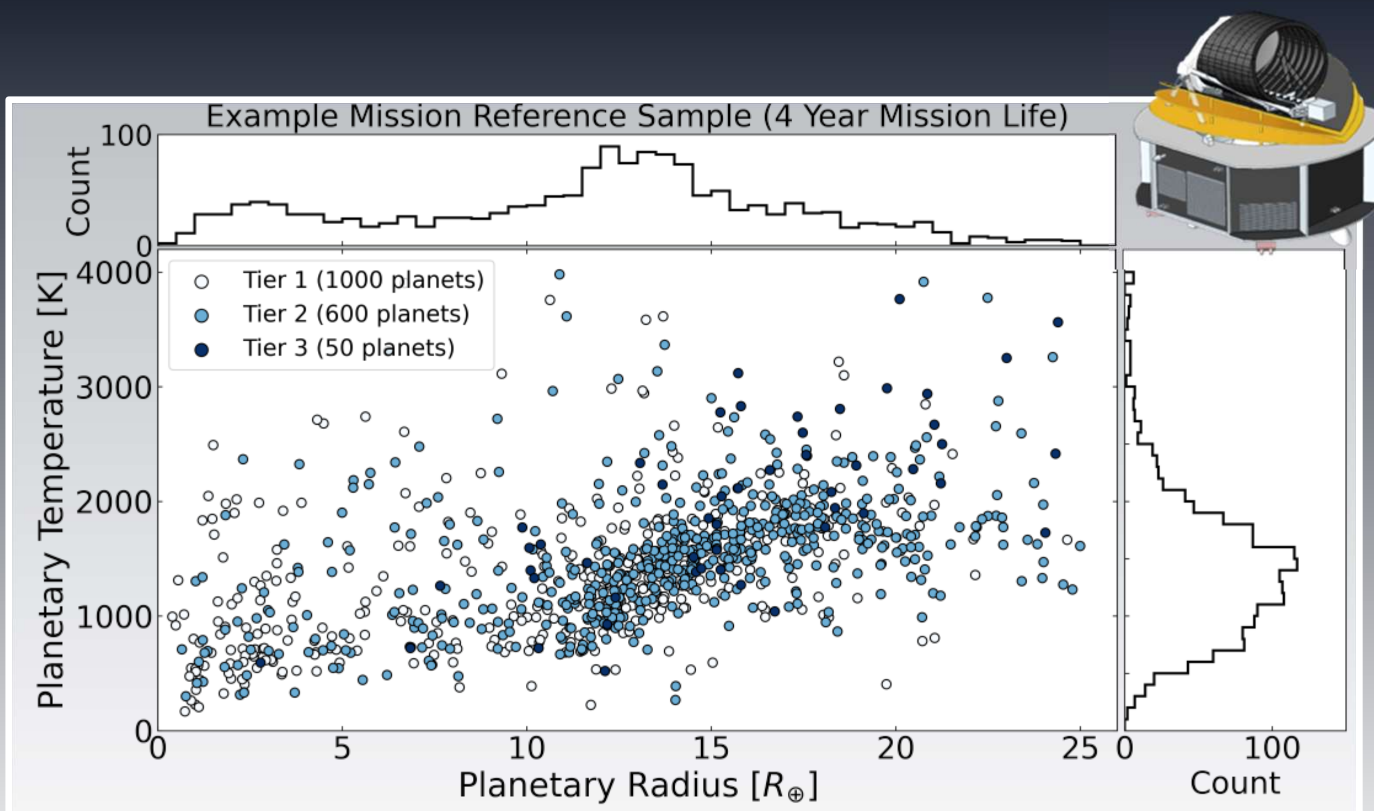
Ariel data:

Homogeneous with same instrumentation.

Wide Survey(s), not GO led. Flexibility!

25k hours by end of primary.

Ariel target candidates (MCS)



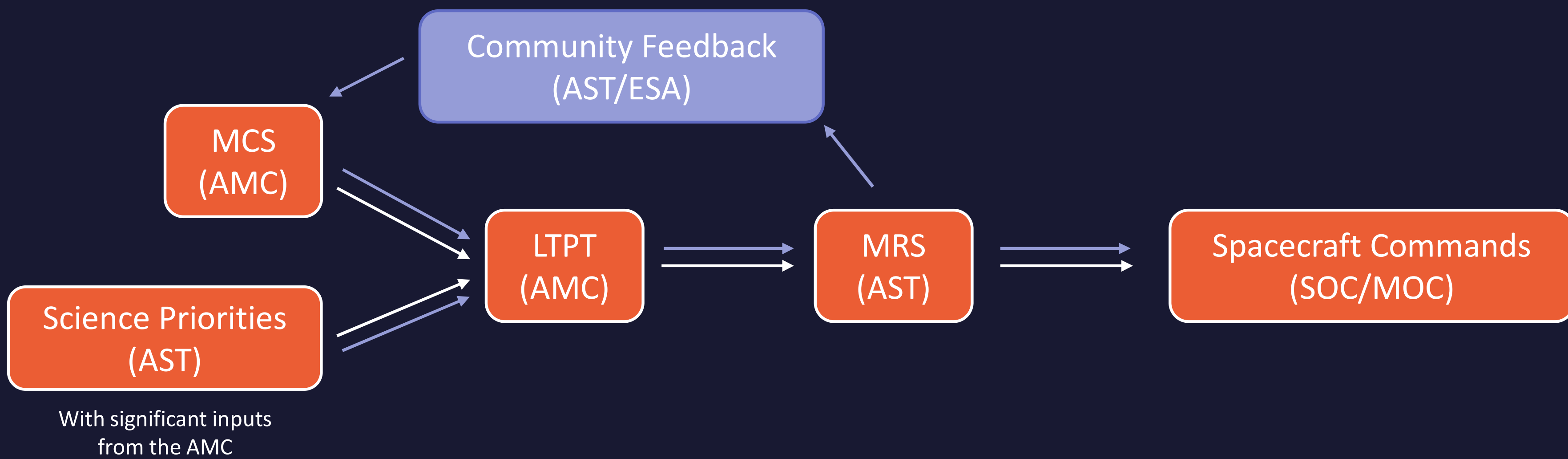
Edwards & Tinetti 2022

Ariel MCS GitHub created and maintained by Billy Edwards

MRS: Mission Reference Sample

MRS
A list of exoplanets that can be studied by Ariel in 3.5 years (prime mission)

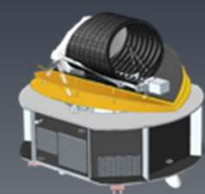
Question: How will the final list be selected?



AMC: Ariel Mission Consortium
AST: Ariel Science Team
LTPT: Long-Term Planning Tool
MCS: Mission Candidate Sample
MRS: Mission Reference Sample
MOC: Mission Operations Centre
SOC: Science Operations Centre

Synergy Ariel-Webb

Complementarity and synergy between Ariel and Webb will be transformational

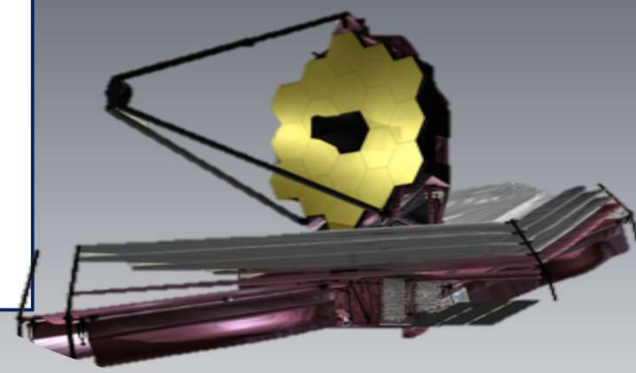


On the synergetic use of Ariel and JWST for exoplanet atmospheric science

Q. Changeat[1], P-O. Lagage[2], G. Tinetti[3], B. Charnay[4], N. B. Cowan[5, 6], C. Danielski[7, 8], E. Ducrot[2, 4], A. Dyrek[9, 2], B. Edwards[10], T. Lueftinger[11], G. Micela[12], G. Morello[8, 12], E. Pascale[13], S. Robert[14], O. Venot[15], J. K. Barstow[16], A. Bocchieri[7, 13], J. Y-K. Cho[17], R. Cloutier[18], A. Coustenis[19], P. Lavvas[20], Y. Miguel[10, 21], and K. H. Yip[3]

[1]Kapteyn Institute, University of Groningen, 9747 AD Groningen, NL
[2]Université Paris-Saclay, Université Paris Cité, CEA, CNRS, AIM, F-91191 Gif-sur-Yvette, France.

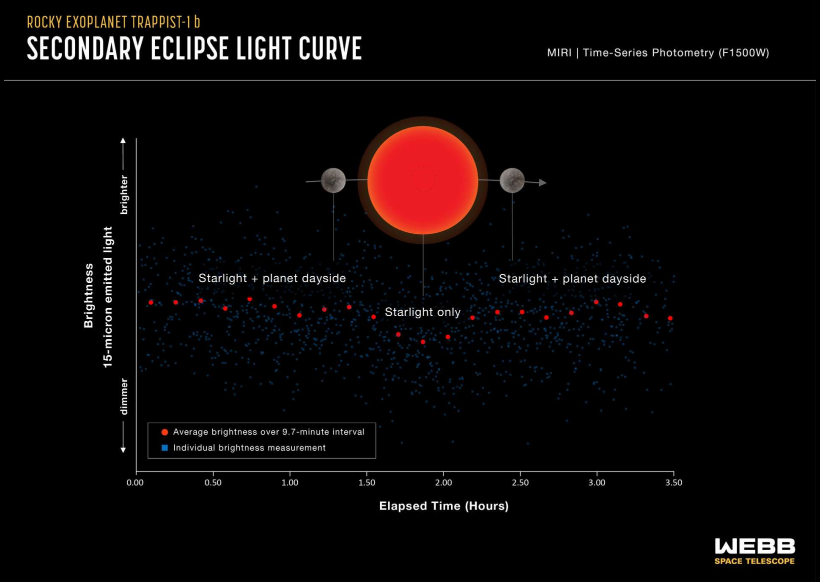
2 Sep 2025

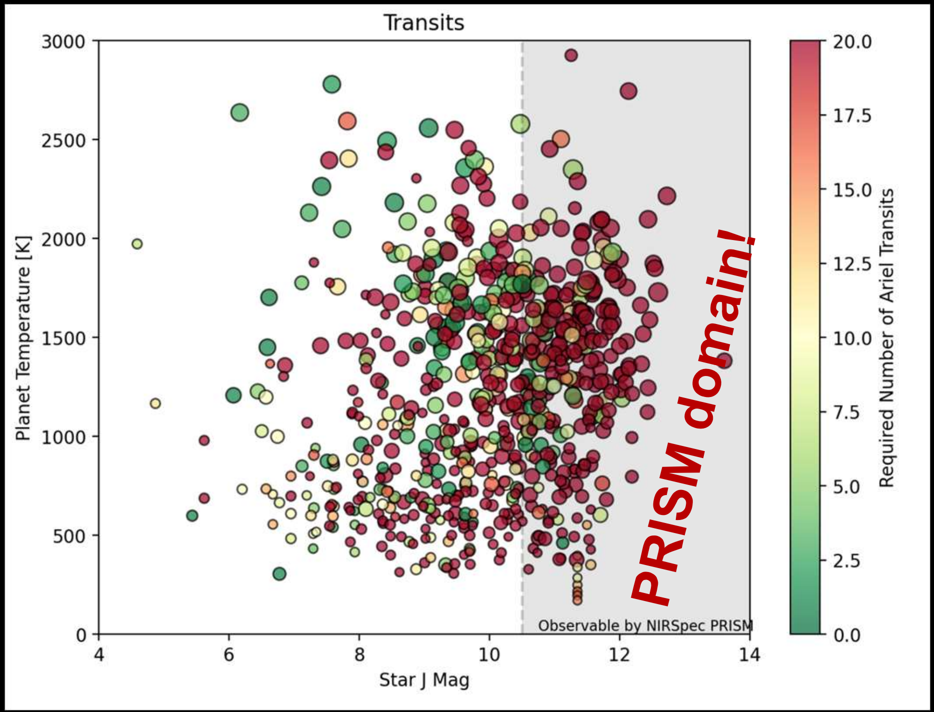


Changeat, Lagage et al. https://arxiv.org/pdf/2509.02657

JWST unique

- Small & temperate transits
- Faint targets



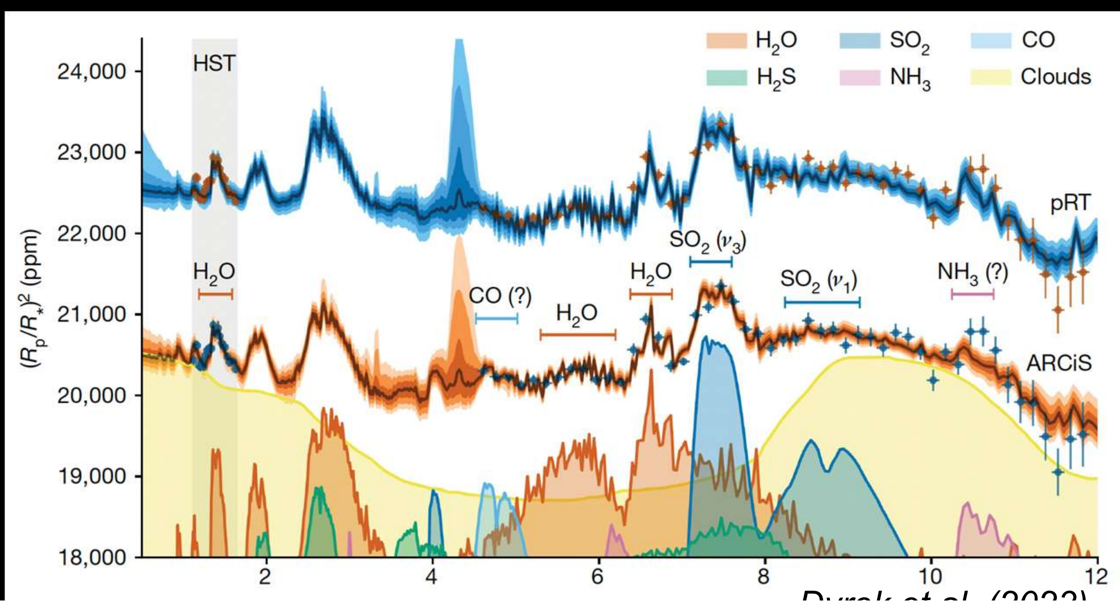


Follow up Ariel targets

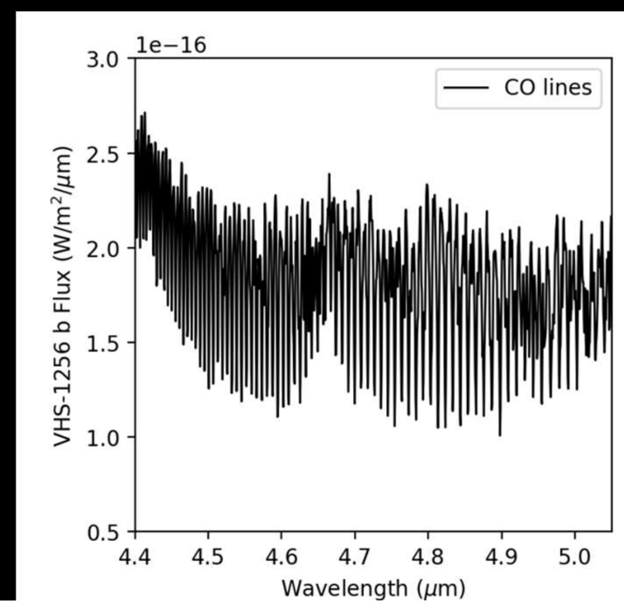
En 2031+, le JWST devrait encore être opérationnel

High-res science cases
Longer wavelengths MIRI

Si clouds only in MIRI



CO in VHS-1256-1257 b



Atelier de travail préparation réponse appel à proposition JWST cycle 6

Nice du 16 au 18 juin

V. Parmentier et al.

Journée Ariel France 9 juin
IAP
P. Drossart, J.-P. Beaulieu

https://www.ariel-mission.fr/les-journees-ariel/