The physics of brown dwarfs and exoplanets – a JWST/NIRSpec GTO program overview

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on behalf of the NIRSpec GTO team

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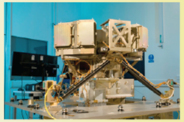
Outline

- The NIRSpec instrument in a nutshell
- The NIRspec GTO program
- Characterising exoplanets with NIRSpec
- The physiscs of brown dwarfs program
- Summary

The European contribution to JWST

jwst

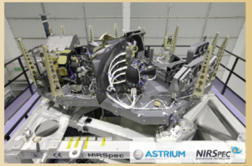
The MIRI instrument is a 50%/50% partnership between Europe and the USA.



MIRI optical system

MIRI cryogenic cooler system

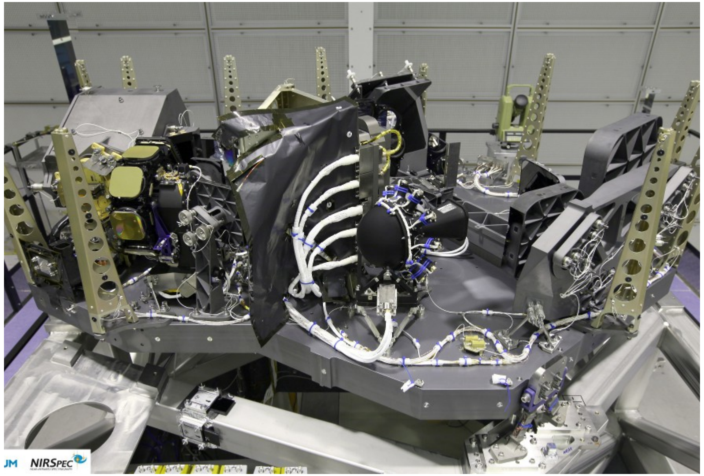
The NIRSpec instrument is provided by the European Space Agency (ESA).



JWST will be launched by a European Ariane 5 rocket from Kourou's spaceport.

An ESA team of 15 people will work together with its US counterparts to operate JWST's instruments.

Space Telescope Science Institute (STScI)



NASA

esa European Space Agency

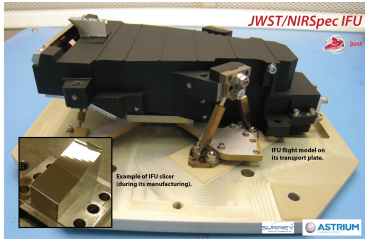
CSA ASC

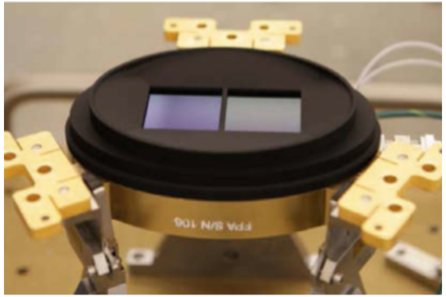
The James Webb Space Telescope (JWST) is an international partnership between NASA, ESA and the CSA.

NIRSpec Observing Modes

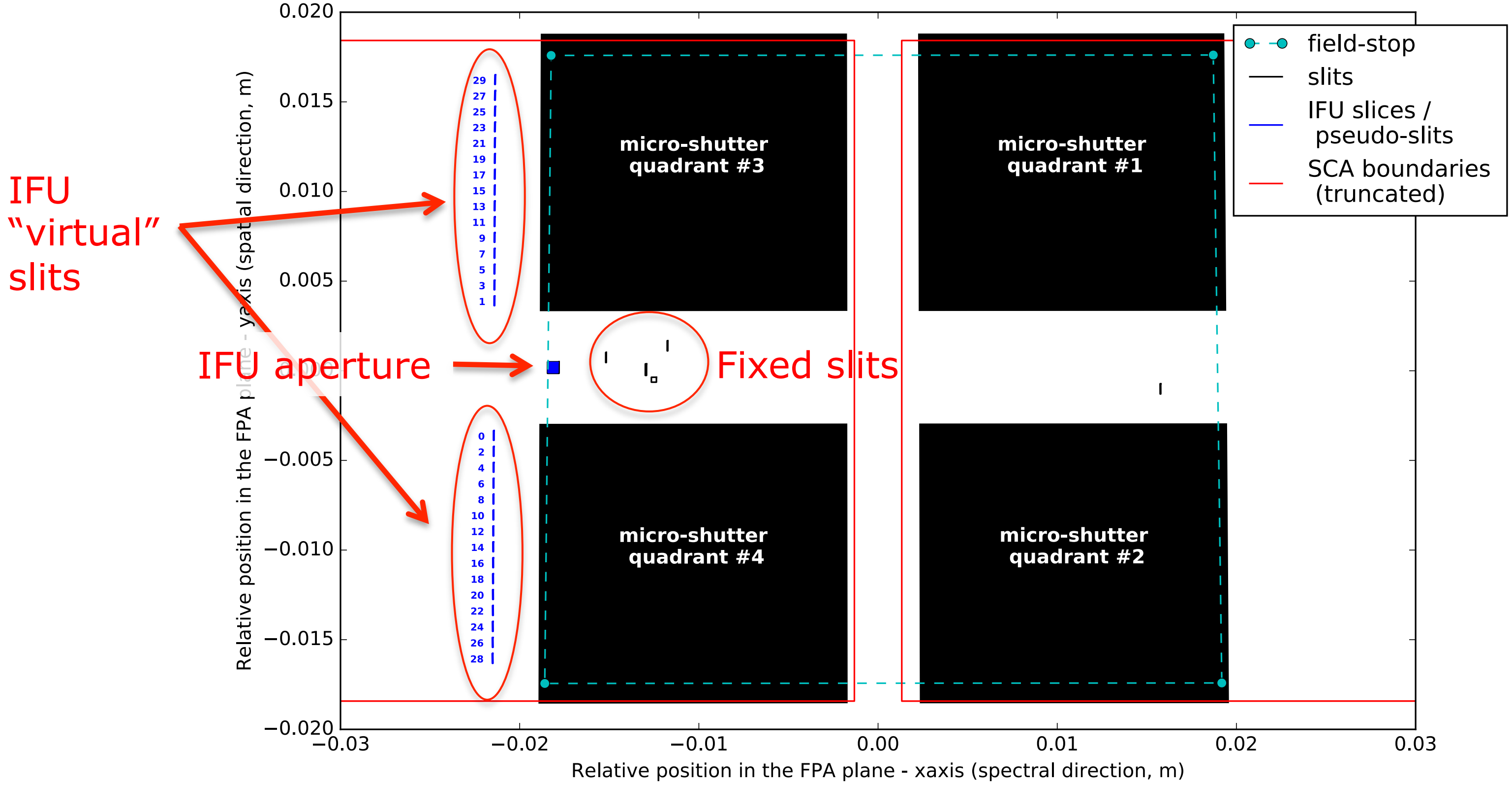
Mode	Target Type	Aperture Mask
MOS: Multi-Object Spectroscopy	Rich fields or extended objects	Selectable from ~250,000 0.2″ x 0.46″ micro-shutters
IFS: Integral-Field Spectroscopy	Moderately extended objects	3.0″ x 3.0″ IFU with 0.1″ spaxels
FSS: Fixed Slit Spectroscopy	Single (compact) object	0.2″ x 3.2″ slits (3) 0.4″ x 3.65″ slit 1.6″ x 1.6″ aperture
BOTS: Bright Object Time Series	Transit/eclipse spectroscopy	1.6″ x 1.6″ aperture

NIRSpec's Focal Plane Assembly (FPA) consists of two closely spaced HAWAII-2RG sensor chip arrays with 5.3 μm cut-off wavelength and ~100 mas pixels on the sky

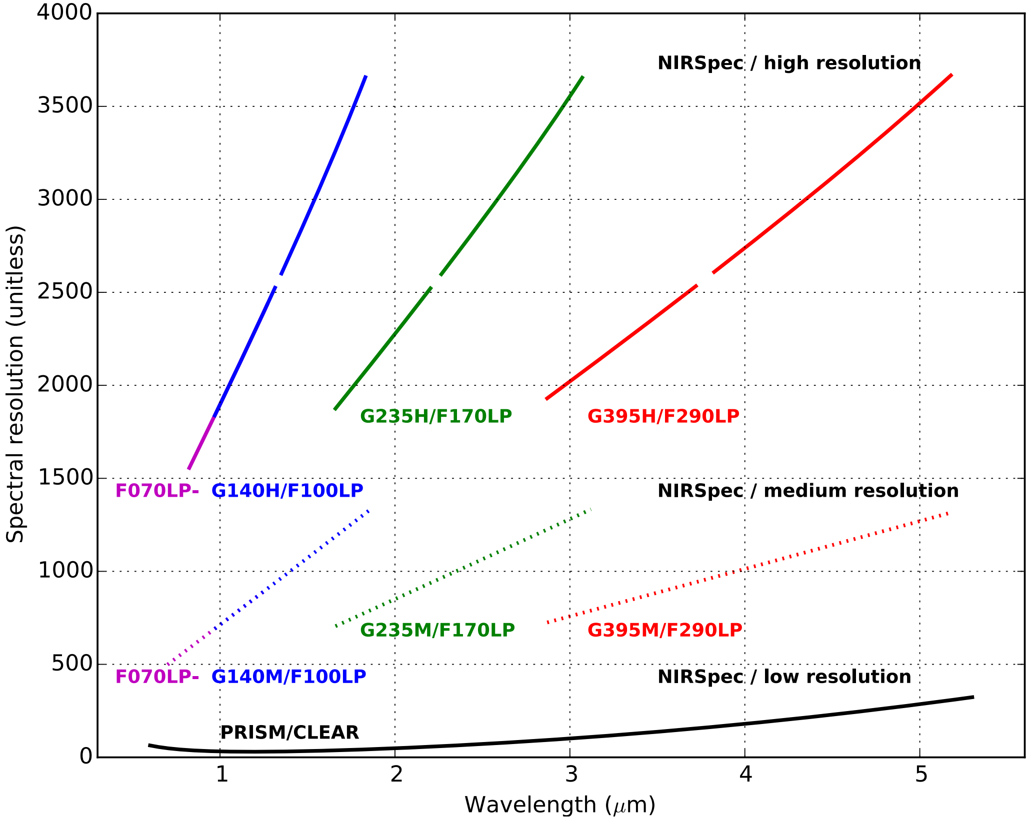


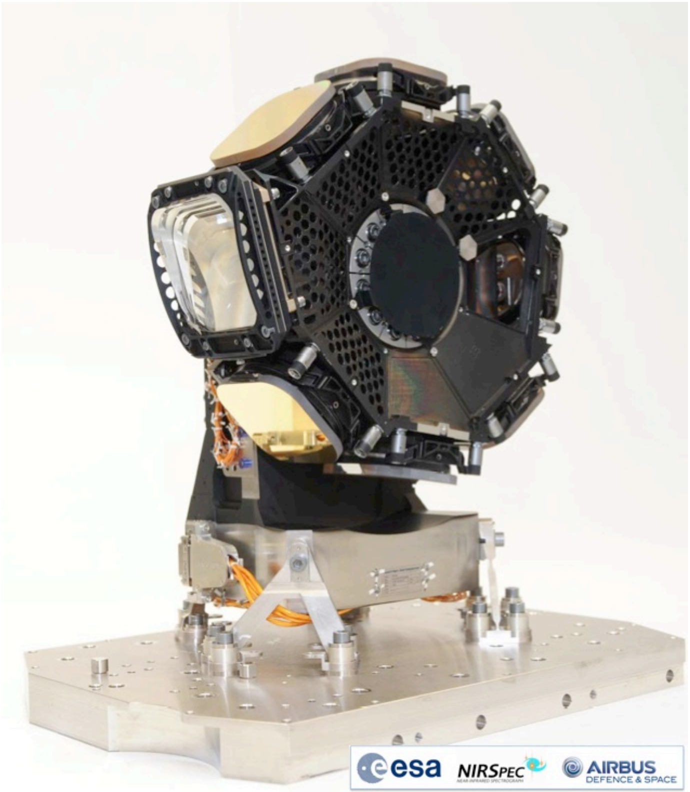


NIRSpec Aperture Layout



NIRSpec Spectral Configurations





NIRSpec GTO Programs

There are nine NIRSpec GTO programs managed by the ESA JWST project scientist Pierre Ferruit. The full list of programs and their description is available at:

https://www.cosmos.esa.int/web/jwst-nirspec-gto

In this presentation, we focus on three programs:

I. Transiting exoplanet characterization with JWST/NIRSpec (50 hours)

II. Direct spectroscopy of an exoplanet with the JWST/NIRSpec IFU (6 hours)

III. The physics of brown dwarfs (17 hours)

Transiting Exoplanets Program - Overview

Goal: Characterization of exoplanets and their atmospheres by means of transit and/or eclipse spectroscopy; demonstrate NIRSpec capabilities

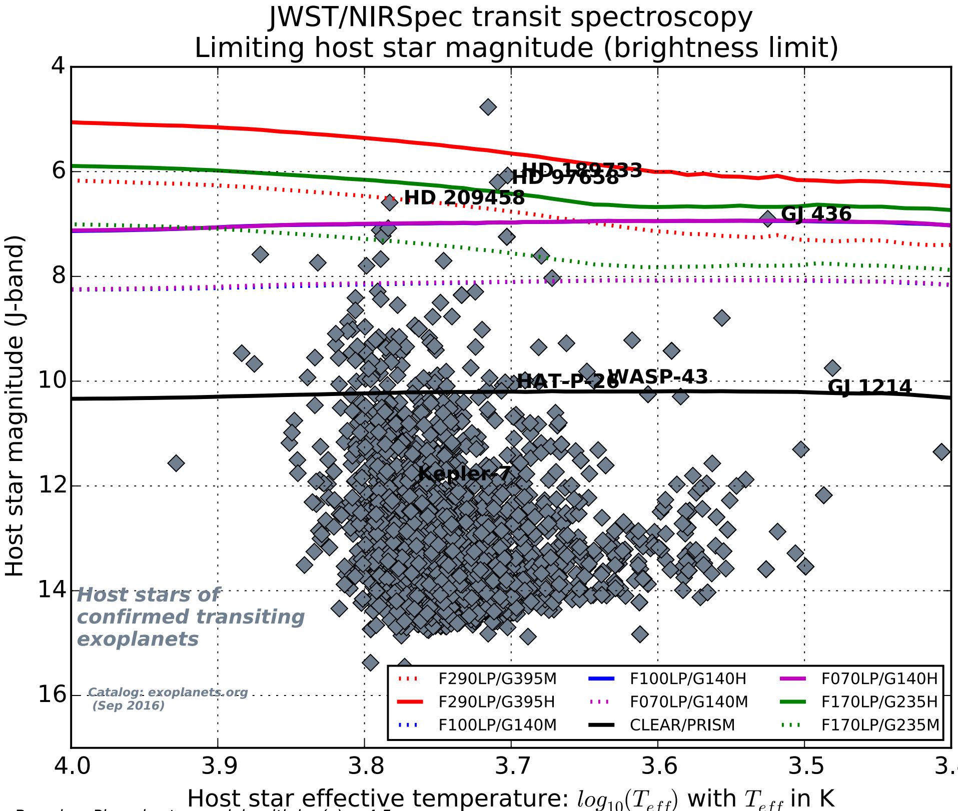
Theme	Target/Observation	Mode/Setup
Detection of molecular features in a super earth	LHS 1140b, 1 transit	BOTS, G395H/F290LP
Full phase curve of a hot Jupiter	WASP-43b, phase curve (2 eclipses, 1 transit)	BOTS, PRISM/CLEAR
Giant planet atmospheres	WASP-107b, 1 transit WASP-80b, 1 eclipse	BOTS, G395H/F290LP

Target Acquisition: either WATA (acquire science target or nearby reference in S1600A1) or perform "blind" pointing (no TA, "point and shoot")

Considerations for Exoplanet Observations

Saturation, saturation, saturation!

- Use the Exposure Time Calculator (ETC, https://jwst.etc.stsci.edu/) to determine suitable combination of subarray and readout mode/length of individual integration to check for saturation with the desired disperser/filter combination. The latter dictate wavelength coverage and spectral resolution.



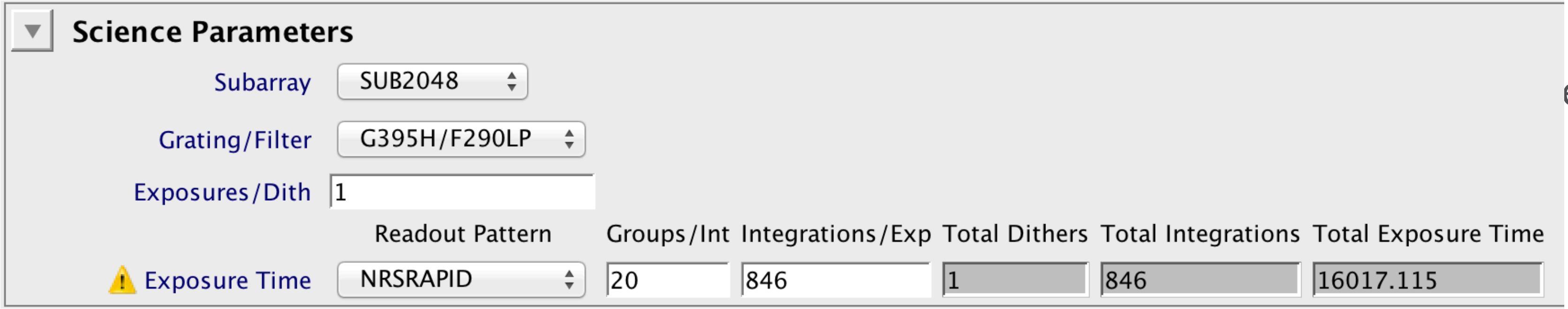
Based on Phoenix star models with log(g) = 4.5

Considerations for Exoplanet Observations

Target acquisition:

- Many exoplanet host stars will be too bright (< 12.5 m_{ab}) to be directly acquired. Use fainter nearby (within visit splitting distance) reference target in those cases (WATA, available in APT 25.4).
- Consider if "blind" pointing (no TA) is an option for your target.

Exposure setup:

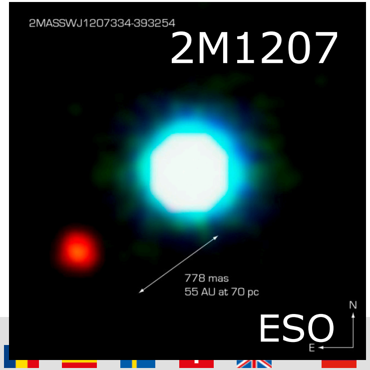
- 

IFU Spectroscopy of a Directly Imaged Exoplanet Overview

Goal: Characterization of directly imaged giant planet by means of IFU spectroscopy; demonstration of NIRSpec capabilities

Target	**Mode/Setup**
TWA 27 (2M1207)	IFU: G140H/F100LP, G235H/F170LP, G395H/F290LP 4 dither positions in IFU
2MASSW J1205527-385451 (reference star)	IFU: G140H/F100LP, G235H/F170LP, G395H/F290LP 4 dither positions in IFU

Target Acquisition: WATA (acquire science or nearby reference target)



Spectroscopy of Directly Imaged Planets

- NIRSpec has no coronagraph, but sufficiently separated planets should be observable by e.g. keeping the host star outside the aperture
- See posters by Marie Ygouf+ (114.04) and Klaus Hodapp+ (114.06) on the HR8799 system

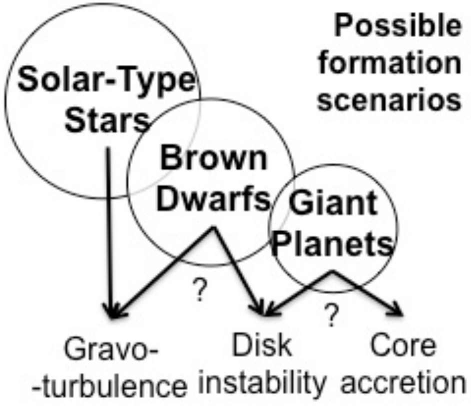
The Physics of Brown Dwarfs - Overview

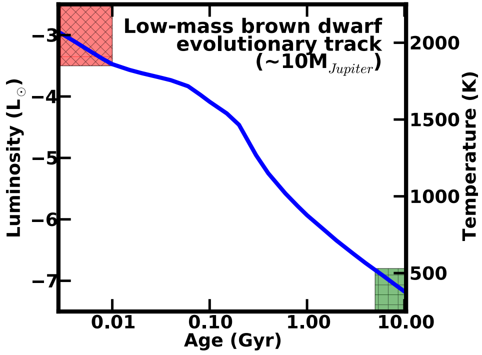
Goal: Discovery and spectral characterization of the coldest and least massive brown dwarfs to test formation theories and advance the physics of cool atmospheres

Proposal is divided into two complementary programs aimed at:

I. Testing star formation models by finding and characterizing the lowest mass young planetary-mass brown dwarfs (uses **MOS**)

II. Testing models of cool atmospheres by studying the coldest known brown dwarf in the solar neighborhood (uses **FSS**)





I. Observations

ONC-shallow: NIRSpec MOS

Target selection	Candidate brown dwarfs selected from HST/WFC3 Treasury program on the ONC
Experimental Design	Low and medium-resolution spectra to assess their (i) youth and membership to the cluster, (ii) surface gravity, (iii) temperature, and (iv) investigate the presence of heavy elements enrichment as a clue to the formation process
Instrument setup	NIRSpec/MOS observations w/ PRISM and G395M 3-point nodding on a 3-shutter slitlet

IC 348: Same cycle NIRCam imaging + NIRSpec MOS

Target selection	NIRCam imaging to select candidate brown dwarfs NIRSpec MOS follow-up on targets with colours consistent with young low mass brown dwarfs
Experimental Design	Candidate selection based on colour-colour magnitude diagrams and expected colours for substellar objects NIRSpec follow-up analogous to the ONC
Instrument setup	4 NIRCam tiles with module A+B F140M, F162M, F182M short filters (F277W, F360M, and F444W long filters) NIRSpec/MOS observations w/ PRISM and G395M 3-point nodding on a 3-shutter slitlet

II. Observations

WISE 0855−0714: NIRSpec SLIT

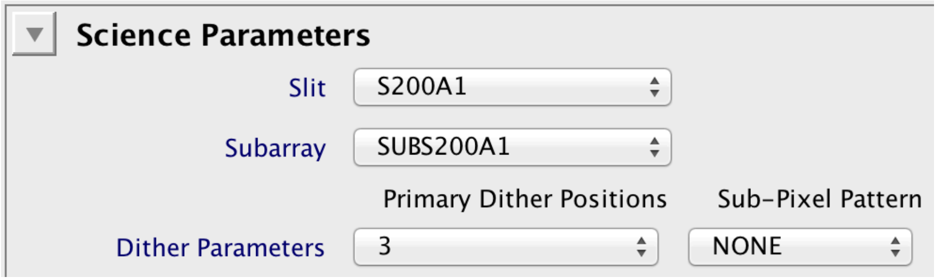
Target selection	coldest object discovered outside the Solar System and the 4th closest neighbor to the Sun (2.2 pc)
Experimental Design	Low and medium resolution spectroscopy to constrain: temperature, gravity, degree of turbulence, chemical equilibrium/disequilibrium, clouds
Instrument setup	S200A1 PRISM/CLEAR and G395M/F290LP

Considerations for Brown Dwarf Program - MOS

- The N… …an 100 objec…
  - I… …cantly v…
- Final… …as been sched…
- Targ… …ec FoV (field rotat…
- Same… …owed. It requi… …lans for NIRS…
- Planning tool for MOS observations (MPT) is part of APT -> sign up for demos

Considerations for Brown Dwarf Program - SLIT

- Dithering along the slit is recommended if target allows (compact source)



- Fewer longer integrations are better than many short ones (but consider cosmic rays and dithers)
- For faint targets, NIRSpec is detector noise limited -> IRS^2 readout is superior (less total noise, far less correlated noise -> better background subtraction)

Summary

- NIRSpec's GTO program for exoplanets and brown dwarfs utilizes all four observing modes of NIRSpec

- For an overview of the entire NIRSpec GTO program, refer to https://www.cosmos.esa.int/web/jwst-nirspec-gto

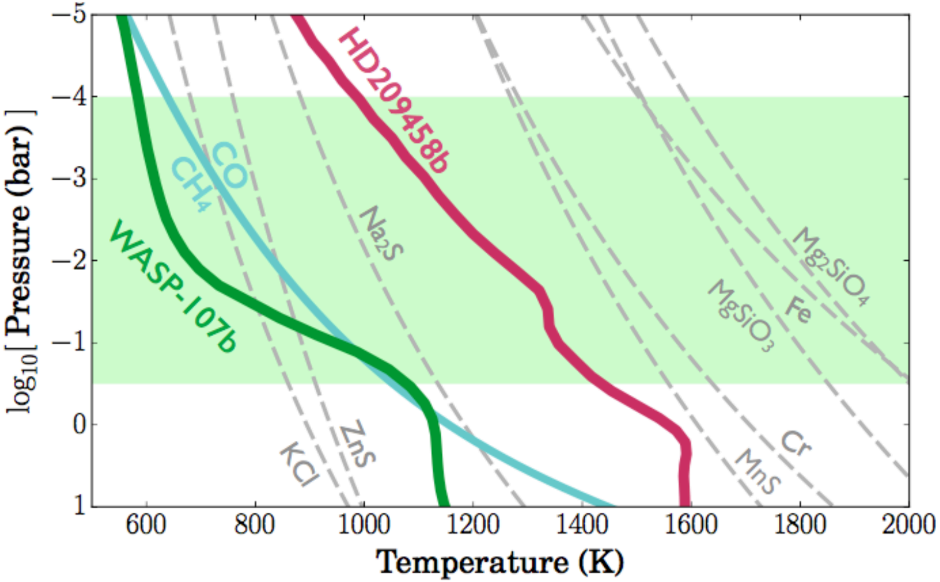
- Instrument documentation and best practices are currently being generated. See STScI JDOX pages for more information (all JWST instruments): https://jwst-docs.stsci.edu/display/JTI

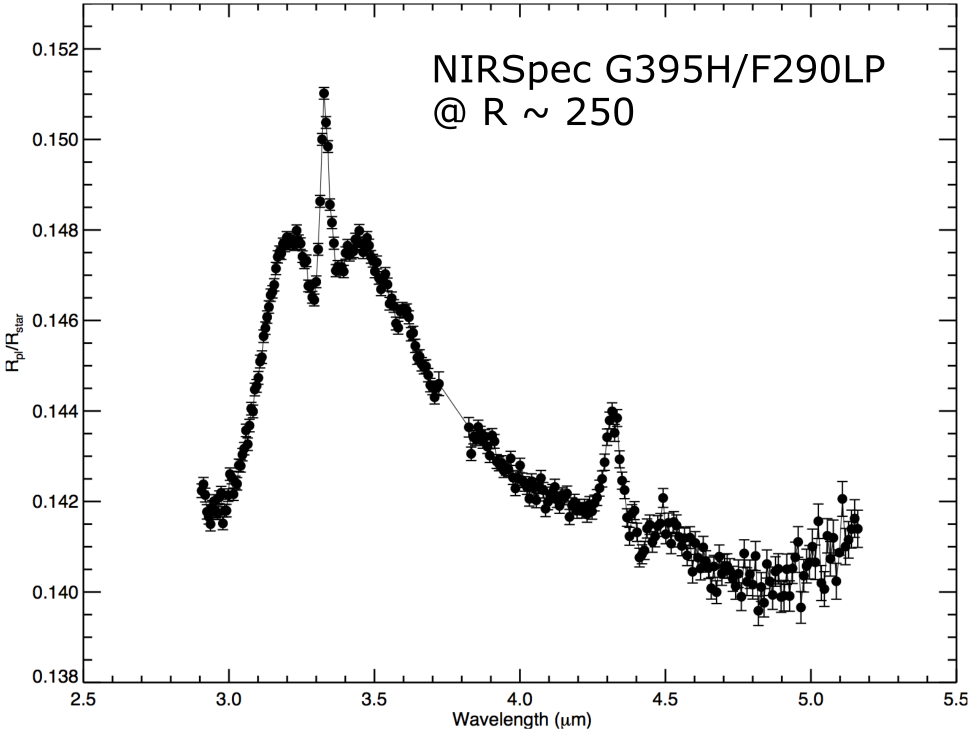
BACKUP

WASP-107b Characterization

Temperature below CO/CH_4 transition

Distinguish between (non)equilibrium models





David Sing

I. Testing star formation models with young, planetary-mass brown dwarfs

Obtain spectra of low mass young brown-dwarfs in nearby star-forming regions to:

i. characterise atmospheric chemical abundances of metal-dominated compounds,

ii. probe the cut-off mass limit of star formation, and the mass function across the planetary-mass regime.

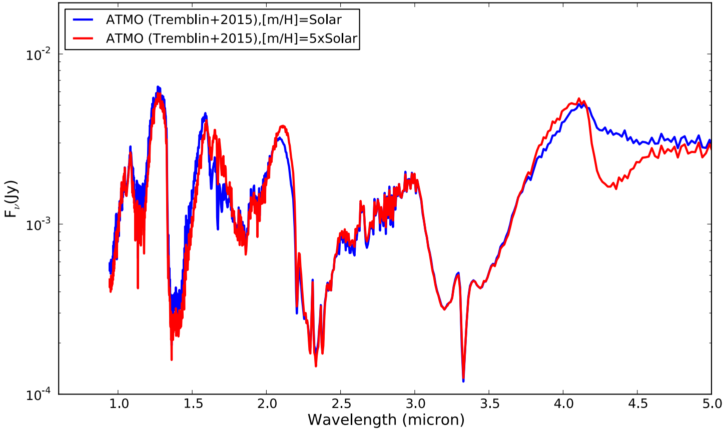
Atmospheric models from P. Tremblin, I. Baraffe, G. Chabrier

The effect of metallicity:

Young Jupiter-mass object:

Teff: 1200K, logg: 4, log K_{zz}: 0

<u>Metallicity: Solar vs 5xSolar</u>

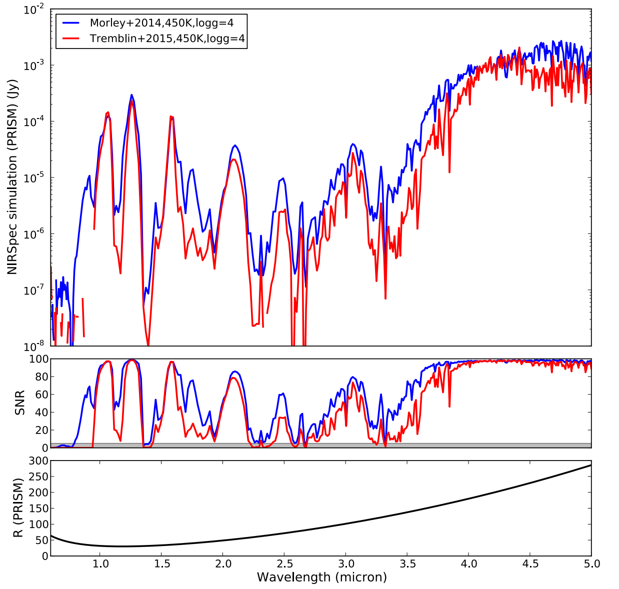


II. Testing models of cool atmospheres

Near-IR spectroscopy of the coldest known brown dwarf, to test model atmospheres at very low temperatures to:

i. constrain whether atmospheres are shaped by chemical disequilibrium driven by vertical transport or the formation of water clouds,

ii. constrain the gravity, hence the mass of this object.



The effect of clouds: atmospheric models from Tremblin +2015 (no clouds) & Morley+2014 (with clouds)

Y dwarf:

Teff: 450K

logg: 4

distance: 5 pc