Peering into the physics of brown dwarfs: spectroscopy with JWST/NIRSpec

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Collaborators:
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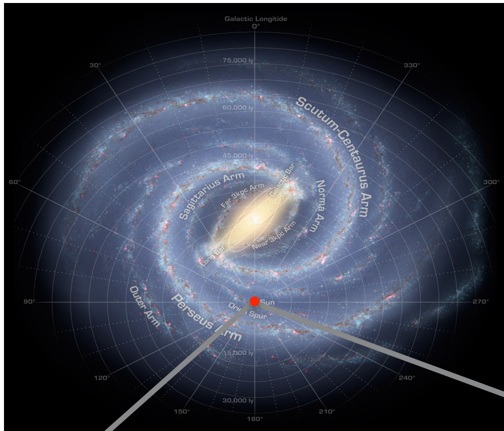
and the NIRSpec team

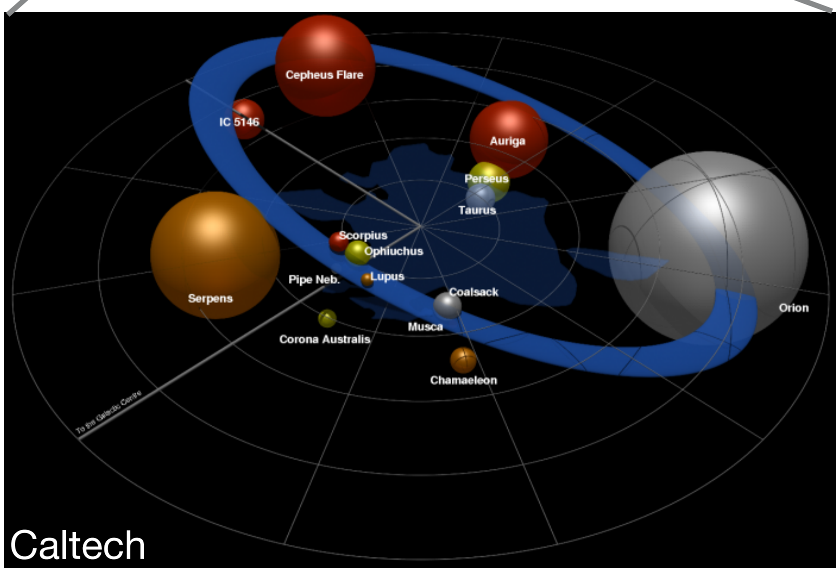
Introduction

Physics of brown dwarfs challenge several areas, for example:

- theory of star and planet formation
- physics of cool atmospheres

E.g., IC 348





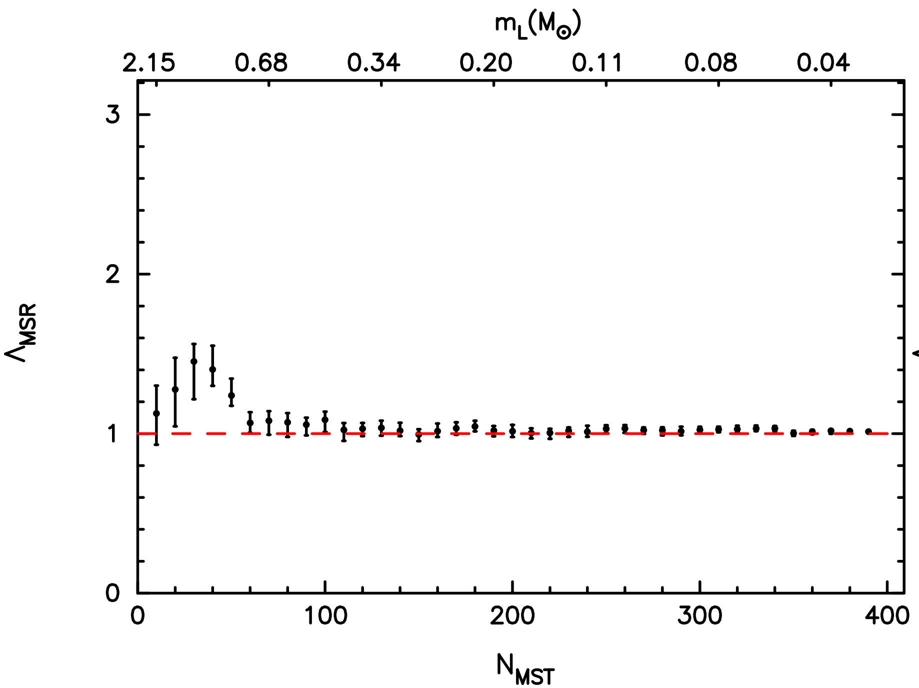
Distance: 316 pc
Size: ~2.6x2.3 pc (~34′x28′)
Age: 2Myr
Population: ~400 spectroscopically confirmed members

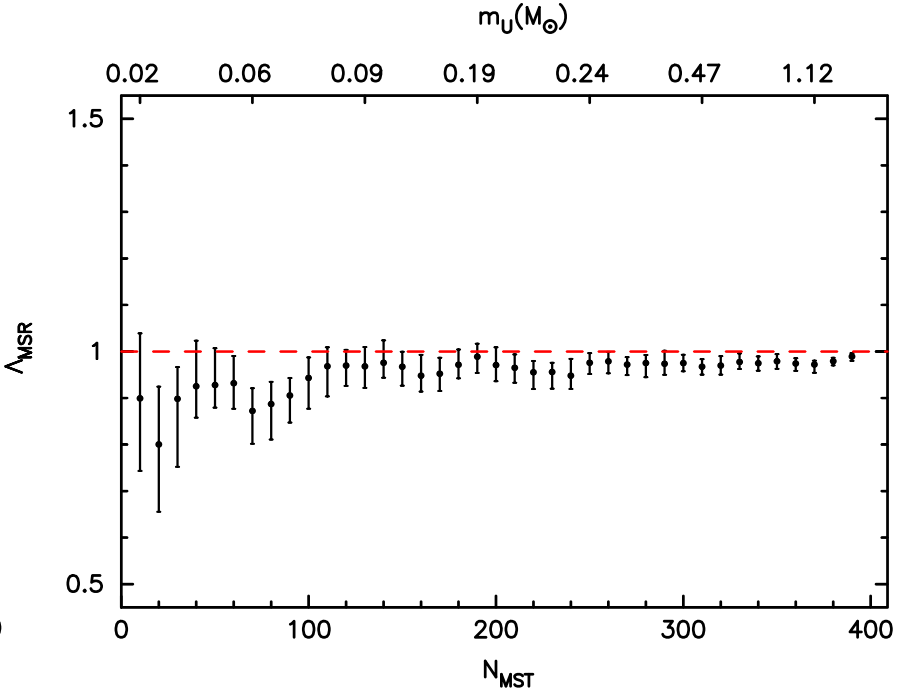
What is the dynamical history of IC 348?

Minimum-spanning-tree method to quantify degree of mass segregation*:

$$\text{'mass segregation ratio' } (\Lambda_{MSR}) = \frac{\text{average random path length}}{\text{path length of massive stars (or brown dwarfs)}}$$

➔ **No evidence that mass segregation has occurred at 2Myr in IC348.**





Parker & Goodwin 2015, Allison et al. 2009, Parker & Alves de Oliveira (in prep.)

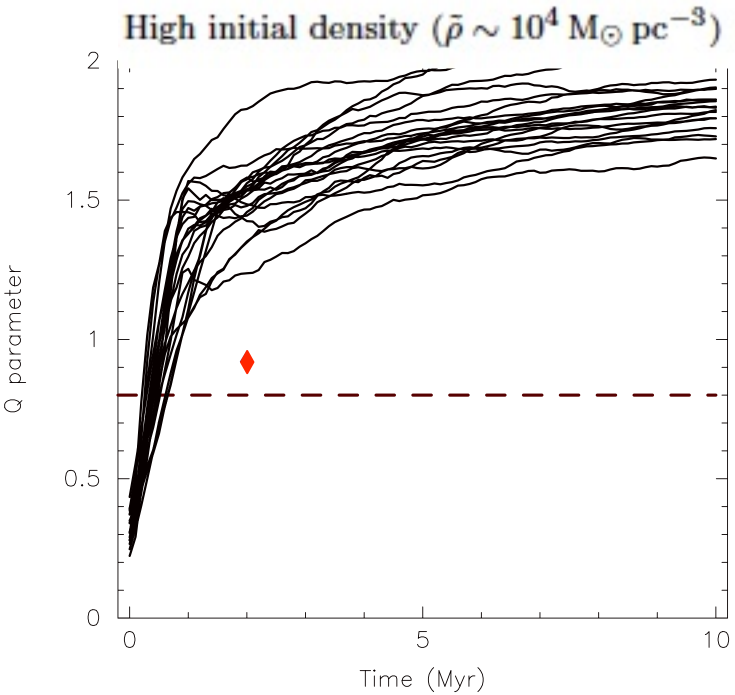
What were the initial conditions for star and planet formation in IC348?

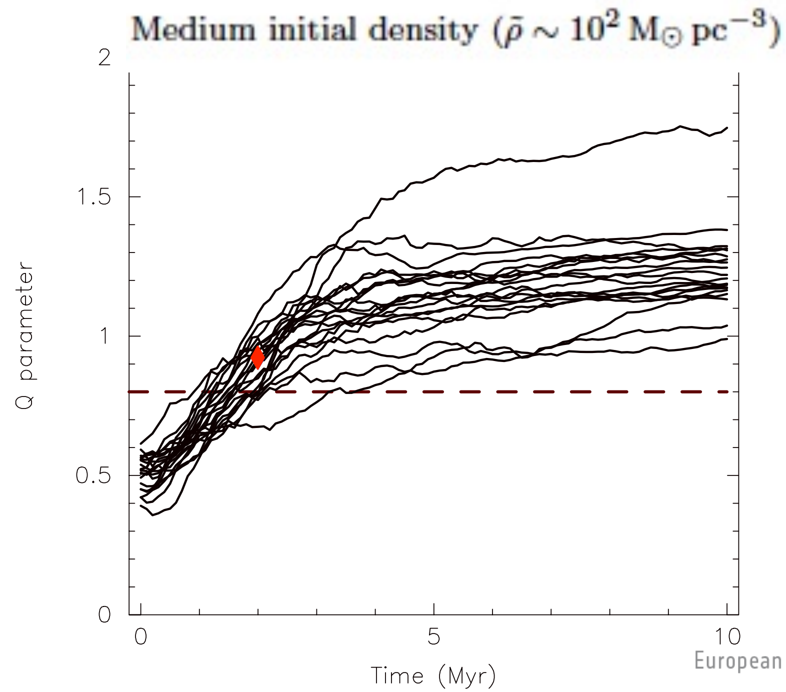
N-body simulations of the dynamical evolution of star-forming regions with varying initial densities to characterize spatial structure and density*.

$$\mathcal{Q}\text{-parameter} = \frac{\text{mean distance between stars}}{\text{mean length of the minimal spanning tree}},$$

quantifies and distinguishes between substructured and centrally concentrated regions.

➔ **Observational value suggests less-dense initial conditions in IC348, and a modest degree of dynamic evolution.**





Parker et al. 2014, Parker 2014, Wright et al. 2014, Parker & Alves de Oliveira (in prep.)

What was the impact of dynamical evolution on star and planet formation in IC348?

N-body simulations of a young cluster with the dynamical history and initial conditions of IC348, to examine the direct effects of interactions in the cluster on stars and planetary systems.

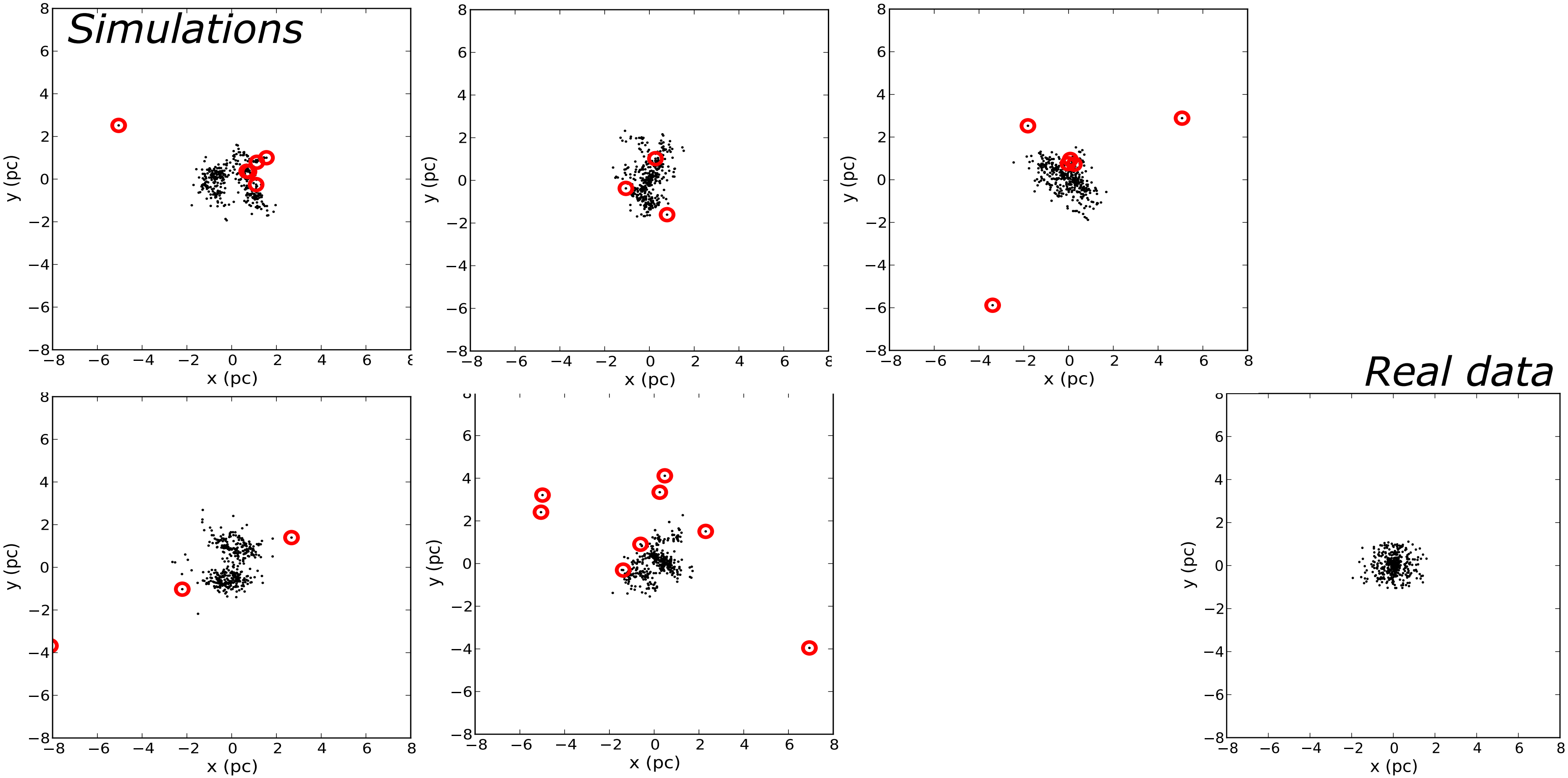
Simulation set-up:

- **Cluster:** based on our findings of most likely initial conditions
- **Primary stars:** 400 stars randomly drawn from an IMF
- **Stellar companions:** assigned based on binary fractions associated with the primary mass
- **Planetary companions:** 1 Jupiter mass planet on a 30 AU orbit is assigned to single stars

Parker & Quanz 2012, Forgan et al. 2015, Parker & Alves de Oliveira (in prep.)

What was the impact of dynamical evolution on star and planet formation in IC348?

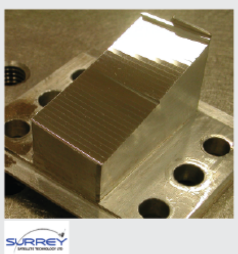
- **After ~2 Myr, ~3 to 7 planets initially orbiting their parent star at 30AU, have been liberated and became free-floating planets.**
- **This is significantly less than what was found for an Orion-like simulation, where ~10% of planetary companions were liberated.**



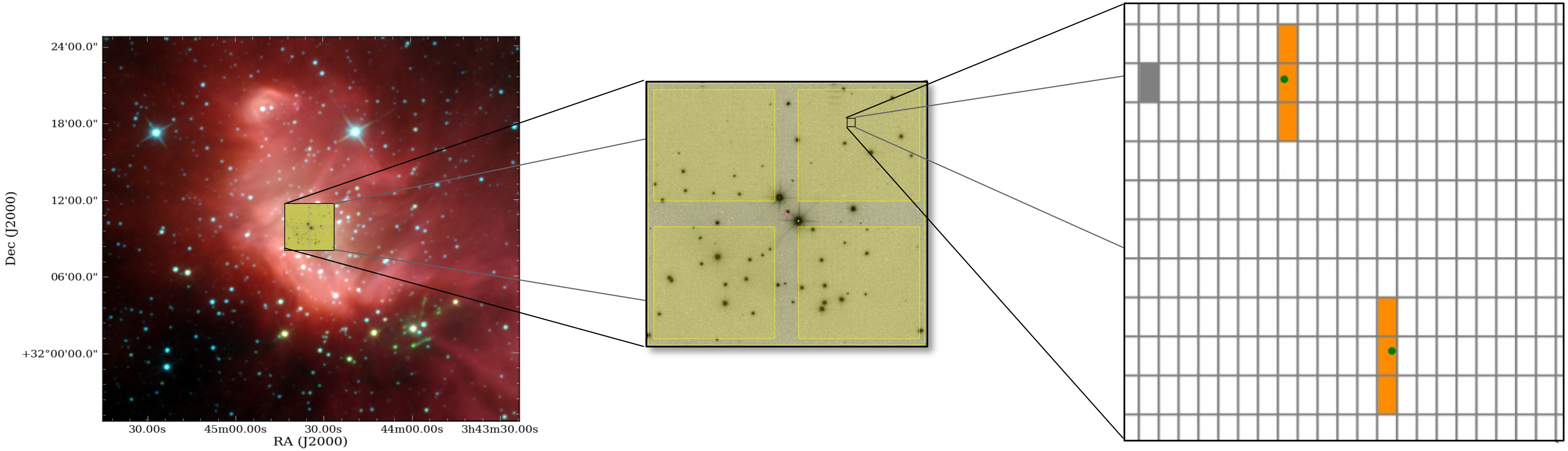
How can JWST help?

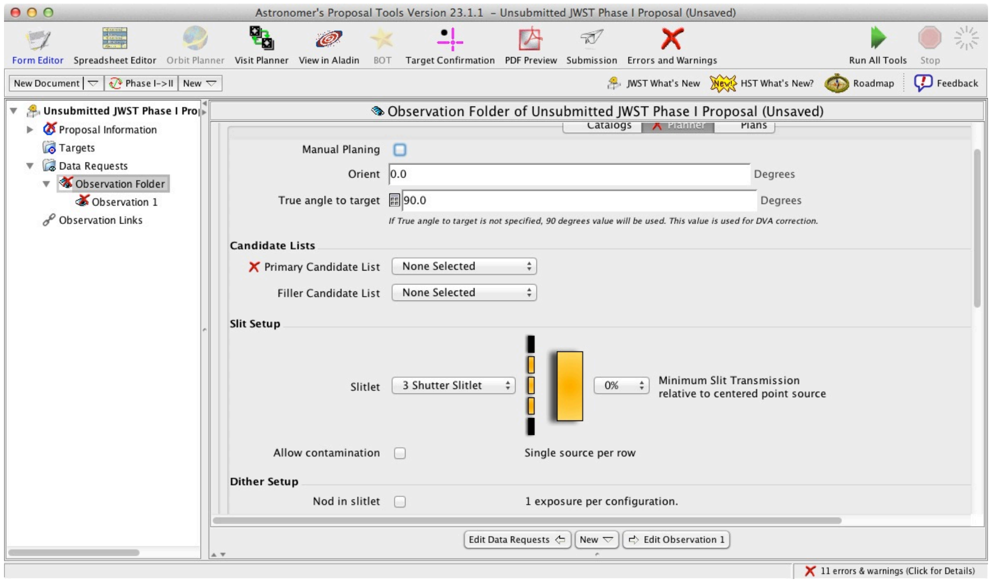
➔NIRSpec observations: multi-object spectroscopy

JWST/NIRSpec

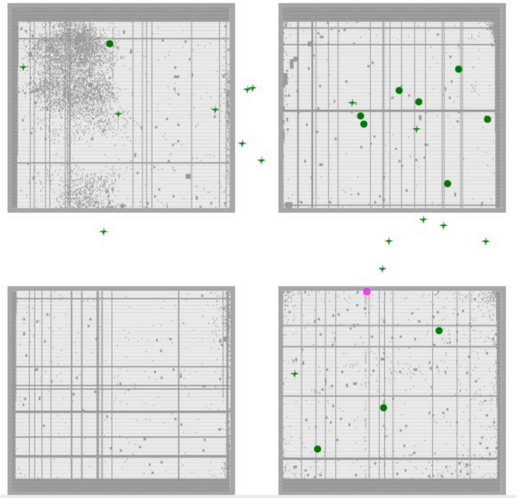
MOS		Multi-object spectroscopy with 0.2"-wide mini-slits.	- 9 square arcmin. field of view - Low spectral resolution (30 to 300), prism-based mode covering the 0.6-5.0 micron range in one exposure. - Medium spectral resolution (500 to 1300), grating-based mode covering the 0.7-5.0 range
IFU		IFU spectroscopy with a 0.1" sampling. (IFU made of 30 slices for a total of 900 "spaxels")	- 3"x3" field of view - Low spectral resolution (30 to 300), prism-based mode covering the 0.6-5.0 micron range in one exposure. - Medium (500 to 1300) and high (1400-3600) spectral resolution modes, covering the 0.7-5.0 range in 4 exposures. - IFU and MOS cannot be used at the same time.
SLIT		High-contrast slit spectroscopy. (including with a 1.6"x1.6" square aperture for extra-solar planet transit observation)	- 5 slits available All spectral resolution modes available. - SLIT can be used simultaneously to IFU or MOS.

Prepare observations with MSA planning tool





E.g., MSA configuration plan



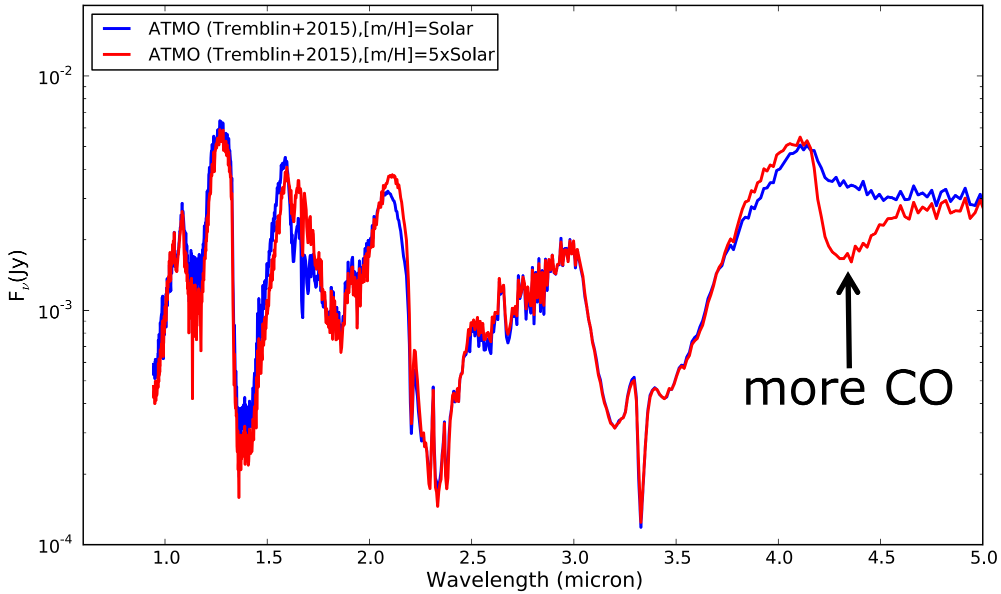
Space Agency

Brown dwarf or planet?

➔ **Can we distinguish between an object formed by dynamical collapse of the interstellar medium, and an object formed by core accretion?**

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>

Brown dwarf or planet?

➔ **Can we distinguish between an object formed by dynamical collapse of the interstellar medium, and an object formed by core accretion?**

Atmospheric models from

P. Tremblin, I. Baraffe, G. Chabrier

The effect of vertical mixing:

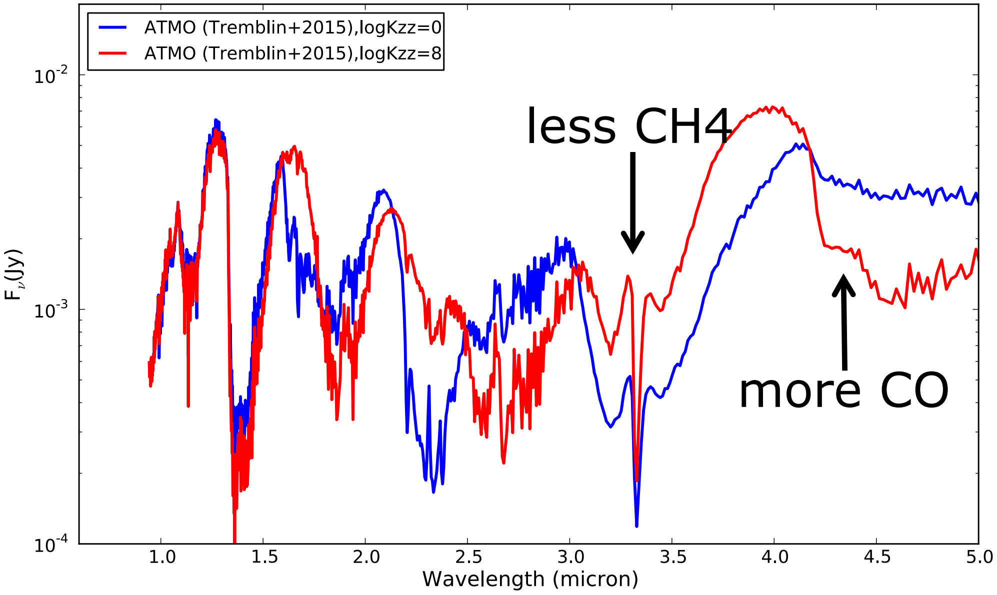
Young Jupiter-mass object:

Teff: 1200K

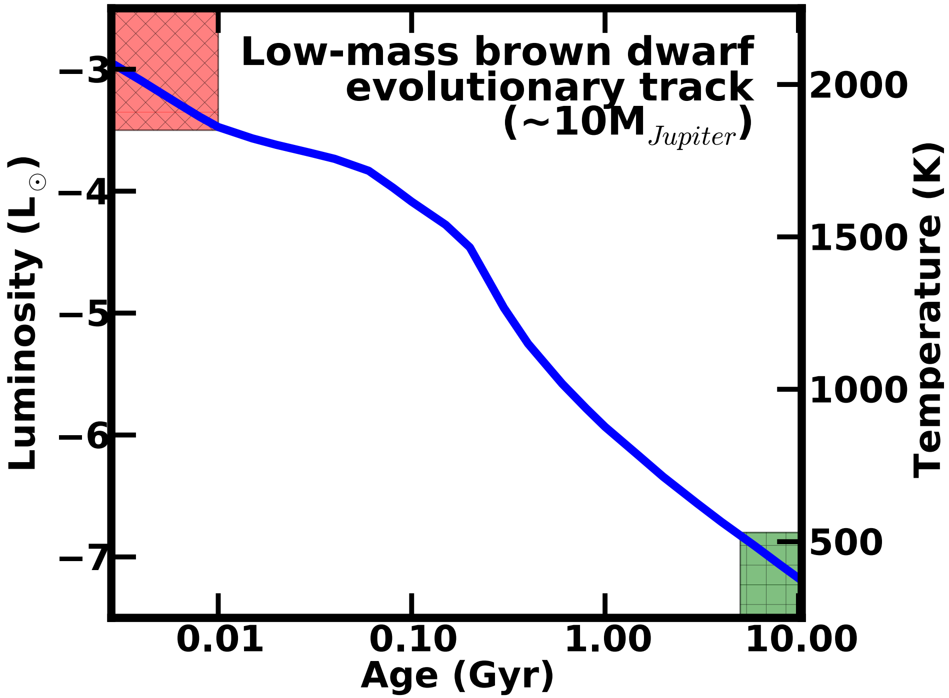
logg: 4

log K_{zz}: 0 or 8

Metallicity: Solar



What happens when a young brown dwarf, ~10 Jupiter masses, evolves?

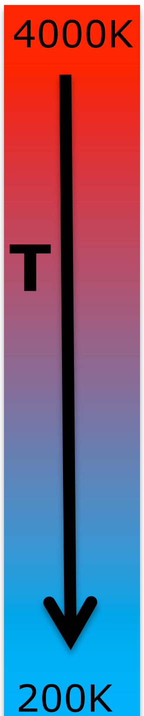


It just gets cooler and dimmer.

Such objects, Y dwarfs, have now been found in the solar neighbourhood.

What can we learn from studying Y dwarfs in the field?

Major challenge in the development of cool atmosphere models characterised by strong molecular absorptions, condensate cloud formation and non-equilibrium chemistry.



M-dwarfs: formation of molecules (H2, TiO, VO, H2O, CO, FeH, CaH,..)

M/L transition from "clean" to "dusty" atmospheres

L-dwarfs: molecules condense (dusty atmospheres)

L/T transition: clearing of dust and the formation of CH4

T-dwarfs: methane absorption bands

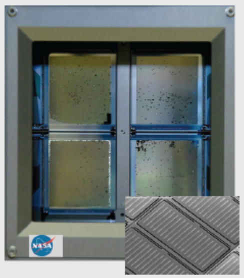
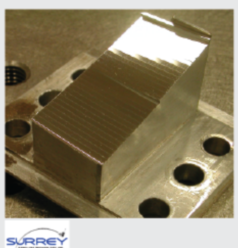
T/Y transition: ammonia depletion? quenching of CO and CO_2?

Y dwarfs: sulfide/H2O clouds? non-equilibrium chemistry due to vertical mixing?

Coolest known brown dwarf has an estimated T_{eff}~250K (about the same temperature has here in ESTEC!, Jupiter has a Teff~120K)

How can JWST help?

➔ **NIRSpec observations: single/binary cool Y dwarfs**

JWST/NIRSpec	MOS		Multi-object spectroscopy with 0.2"-wide mini-slits.	- 9 square arcmin. field of view - Low spectral resolution (30 to 300), prism-based mode covering the 0.6-5.0 micron range in one exposure. - Medium spectral resolution (500 to 1300), grating-based mode covering the 0.7-5.0 range
	IFU		IFU spectroscopy with a 0.1" sampling. (IFU made of 30 slices for a total of 900 "spaxels")	- 3"x3" field of view - Low spectral resolution (30 to 300), prism-based mode covering the 0.6-5.0 micron range in one exposure. - Medium (500 to 1300) and high (1400-3600) spectral resolution modes, covering the 0.7-5.0 range in 4 exposures. - IFU and MOS cannot be used at the same time.
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Y dwarfs - NIRSpec simulations

➔ **Can NIRSpec observations of Y dwarfs distinguish between different model predictions?**

Atmospheric models from

Tremblin+2015 & Morley+2014

Y dwarf:

Teff: 450K

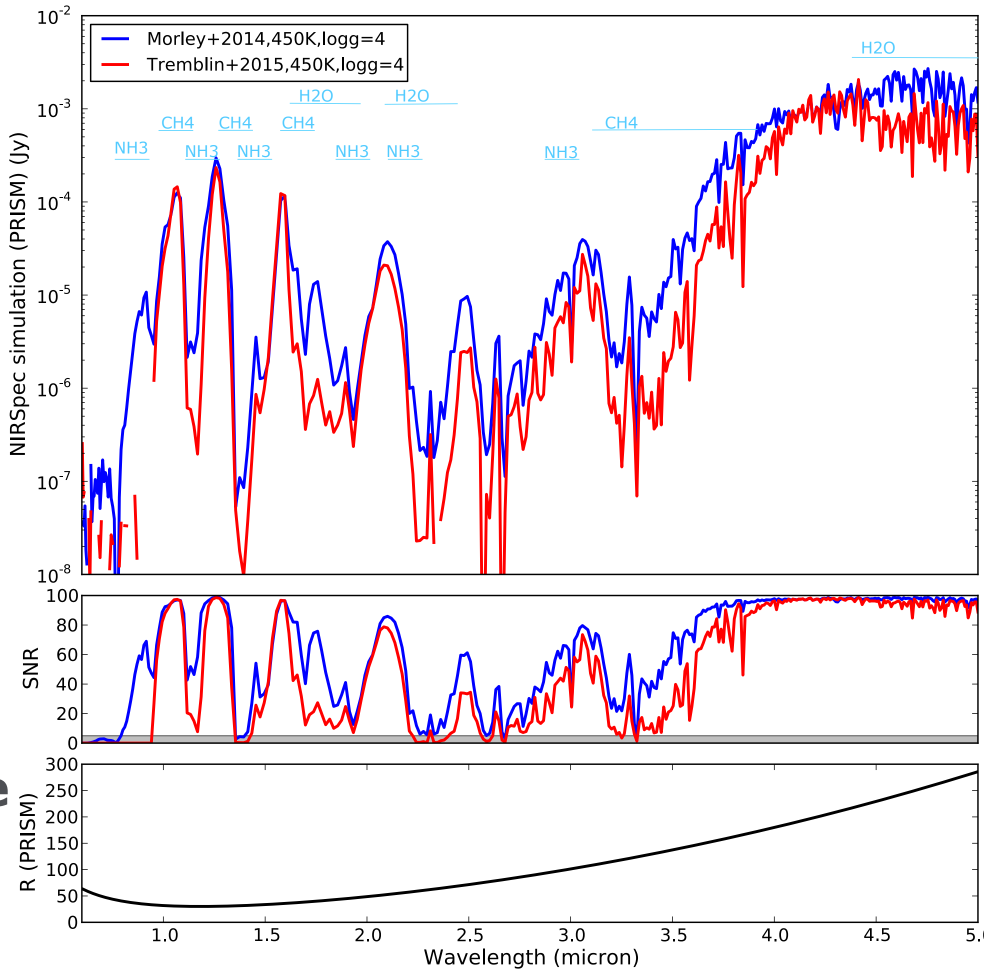
logg: 4

distance: 5 pc

Simulations:

NIRSpec, 15 minutes on-source

JWST/NIRSpec, PRISM, ~15 minutes



Distance to the Sun: 5.00 pc - Radius: 1.03 R_Jupiter.

2015-10-07T16:57:33.693358

Created by C. Alves de Oliveira

Y dwarfs - NIRSpec simulations

➔ Can we observe Y dwarfs at different temperatures?

Atmospheric models from Morley+2014

Y dwarf:

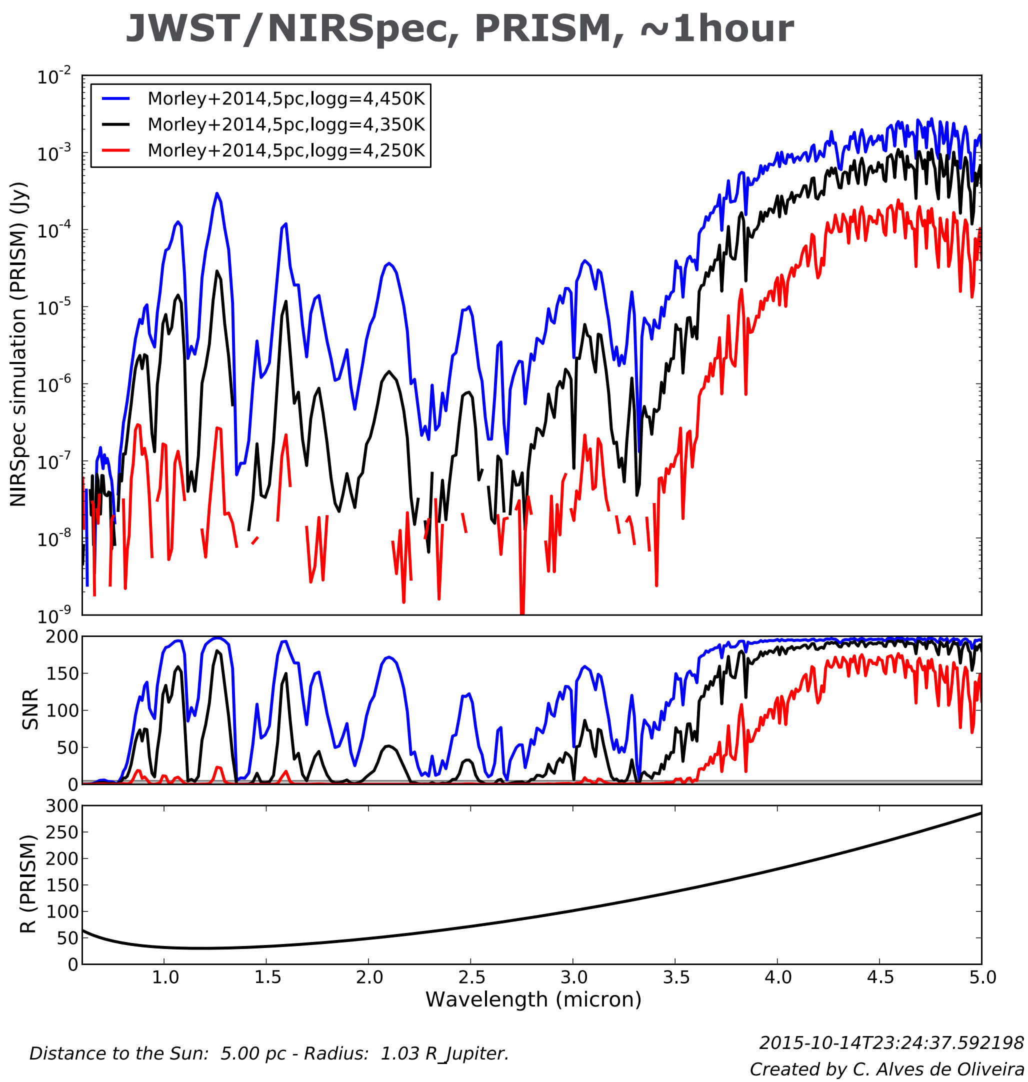
Teff: 450K, 350K, 250K

logg: 4

distance: 5 pc

Simulations:

NIRSpec, 1 hour on-source



Y dwarfs - NIRSpec simulations

➔ **Can we extend the study of cool atmospheres to the lowest temperature Y dwarf known?**

Atmospheric models from Morley+2014

Y dwarf (e.g., WISE0855):

Teff: 250K

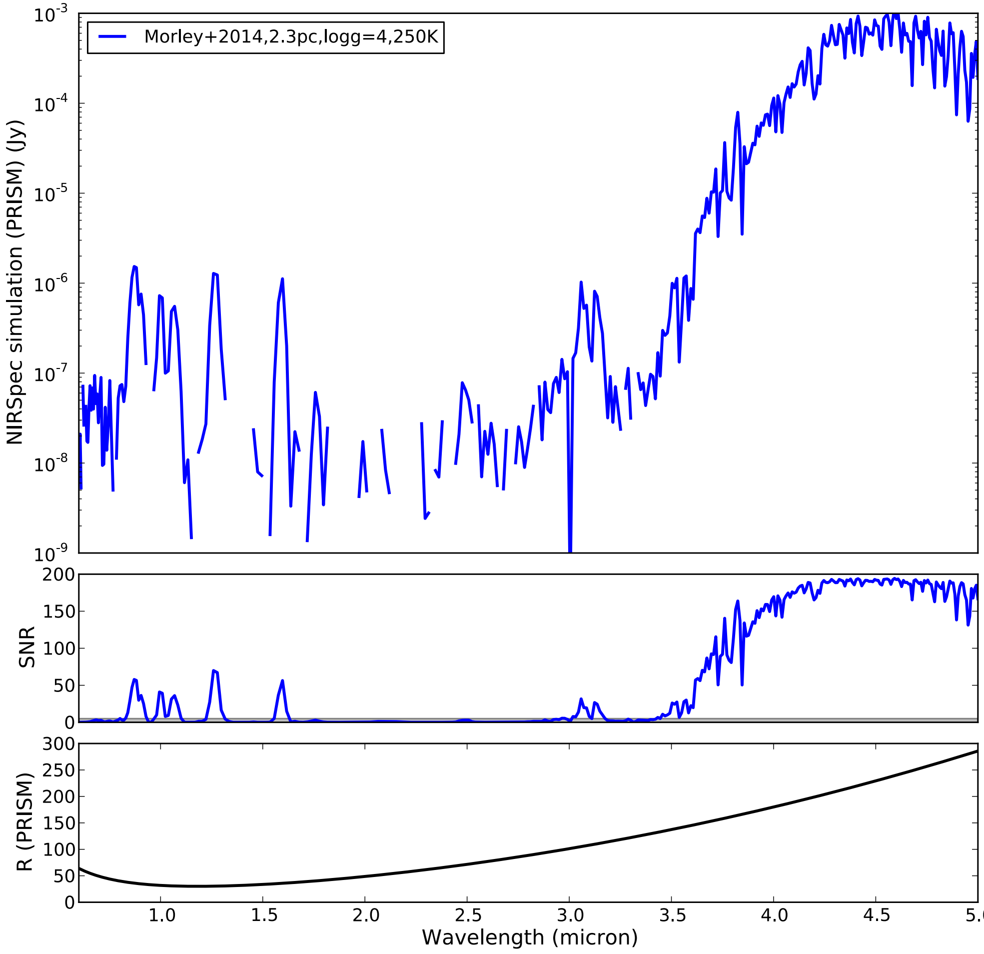
logg: 4

distance: 2.3 pc

Simulations:

NIRSpec, 1 hour on source

JWST/NIRSpec, PRISM, ~1 hour



Distance to the Sun: 2.30 pc - Radius: 1.03 R_Jupiter.

2015-10-14T23:40:24.995384

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Conclusions

By studying the lowest mass and coolest brown dwarfs, JWST has the potential to:

- place one of the most stringent observational constrains on star formation theories by unveiling the low-mass end and cut-off of the IMF
- peer into the fate of embryonic planetary systems and their chances for survival in the parent cluster environment
- unveil the ingredients and the physics of the coolest brown dwarf atmospheres

NIRSpec capabilities are well suited to facilitate such observations.

Synergy with other JWST capabilities (e.g., MIRI spectroscopy, NIRCam photometry, NIRISS spectroscopy or AMI) will further complement and enlarge the scientific results.

Thank you

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Thanks to K. Luhman for providing data on IC348 census ahead of publication, and to C. Morley for providing model spectra of Y dwarfs.