What we could have done and we will not (??)

Valentina D’Orazi
INAF –Osservatorio Astronomico di Padova

SPICA Italian Workshop 2016, Roma, April 4-5 2016

The search for other worlds has been since always one of the fundamental inquiry for the human being.

“There are infinite worlds both like and unlike this world of us. We must believe that in all worlds there are living creatures and planets and other things we see in this world”

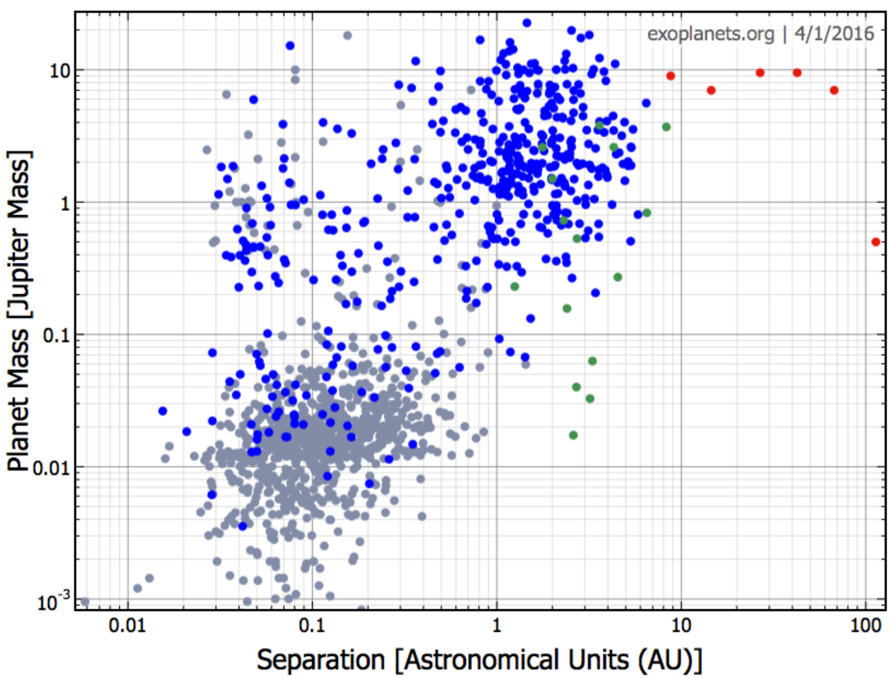
Epicurus, 300 BC

Since the first discovery by Mayor & Queloz (1995) of a planet orbiting the solar analog 51 Peg, followed soon thereafter by the detection of planets around 47 UMa (Butler & Marcy 1996) and 70 Vir (Marcy & Butler 1996), the search for extrasolar planets has evolved into a mature field in astrophysics.

→ Outstanding efforts in detecting exoplanets: to date 1642 confirmed planets+3786 unconfirmed Kepler candidates have been discovered (source http://exoplanet.org, April 2016).

Different detection techniques:

- Radial velocity
- Direct imaging
- Microlensing
- Transits



Surfing through NASA ADS database

Authors: (Last, First M, one per line) ☑ **SIMBAD** ☑ **NED** ☑ **ADS Objects**

☐ Exact name matching — Object name/position search

☐ Require author for selection — ☐ Require object for selection

(◉ OR ○ AND ○ simple logic) — (Combine with: ◉ OR ○ AND)

Publication Date between (MM) 1995 (YYYY) and (MM) 2016 (YYYY)

Enter Title Words ☐ Require title for selection

(Combine with: ◉ OR ○ AND ○ simple logic ○ boolean logic)

Enter Abstract Words/Keywords ☑ Require text for selection

(Combine with: ◉ OR ○ AND ○ simple logic ○ boolean logic)

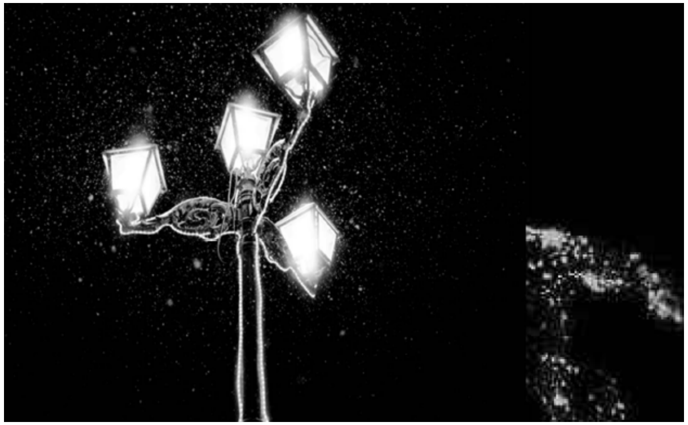
exoplanet

SAO/NASA Astrophysics Data System (ADS)

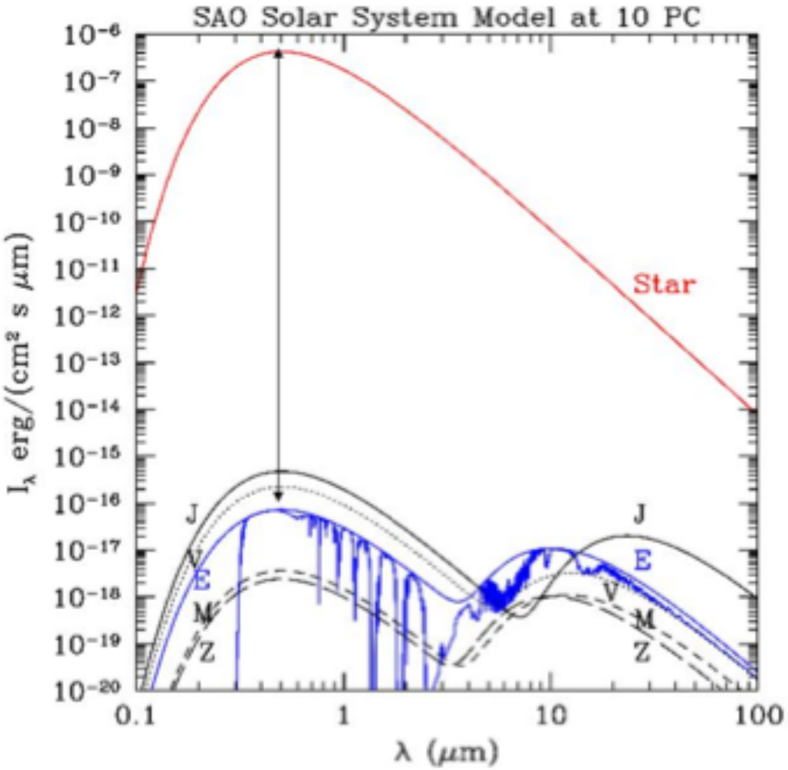
Query Results from the ADS Database

Retrieved **200** abstracts, starting with number **1**. Total number selected: **12212**.

...Main Difficulties with Planets....



We aim at seeing a moth flying around a street-lamp from a satellite at 500 km height



Contrast:
Jupiter/Sun = 10^{-8} = 20 mag
Earth/Sun = 10^{-10} = 25 mag

Angular Separation:
Jupiter = 0.5 arcsec @ 10 pc
Jupiter = 0.1 arcsec @ 50 pc

Spectro-Polarimetric High-contrast Exoplanet REsearch

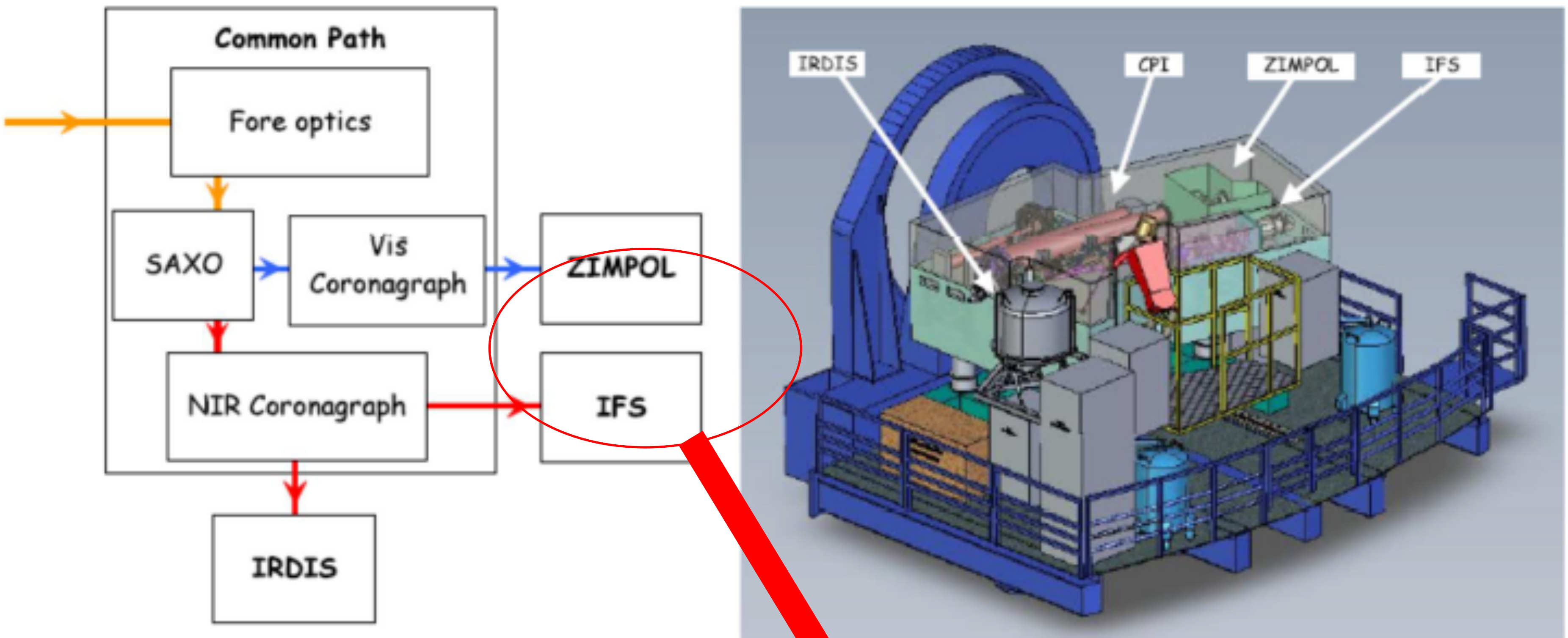
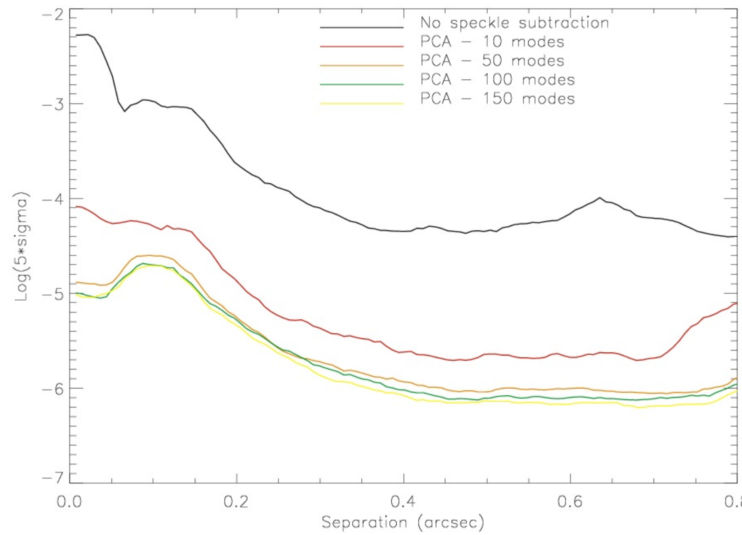


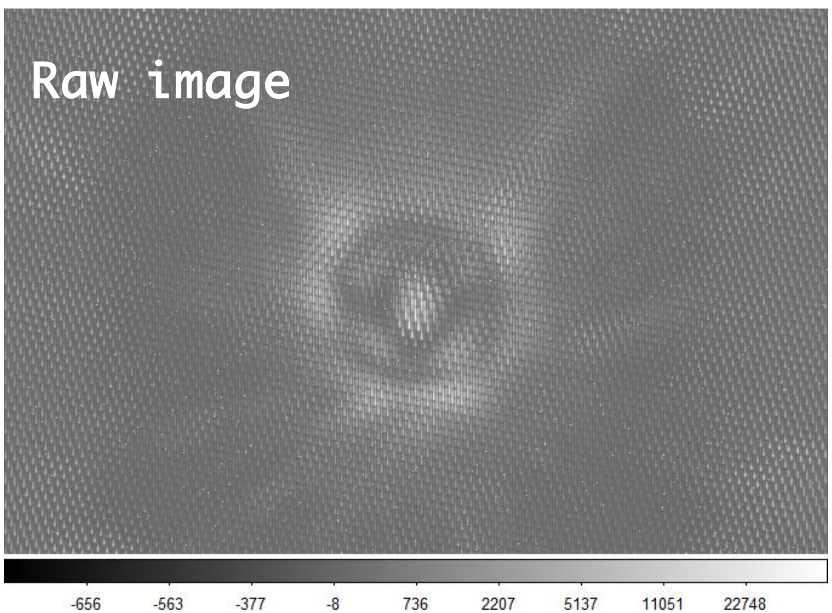
Figure 1: SPHERE sub-systems (left) including the common path (CPI) with adaptive optics system SAXO, coronagraphs, and sub-instruments IRDIS, IFS and ZIMPOL. Left: schematic view of the instrument on the Nasmyth platform.

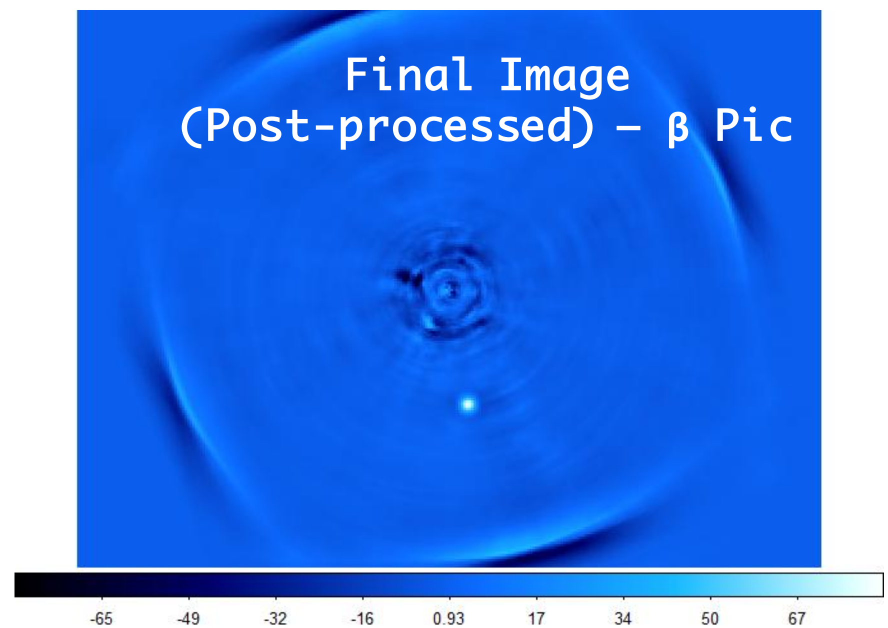
Integral Field Spectrograph

Contrast plot for β Pic with IFS –

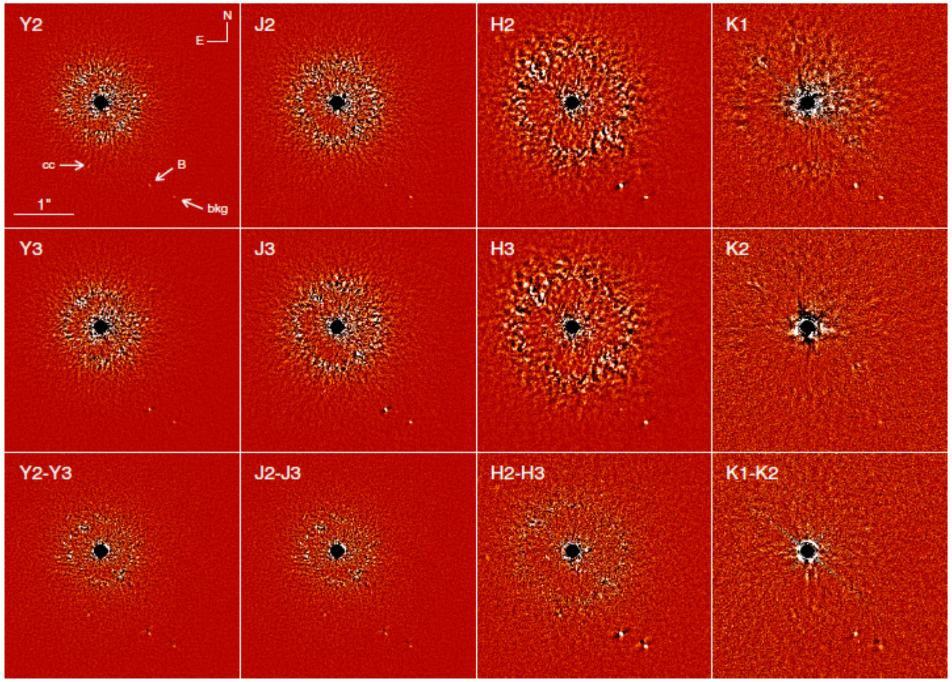
Contrasts better than 10^5 can be obtained at 0.5 arcsec separation





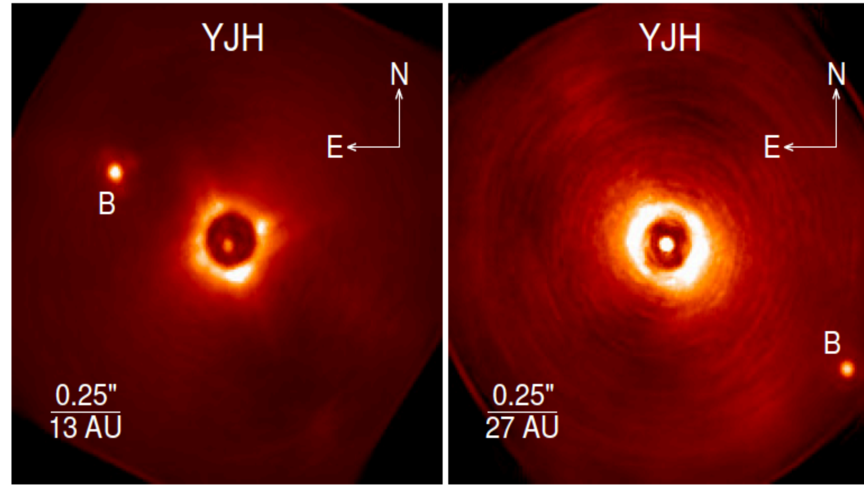


Some differential image techniques can be coupled to improve contrast: e.g., **ADI** with speckle deconvolution or spectral differential imaging or polarimetric differential Imaging or **Principal Component Analysis (PCA), T-LOCI**

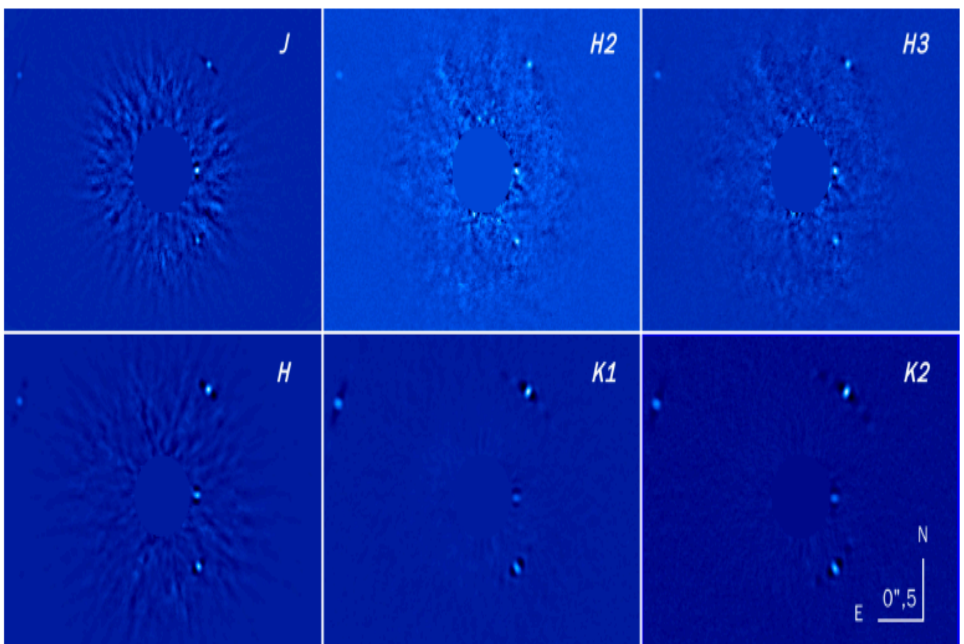


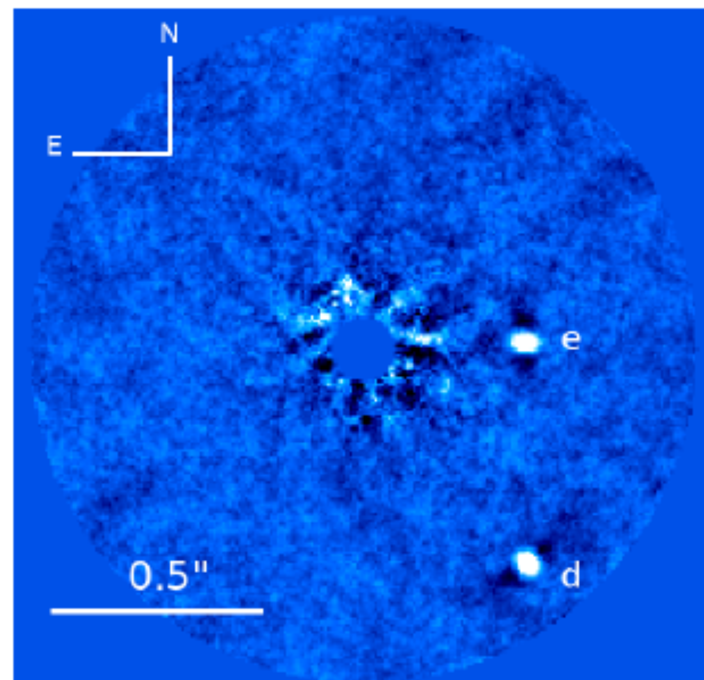
IRDIS GJ758 system (Vigan+ 2016)

Pz Tel & HD 1160 (Maire+ 2016)

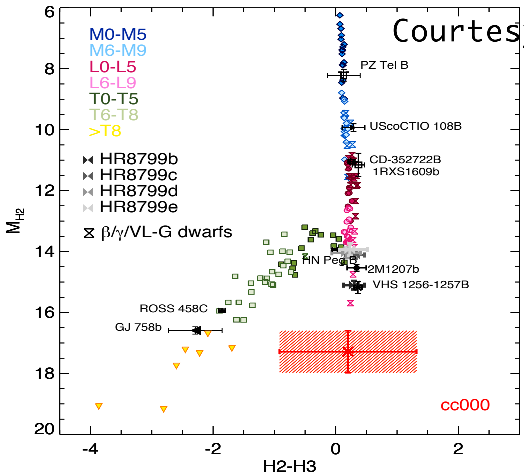


IRDIS (left) and IFS (right)
HR8799 (Zurlo+ 2015)

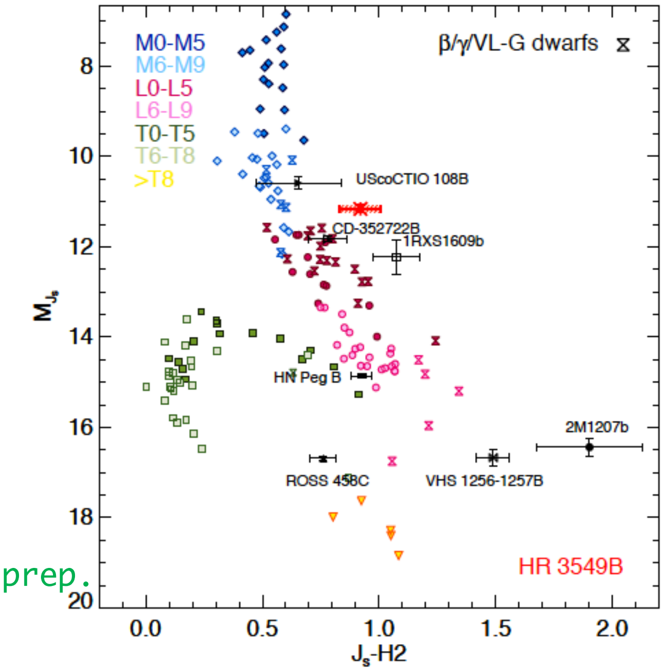




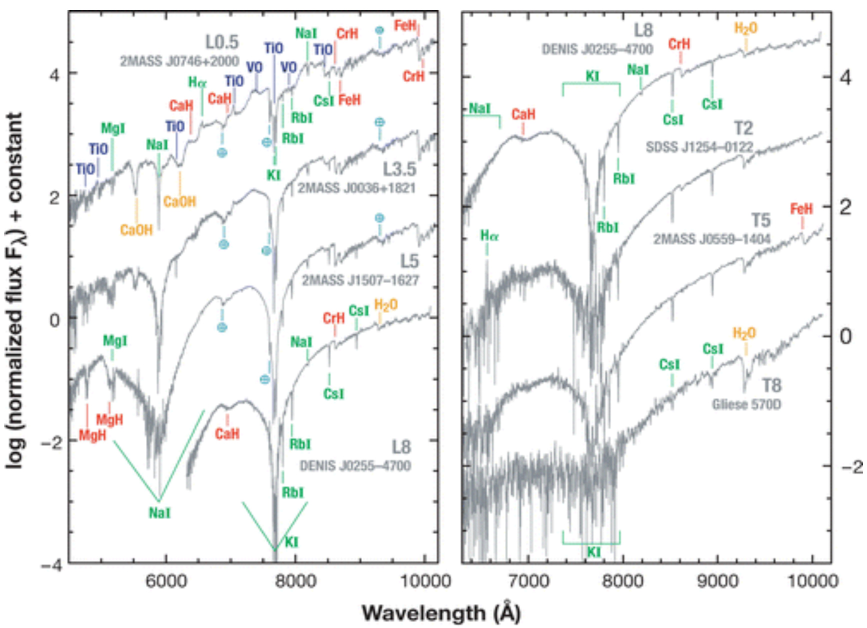
The L-T transition

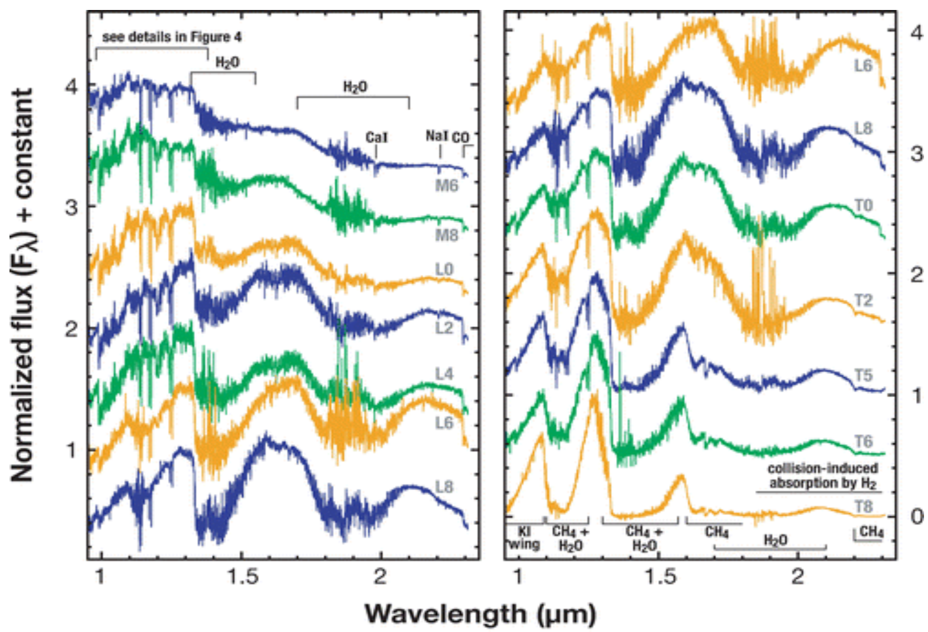


Courtesy of M. Bonnefoy

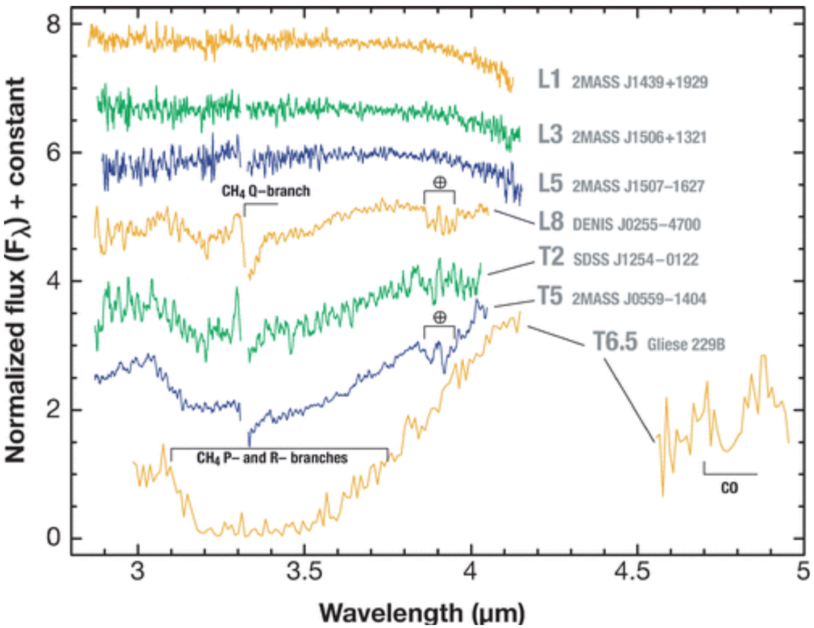


Mesa+ 2016, in prep.



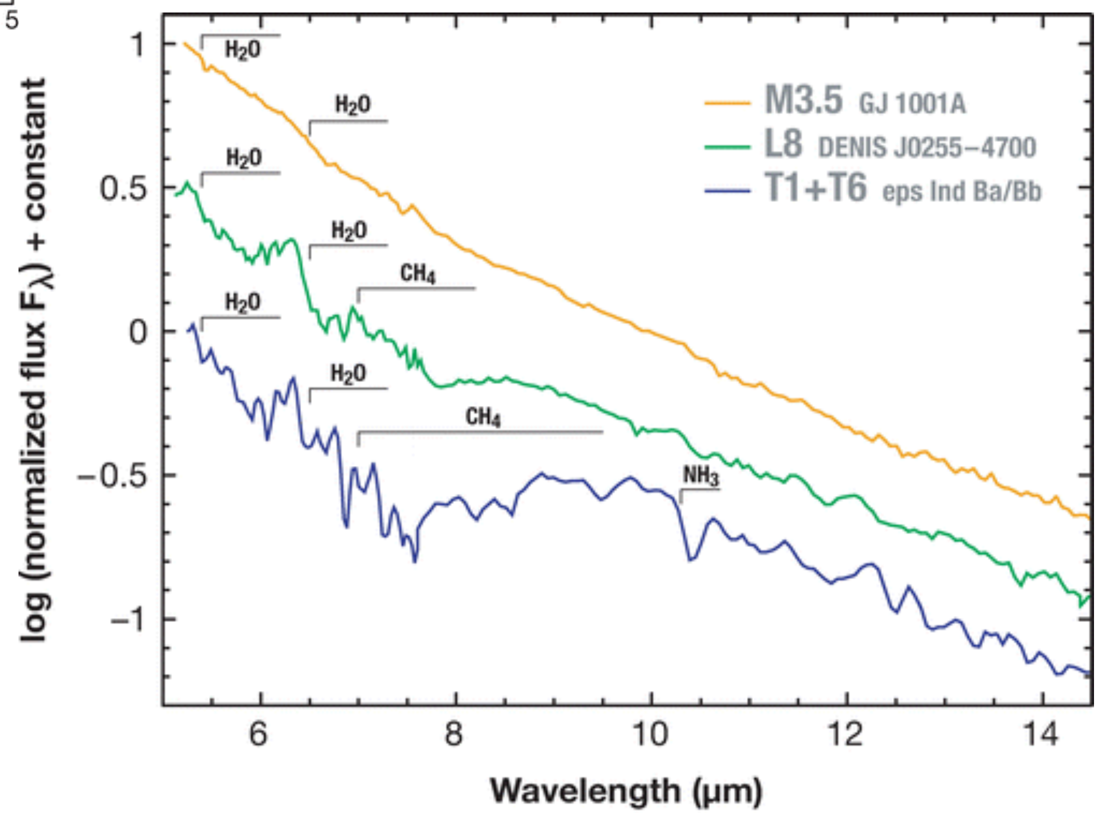


Kirkpatrick+ (2005)



Beyond 5 micron..

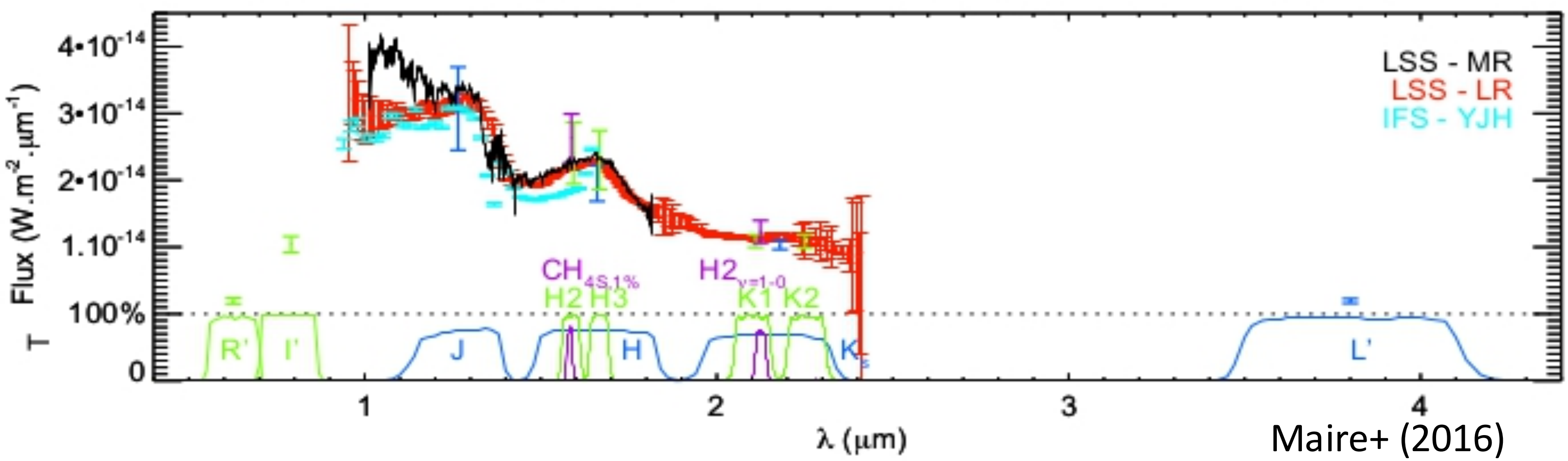
H_2O, NH_3, and CH_4 (the hallmarks of T-type)



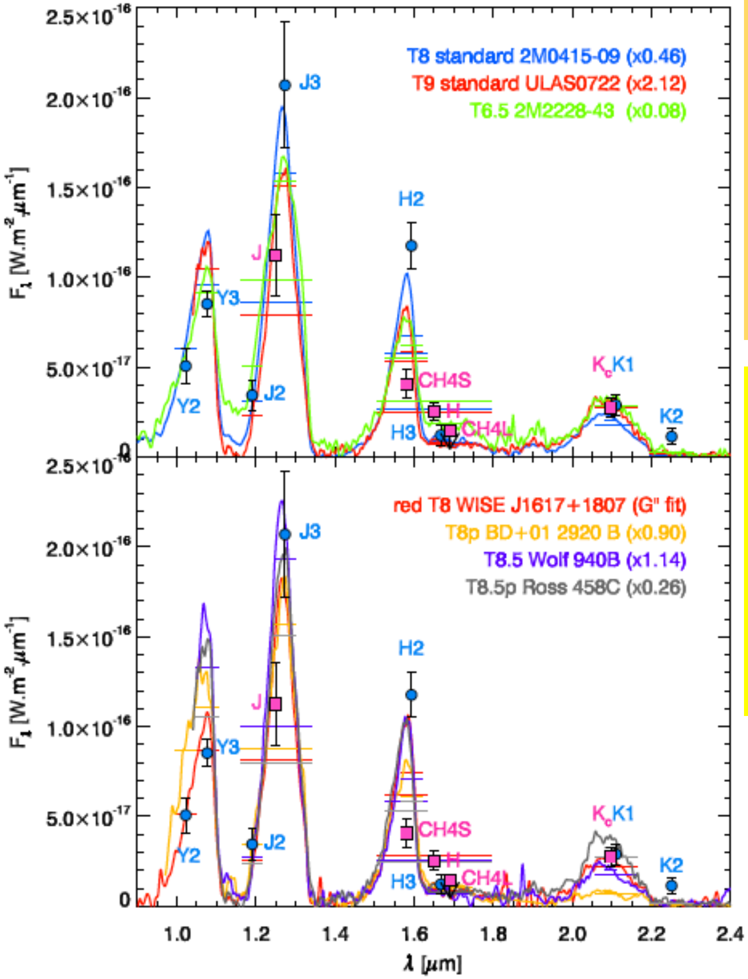
One fundamental advantage wrt JWST would have been the possibility of carrying out "direct" spectroscopy with SPICA/SCI in the critical MIR domain (using a grism/prism providing R ~ 20 - 200) in addition to imaging (a la IRDIS-LLS)

This spectral capability in a wavelength domain rich in chemical signatures (in particular ~ 5 – 10 micron for exoplanet science) represents a unique science possibility of SPICA (H_2O, CH_4, NH_3)

Spectroscopic characterisation of BD/giant planets on wide orbits, such as e.g., GJ 758, GJ 504, HIP 19176. Complementing information coming from the NIR domain → extension to MIR colours to have complete spectral characterisation



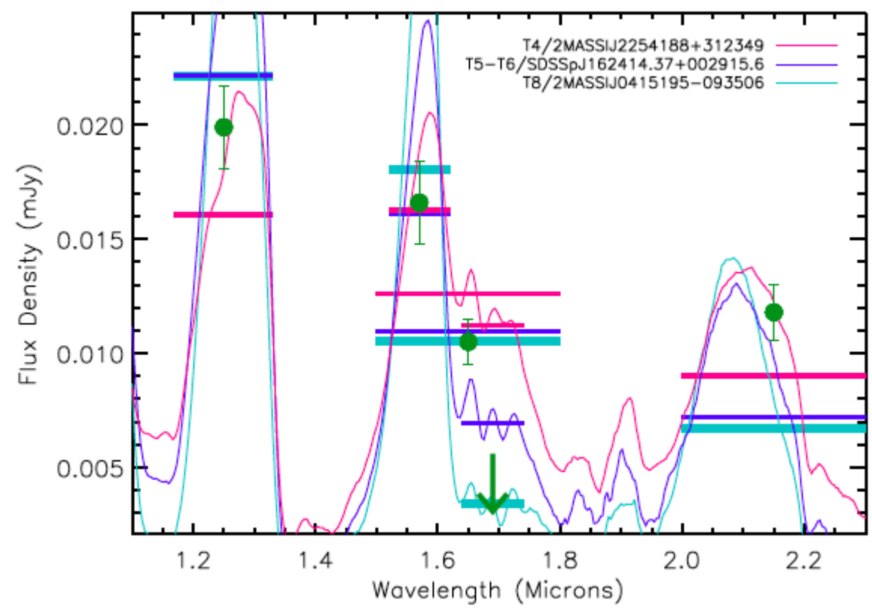
Maire+ (2016)

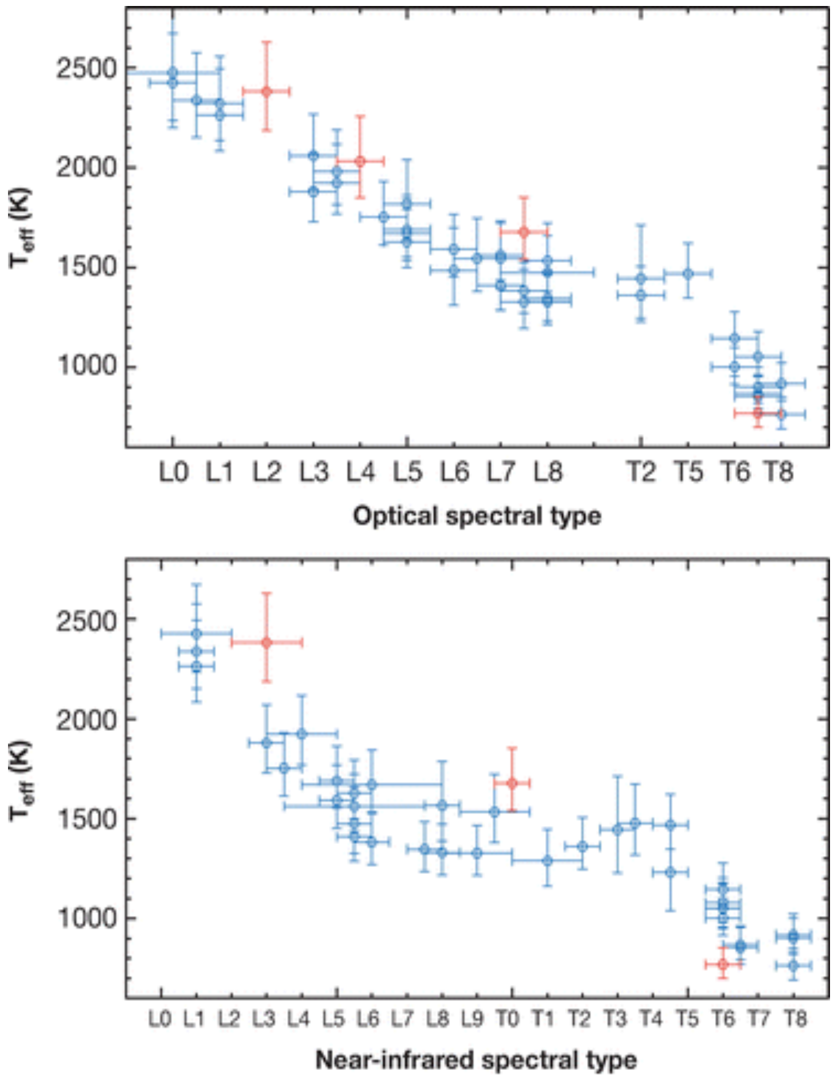


GJ 758B: BD companion of a G-type main-sequence star located at 46 AU (3 arcsec separation for d=15 pc). Detected by Thalmann+ (2009), then further studies by e.g., Janson+2011, Vigan+(2016) with SPHERE

GJ 504B is a sub-stellar companion around the G-type star at ~44 AU. Strongly debated nature of this sub-stellar companion, that is planet (~ 4 M_{jup}, Kuzuhara+2013) or BD (Fuhrman & Chini 2015).

Janson et al. (2013):
FIRST methan-dominated spectrum →
T-type object





Optical spectral type and T_{eff} show a tight correlation throughout the range of L dwarfs, but the correlation is broken at early T.

NIR type shows a different behaviour: T_{eff} and spectral type are well correlated only from early to mid-L. Then we have T~1400 K (but the scatter is quite large); finally cooler T dwarfs show again the correlation.

Stephens (2003) noted the discrepancy suggesting that whereas optical type was primary a proxy for temperature, NIR is more influenced by clouds (and possibly gravity).

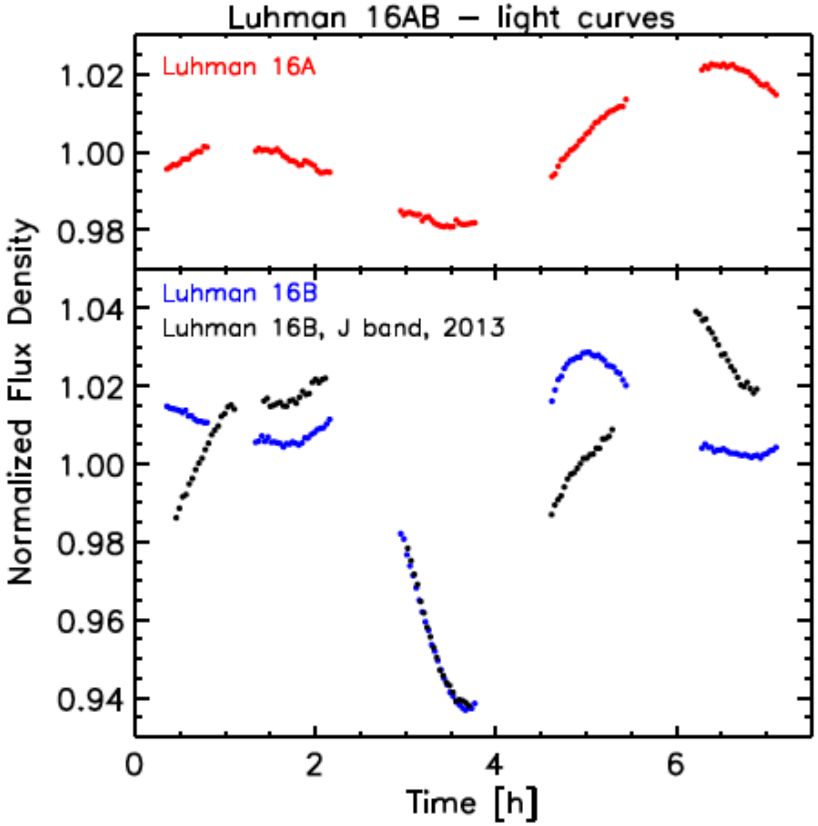
Clouds, are the product of condensation and sedimentation, and their presence has the effect of both veiling features in the spectra and reddening the NIR colors

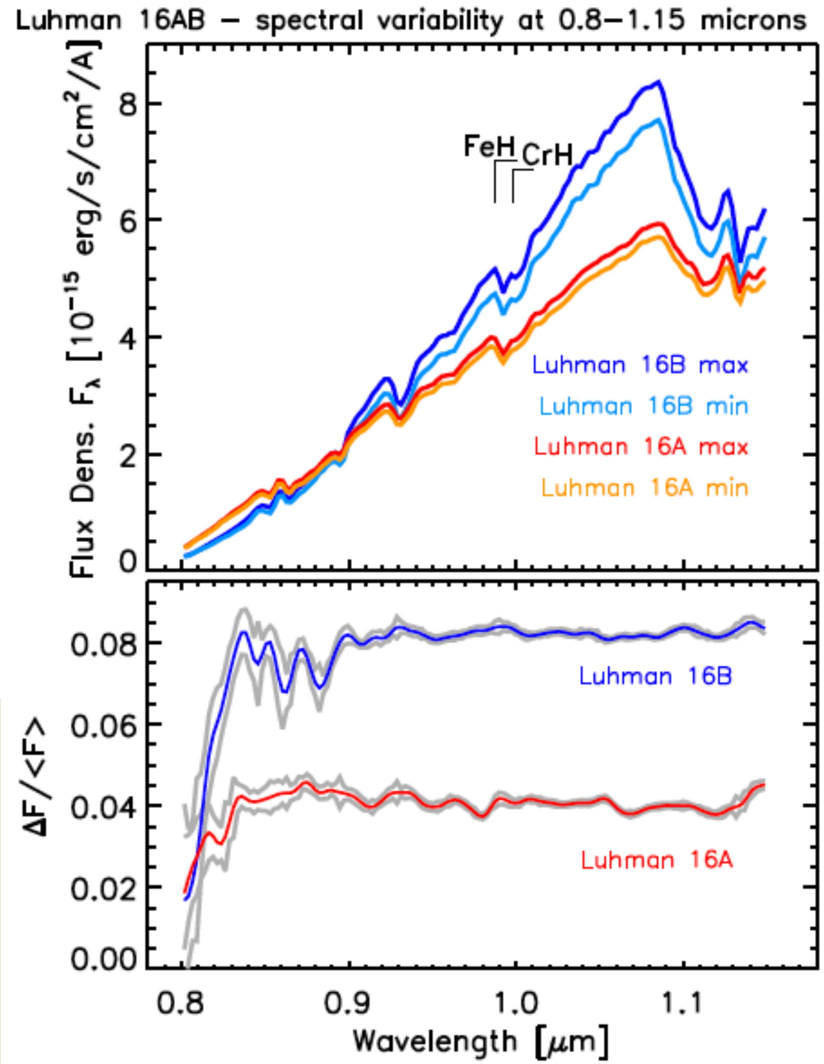
The presence of condensate clouds is one of the most unique features of the ultra-cool atmosphere of directly imaged planets and BDs.

Intensity modulations introduced by heterogeneous clouds can be directly observed and studied via time resolved observations and rotational mapping

Buenzli et al. (2015): HST (five orbits, WFC3, grism G102 0.8-1.15 micron) spectroscopic variability of brown dwarfs (Luhman 16A/B) covering the 0.99 μm FeH feature

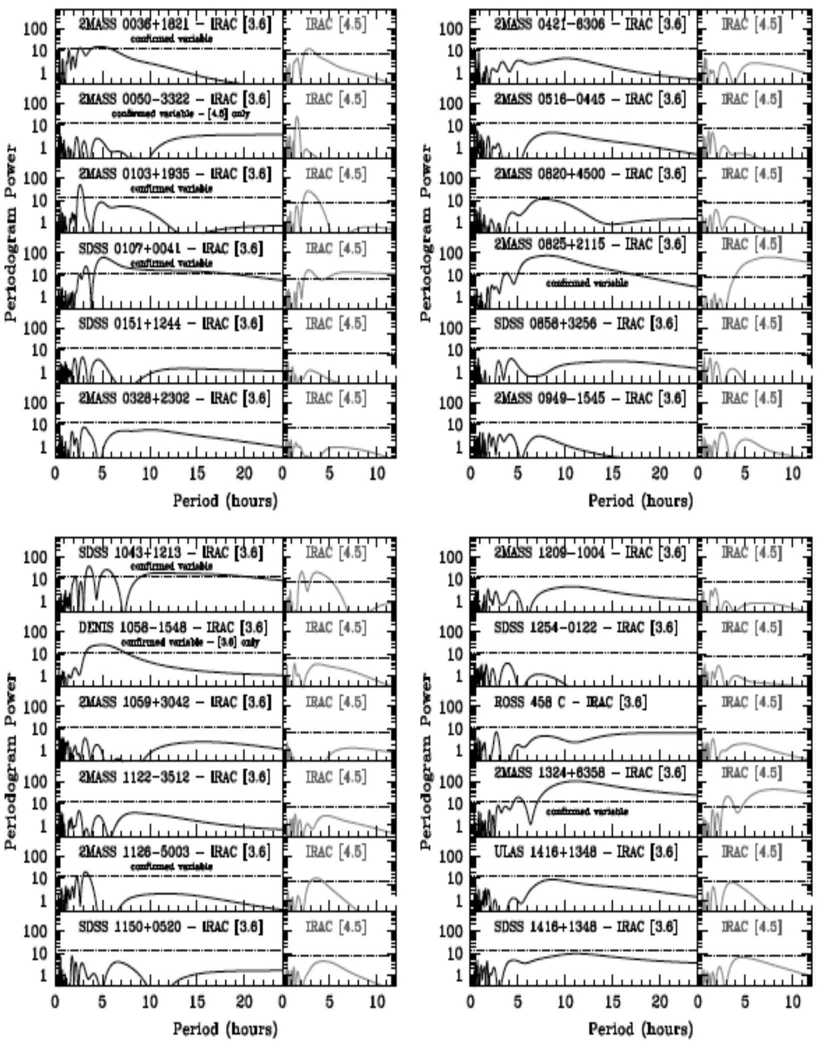
The re-emergence of the 0.99 μm FeH feature in brown dwarfs of early- to mid-T spectral type has been suggested as evidence for cloud disruption where flux from deep, hot regions below the Fe cloud deck can emerge.
The same mechanism could account for color changes at the L/ T transition and photometric variability.





RESULTS: significant variability at all wavelengths for both brown dwarfs, with peak-to-valley amplitudes of 9.3% for Luhman 16B and 4.5% for Luhman 16A. This represents the first unambiguous detection of variability in Luhman 16A: rotational period between 4.5 and 5.5 hr, very similar to Luhman 16B.

Matchev et al. (2015): IRAC photometric campaign of 44 L3–T8 dwarfs, spanning a range of J - Ks colors and surface gravities.

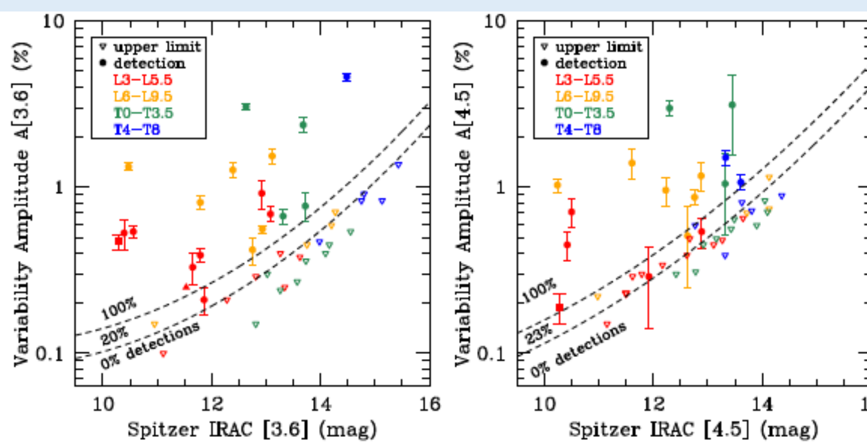


14/ 23 (~60%) of our single L3–L9.5 dwarfs are variable with peak-to-peak amplitudes between 0.2% and 1.5%, and 5/ 16 (~31%) of single T0–T8 dwarfs are variable with amplitudes between 0.8% and 4.6%.

After correcting for sensitivity:

80% of L dwarfs vary by 0.2%, and 36% of T dwarfs vary by 0.4%.

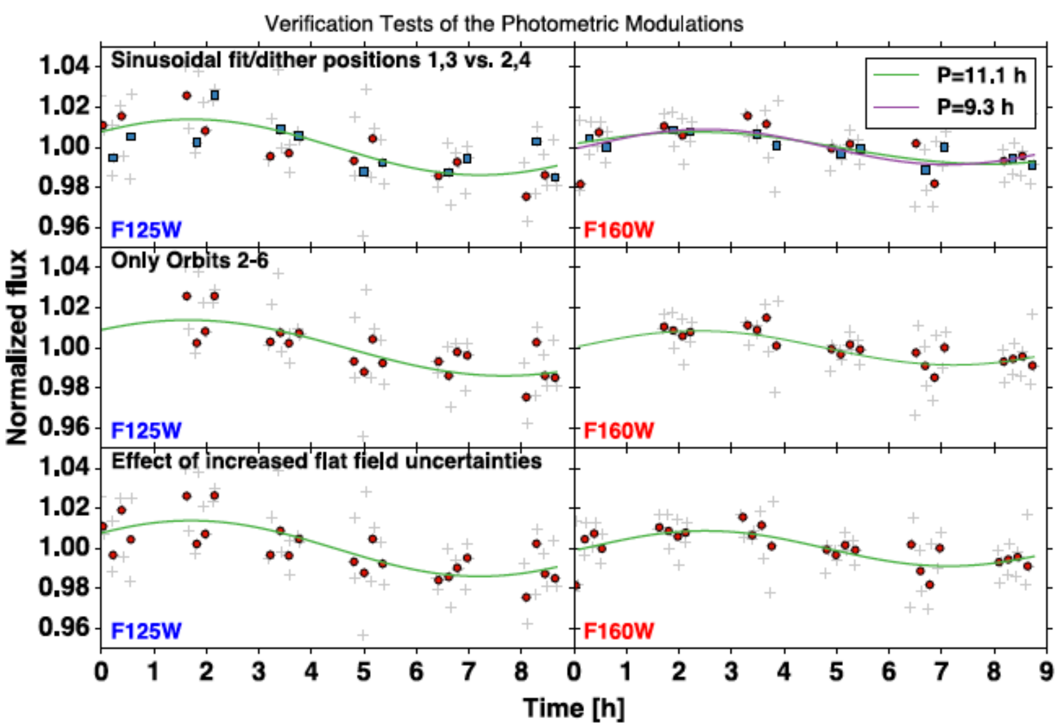
“Given viewing geometry considerations, we conclude that photospheric heterogeneities causing >0.2% 3–5μ m flux variations are present on virtually all L dwarfs, and probably on most T dwarfs.”



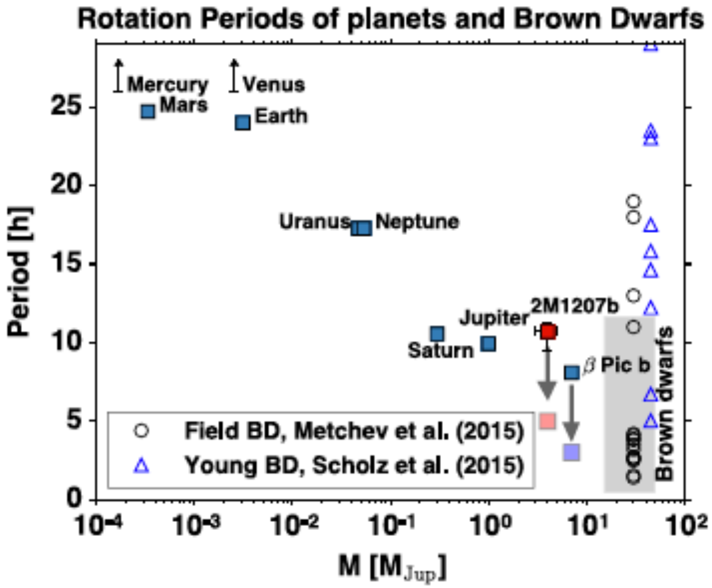
Zhou et al. (2016): 2M1207b (Chauvin et al. 2004) orbiting a young BD at angular separation of 0.78” (~40 AU at d=52 pc)

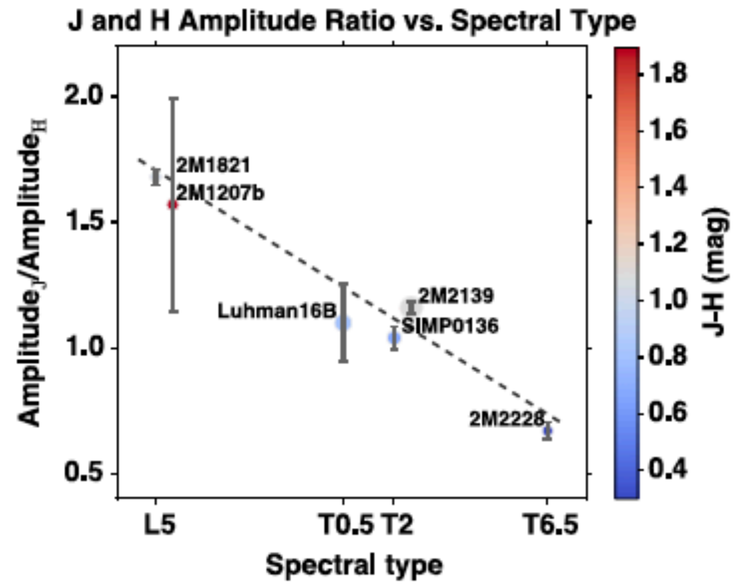
Early observations revealed that 2M1207b’s color is much redder and its NIR luminosity is much lower than those of field BD with similar spectra. Skemer et al. (2012) argued that the apparent under-luminosity of 2M1207b could be explained by a model of spatially heterogeneous atmosphere composed of patches of thin and patches of unusually tick clouds.

Zhou et al. presented high-contrast, high-precision, time-resolved HST photometric time series of 2M1207b (filters F125W and F160W).



Intrinisic modulation and not due to artifacts in data reduction procedures or instrumental change.





2M1207b wrt B Pic measurement from Snellen et al. (2014): demonstrated that it fits the trend defined by SS planets in which more massive planets have faster rotation rates.
The measurement of 2m1207b, similar age of B Pic B, has a rotation that fits the same trend. The rotation period of ~10 hours is longer than those of field BD by Metchev et al. (2105), but matched those of BD with similar age.

Compare the relative amplitude of J- and H-bands of 2M1207b and brown dwarfs that have different spectral types and J–H colors

Interesting possible correlation between the spectral types of the objects and their J to H-band amplitude ratios: earlier spectral type objects have larger amplitudes at shorter wavelength than at longer wavelengths.

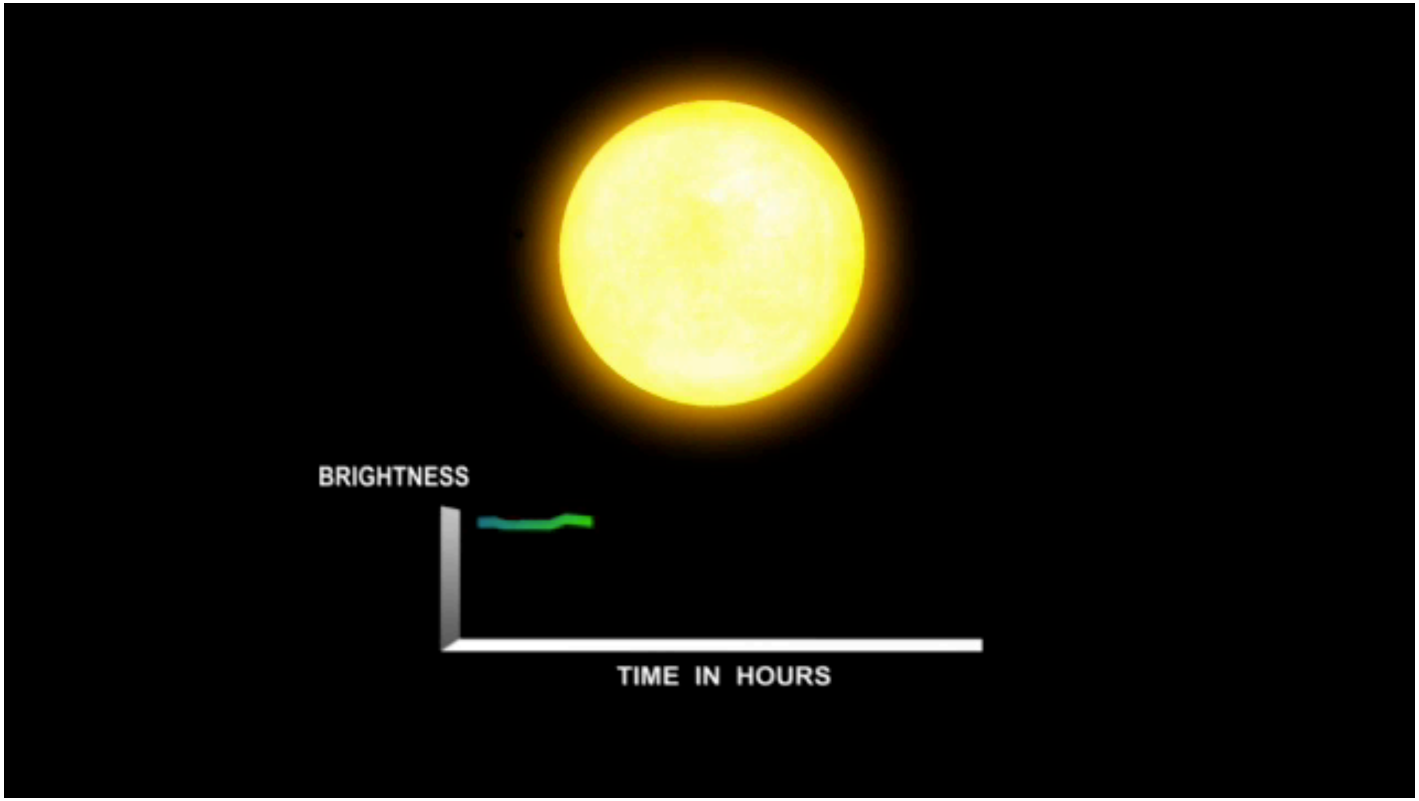
SPICA will change our understanding of exoplanets as global systems: we will have a new look into the very early stages of star and planet formation (circumstellar discs, transitional discs, debris discs)

SPICA would have provided us with a unique tool to study "exoplanet meteorology": cloud characterisation, atmospheric studies, rotational properties and their time evolution, and many more.. Because of the extremely high pressure, this kind of investigations will be almost impossible for JWST

Also, the possibility to have a combination of grism spectroscopy with coronagraphic mode, would have allowed to characterise the extrasolar planets complementing information from the NIR and providing key diagnostics such as e.g., CH_4, or H_2O molecules.
This *WILL NOT* possible with JWST

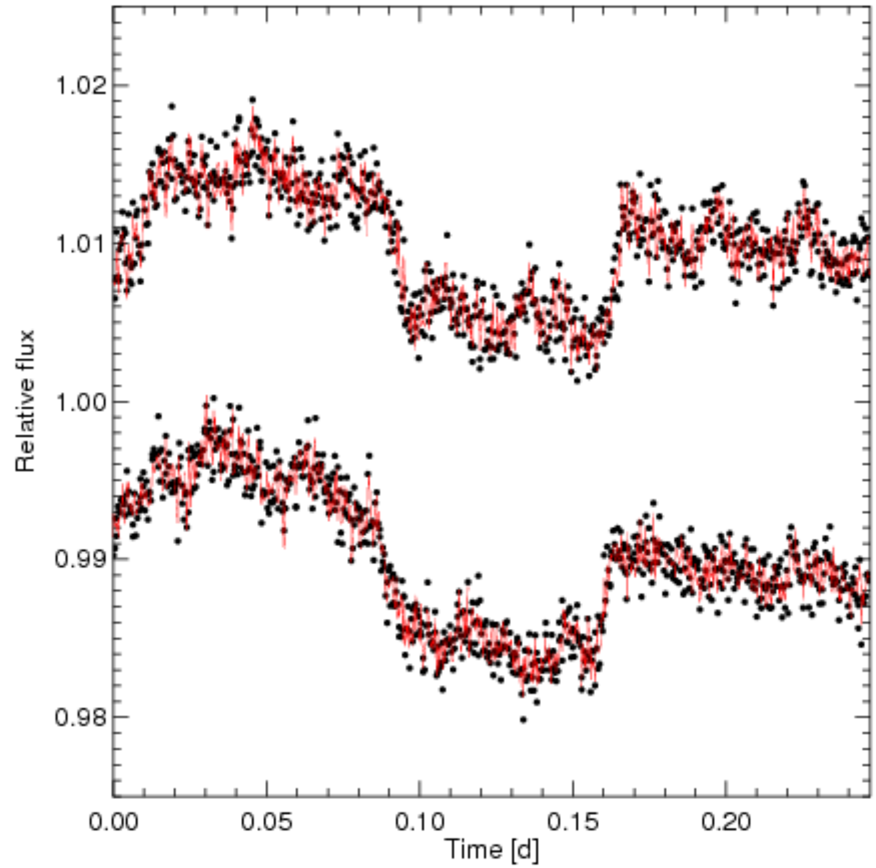
And…. Transits!

EPs orbiting very close to the host star (~0.05 AU) and with a favourable inclination (almost edge-on systems) can be indirectly studied via the transit technique by which the dimming of the starlight as the EP transits the star is followed (Seager & Sasselov 2000).



Because of the precise timing of a transit event, this technique allows high-contrast observations if very sensitive, low background and stable observing conditions are available (i.e., from space). Although not specifically designed for EP research, transit observations with Hubble and Spitzer have revolutionised and redefined the field of EP characterisation

Spitzer/IRAC 4.5 μm for GJ3470b, a Neptune-size planet orbiting a metal-rich M-dwarf (Demory+2013)



SPICA will provide further fundamental information, thanks also to the synergy with missions like PLATO