University of Hertfordshire UH

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Spectroscopic analysis of a large sample of L and T brown dwarfs

Federico Marocco

Hugh R. A. Jones (UH), David J. Pinfield (UH), Avril C. Day-Jones (UH), Ben Burningham (UH), Phil W. Lucas (UH), Alexandre H. Andrei (ON/OATo), Richard L. Smart (OATo), ZengHua Zhang (UH/IAC), Alessandro Sozzetti (OATo)

IPERCOOL

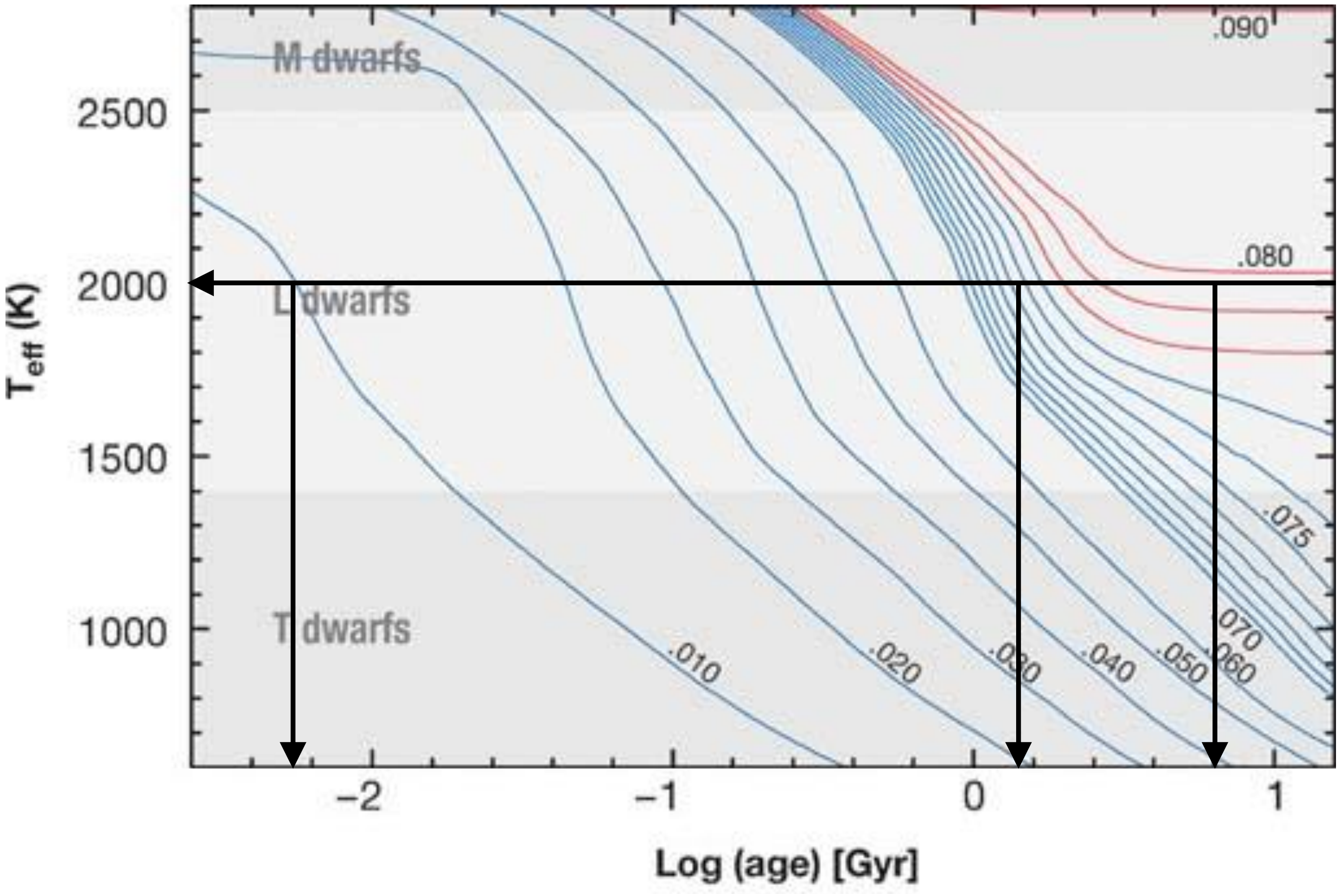
Interpretation and Parameterization of Extremely Red COOL dwarfs

Introduction

Brown dwarfs (BDs) are sub-stellar objects, whose mass is insufficient to trigger and sustain stable hydrogen fusion in their cores ($M < 78\ M_{Jup}$). As a result, they cool down over time.

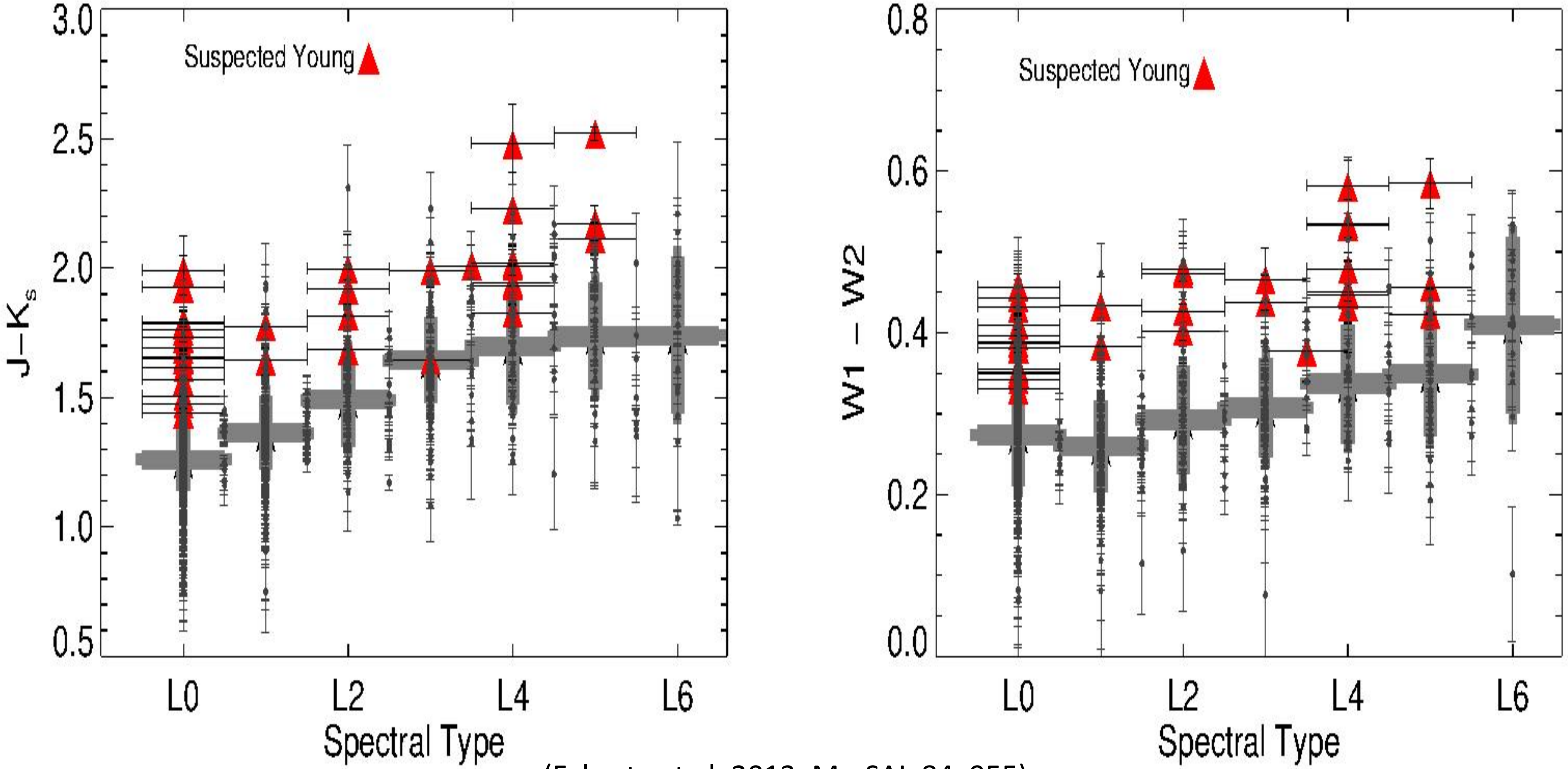
(Kirkpatrick 2005, ARA&A, 43, 195)

Mass, luminosity and age are therefore "degenerate" parameters, i. e. objects of similar T_{eff} can have very different physical properties (e.g. age, mass, metallicity, surface gravity).



Introduction

The wide range of parameters covered is reflected by the NIR colours.

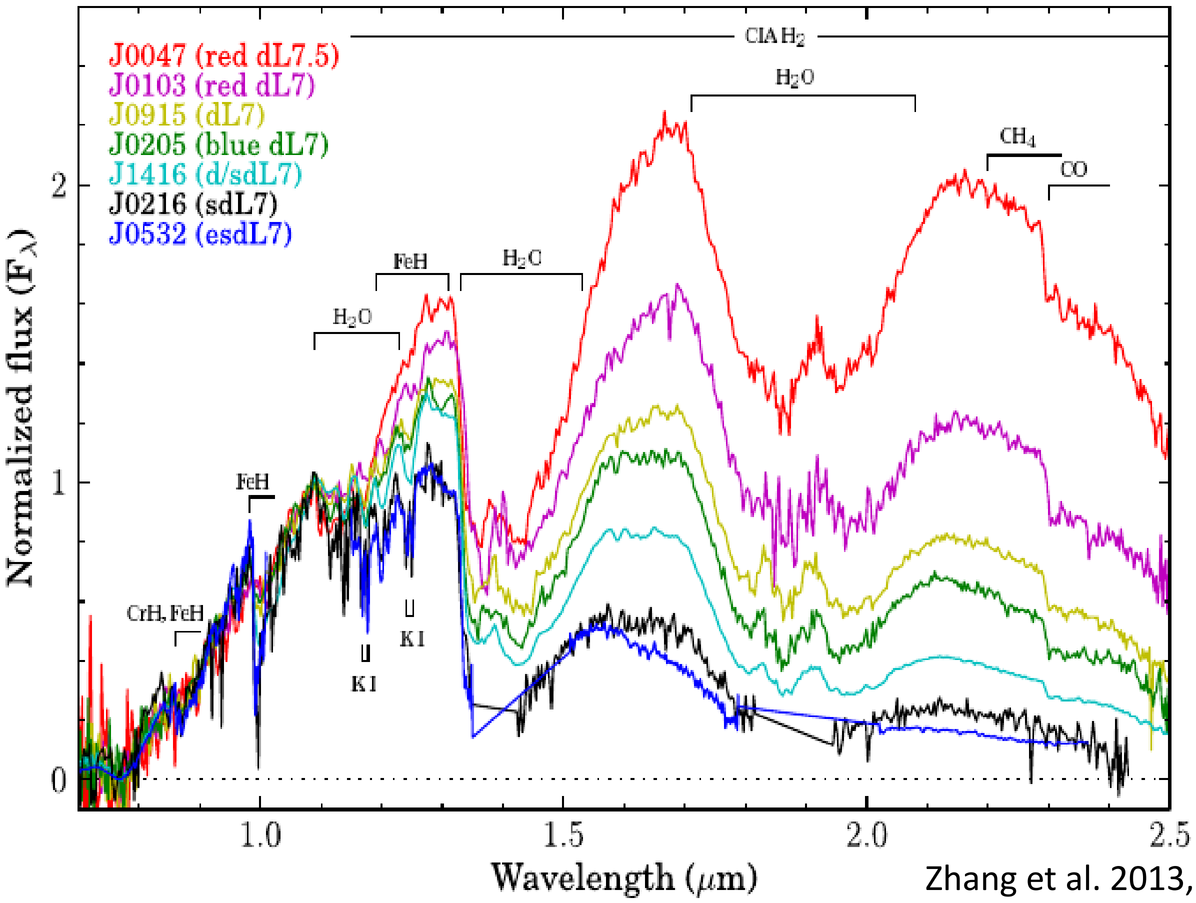


(Faherty et al. 2013, MmSAI, 84, 955)

Introduction

The same effects can be seen in the spectra.

The huge differences in the NIR spectra of these late Ls are due to the large spread in metallicity and surface gravity (i.e. ages) sampled, from the very blue, very metal poor esdL7 to the very red dL7.5.



Young

Old

Zhang et al. 2013, EPJWC

Introduction

Near-infrared spectroscopy is fundamental to characterize BDs. By analyzing the spectra of large samples of BDs, one can understand the atmospheric physics, i.e. the dust formation process, the clouds dynamics, and the dust settling.

My work consists of two parallel and complementary projects:

-The spectroscopic follow-up for the PARSEC program;

-The Birthrate program a.k.a. our attempt to constrain the sub-stellar IMF and formation history.

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PARallaxes of Southern Extremely Cool objects

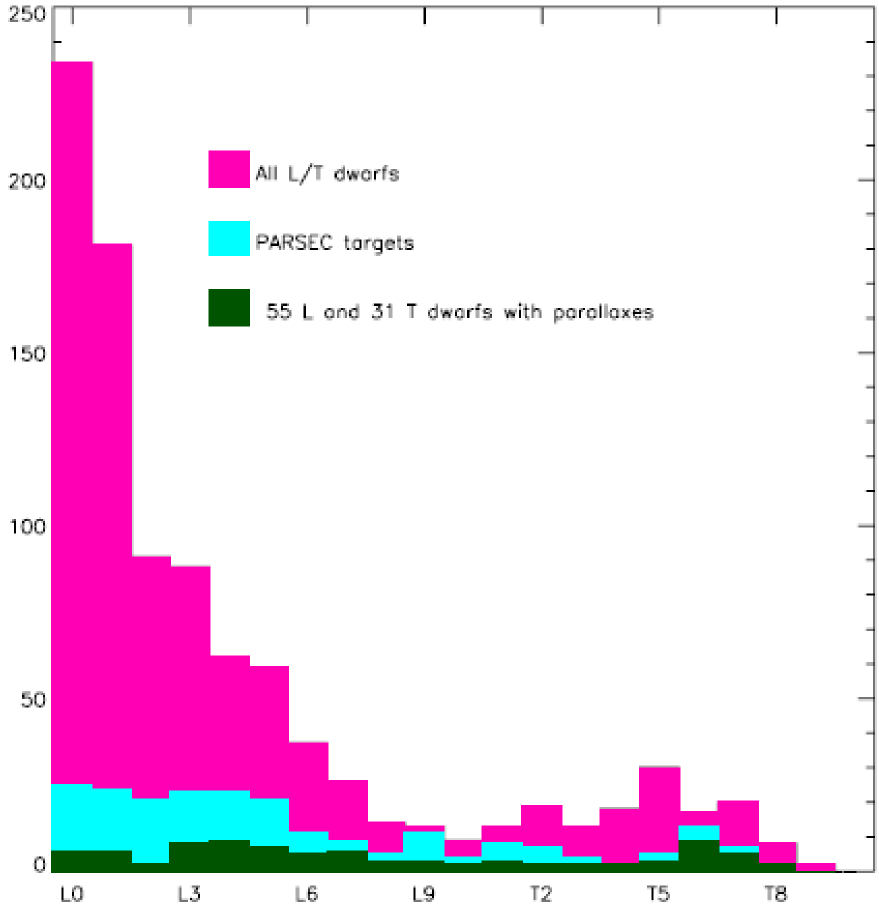
Large astrometric program to determine parallaxes and proper motions of ~140 L and early-T dwarfs in the southern hemisphere.

http://parsec.oato.inaf.it

Observations began in April 2007, using ESO2.2 in La Silla. First results are presented in Andrei et al. 2011 and Marocco et al. 2013 (31 parallaxes + PM catalogue)

PARSEC doubles the number of L and T dwarfs with parallaxes.

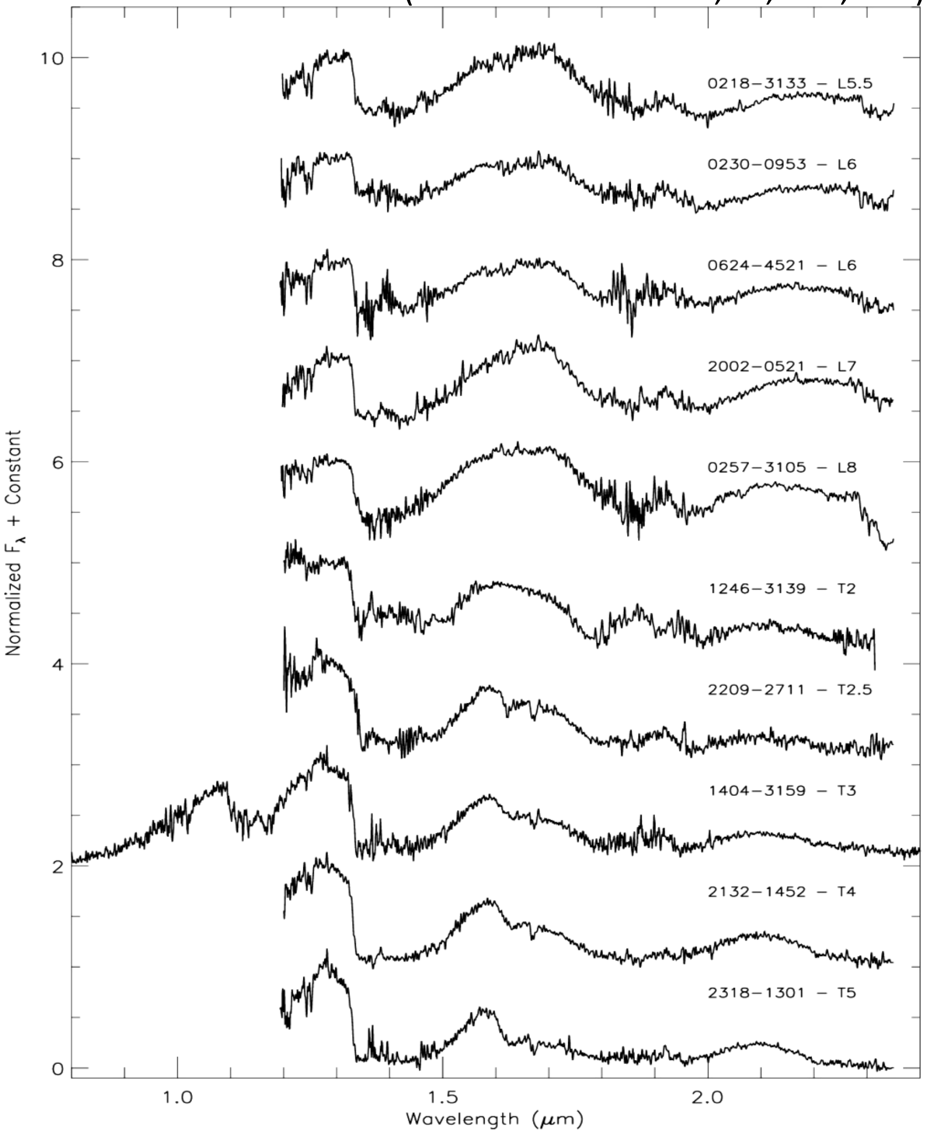
(Andrei et al. 2011, AJ, 141, 54)



~50% of the targets did not have NIR spectra, so we started a spectroscopic follow-up campaign using SOAR/OSIRIS, VLT/Xshooter, and NTT/SOFI.

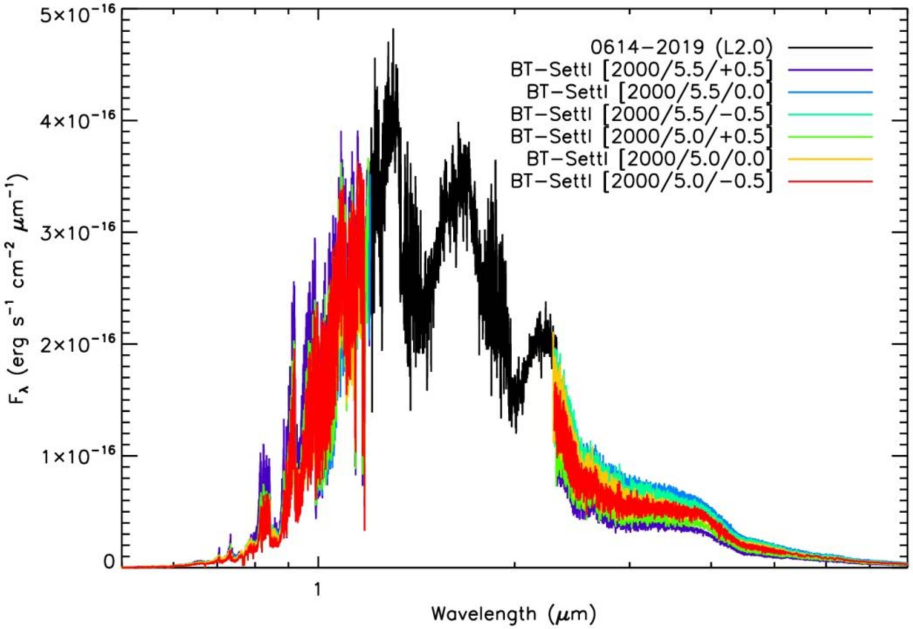
We obtained NIR spectra for 52 targets (45 with OSIRIS, 5 with Xshooter and 2 with SOFI). **21 of them have parallaxes.**

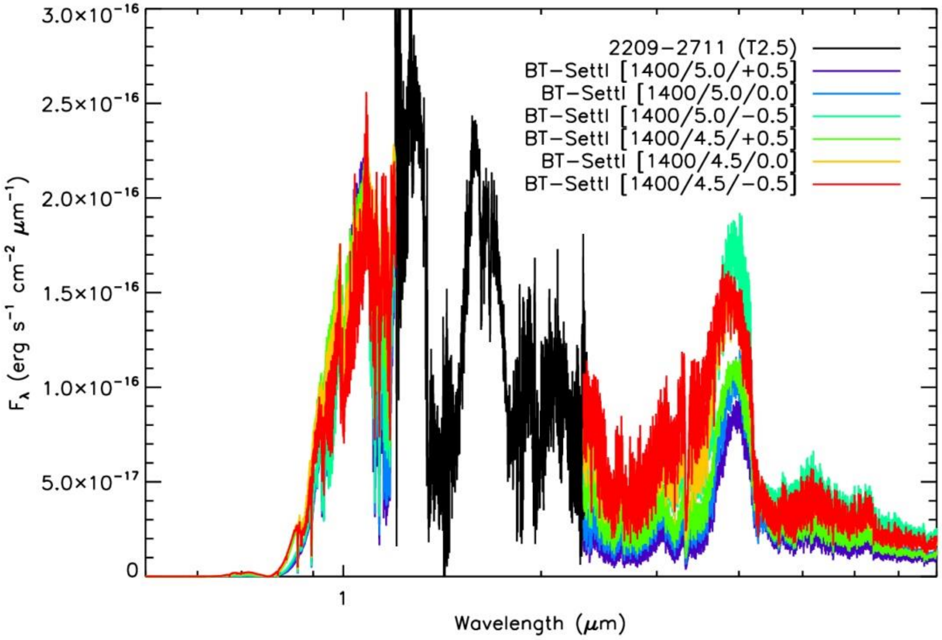
Combining spectroscopy and parallaxes we obtained L_{bol} and T_{eff} for our targets.



(Marocco et al. 2013, AJ, 146, 161)

To estimate the bolometric correction we used the BT-Settl and BT-Dusty atmospheric models (Allard et al. 2001, 2003, 2011).



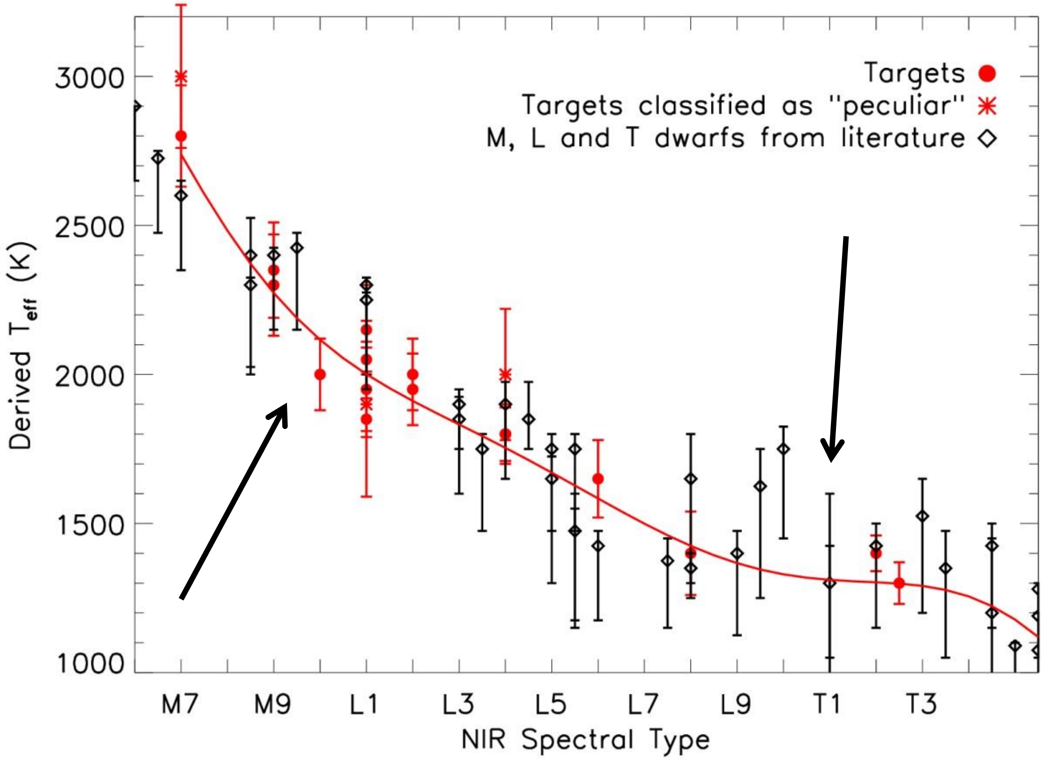


For the coolest objects , at long wavelengths (i.e. λ > 3 μm) the bolometric correction is very sensitive to surface gravity and metallicity, but those parameters are unconstrained!

We fit a new T_{eff} vs spectral type polynomial relation.

Our new fit seems to suggest a change in the slope of the sequence at the transition between M and L dwarfs. This may be an effect of dust formation and its migration into the photosphere, that causes a more rapid evolution of the spectral features as a function of T_{eff}.

(Marocco et al. 2013, AJ, 146, 161)



Uncertainties are too large and the sample is still to small to be able to say anything definitive. The full sample will allow us to put a stronger constrain on the relation.

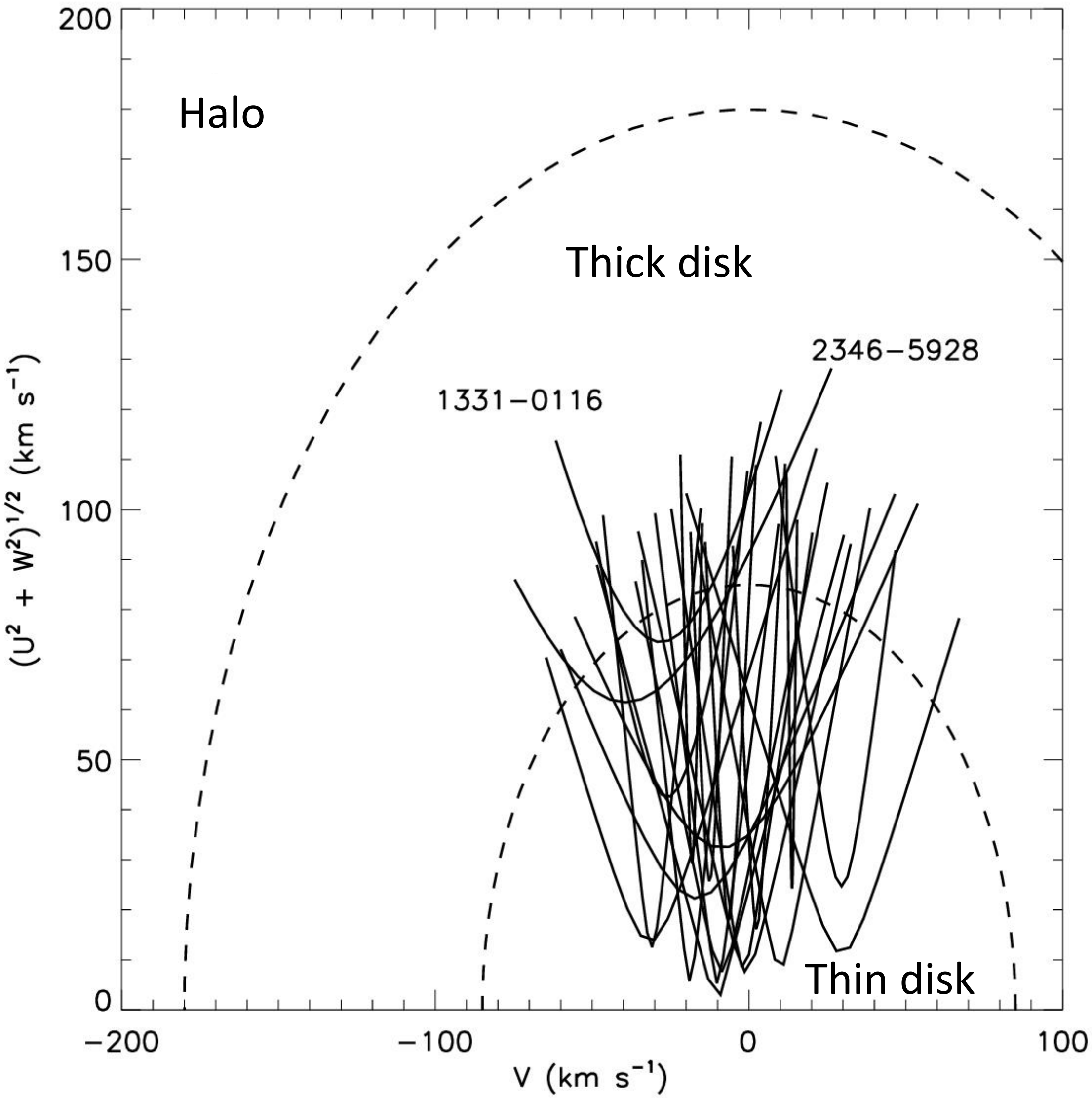
(Marocco et al. 2013, AJ, 146, 161)

The kinematics of the sample provides useful insights on the nature of the targets.

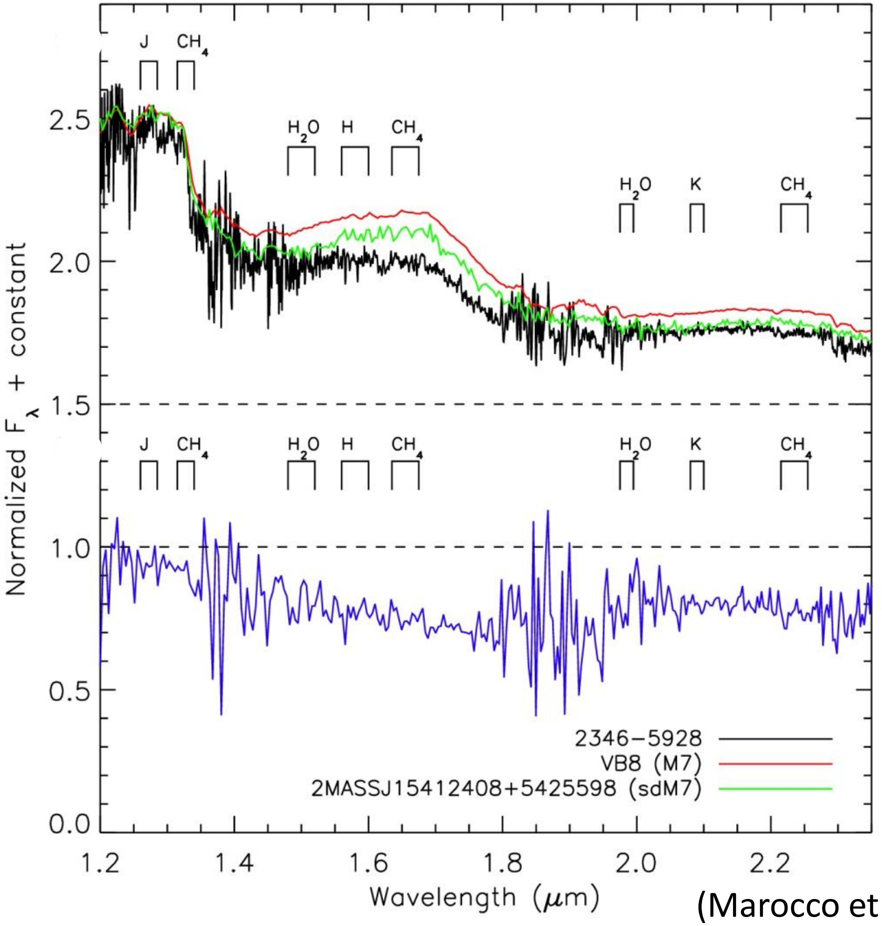
We calculated U,V,W assuming -100 km/s < V_{rad} < +100 km/s

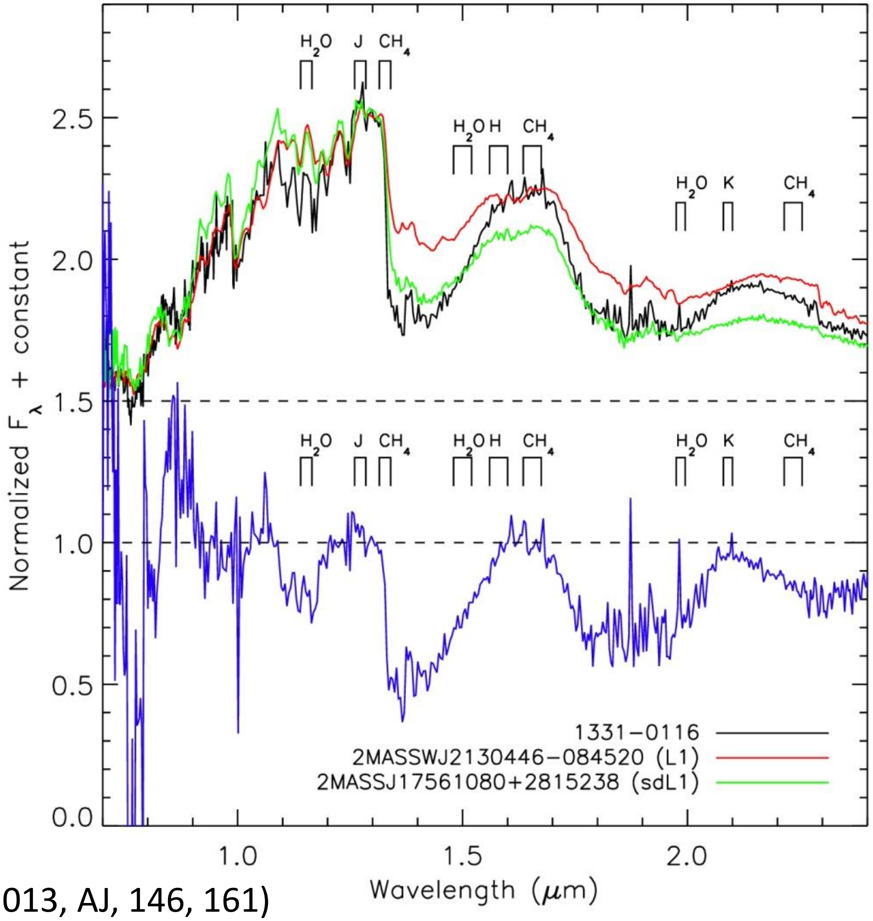
Two objects seem to belong to the thick disk population: 1331-0116 and 2346-5928.

And in fact, if we look at their spectra ...



... both objects are bluer than the spectroscopic standards , and show signs of metal depletion, i.e. stronger H_2O, Na I and K I absorption.



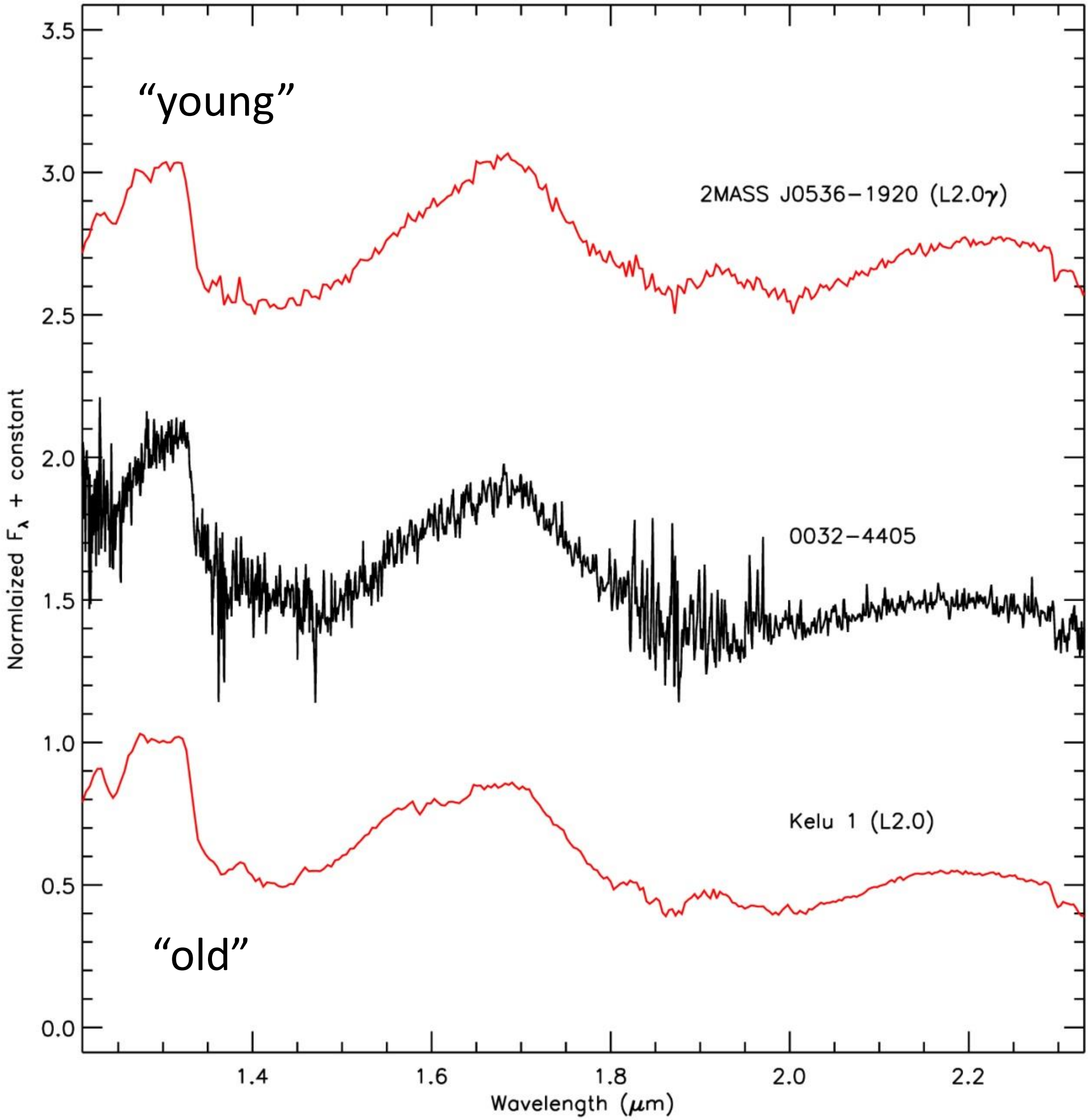


(Marocco et al. 2013, AJ, 146, 161)

The kinematics can also be used to check the possible membership of the targets to any of the young moving groups.

Two objects have non-zero probability of belonging to the Pleiades: 0032-4405 (23%) and 2209-2711 (9%).

Only 0032-4405 shows signs of low gravity (e.g. of youth).



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Constraining the IMF and formation history

Because of the mass-age-luminosity degeneracy, the luminosity function of BDs depends on the formation history. IMF and formation history of sub-stellar objects are poorly constrained.

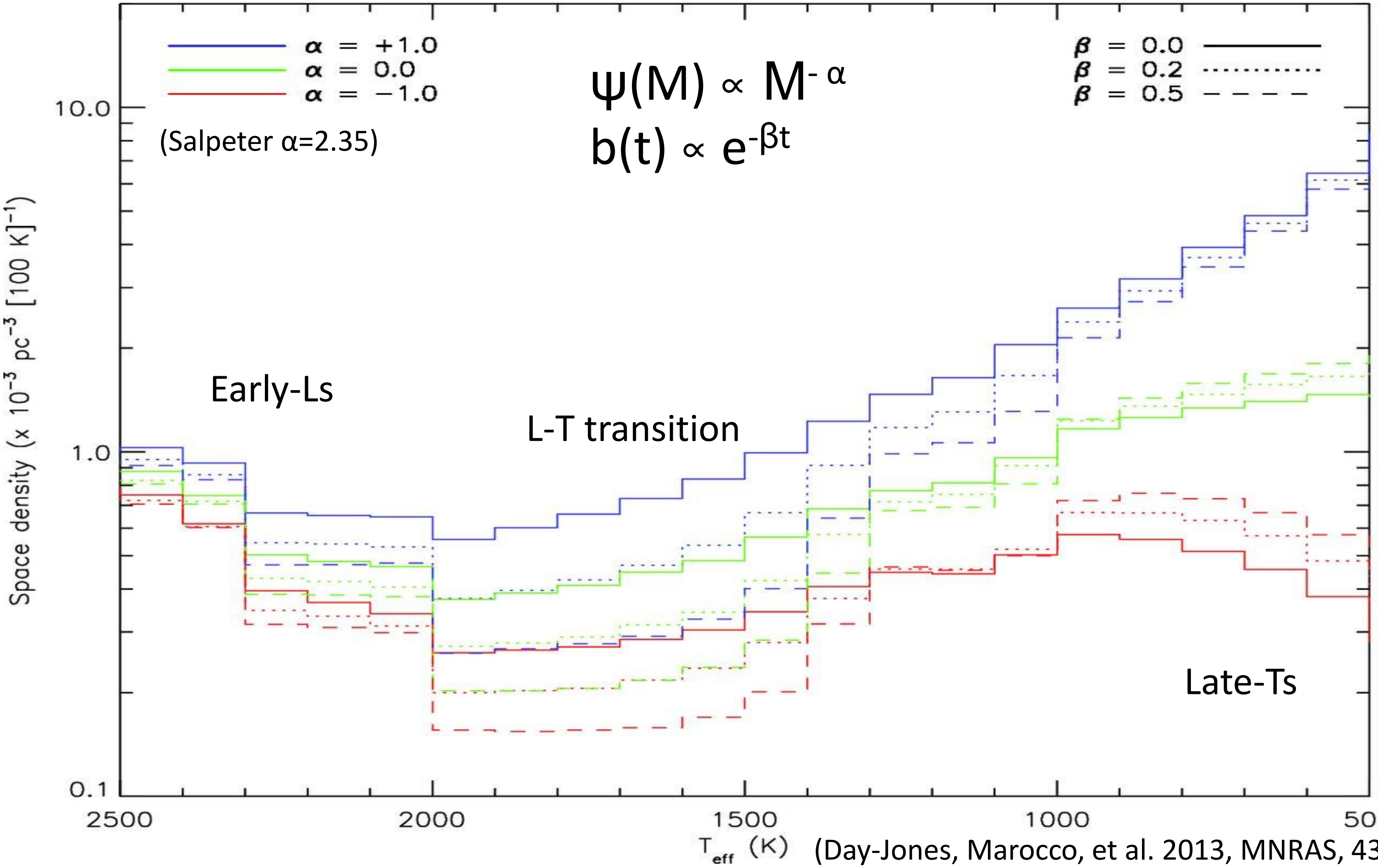
Moreover, the formation process of BDs is still a matter of debate. Two different mechanisms (star-like and planet-like) could contribute to the current population of BDs.

↓

Determining the luminosity function of BDs can help us understand the formation process of sub-stellar objects.

Constraining the IMF and formation history

Monte Carlo simulations show that the L-T transition regime is the most sensitive to the formation history.



$\psi(M) \propto M^{-\alpha}$

$b(t) \propto e^{-\beta t}$

(Day-Jones, Marocco, et al. 2013, MNRAS, 430, 1171)

Constraining the IMF and formation history

We started a spectroscopic campaign to follow-up a sample of 250 L-T transition BD candidates, photometrically selected from UKIDSS LAS DR7.

(Day-Jones, Marocco, et al. 2013, MNRAS, 430, 1171)

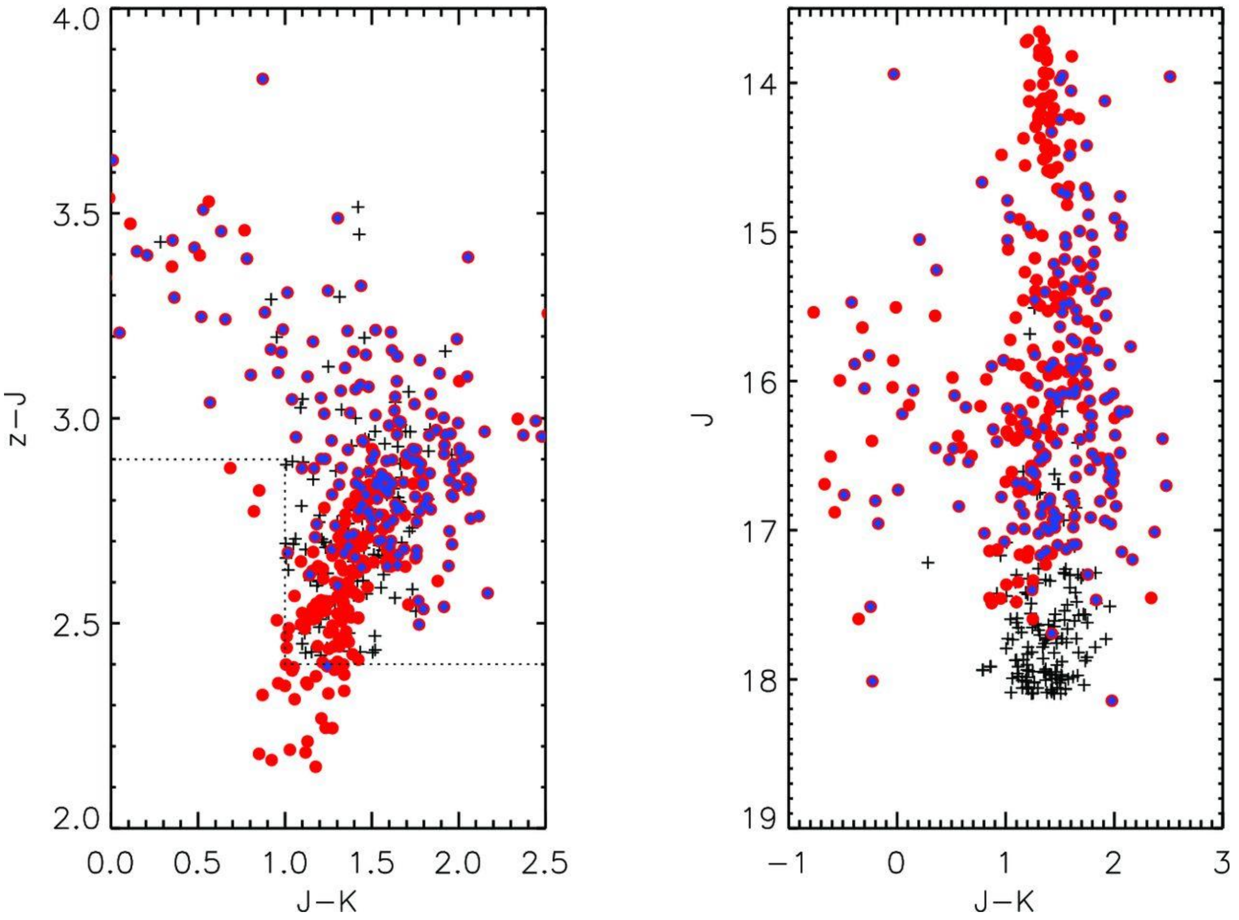
Criteria:

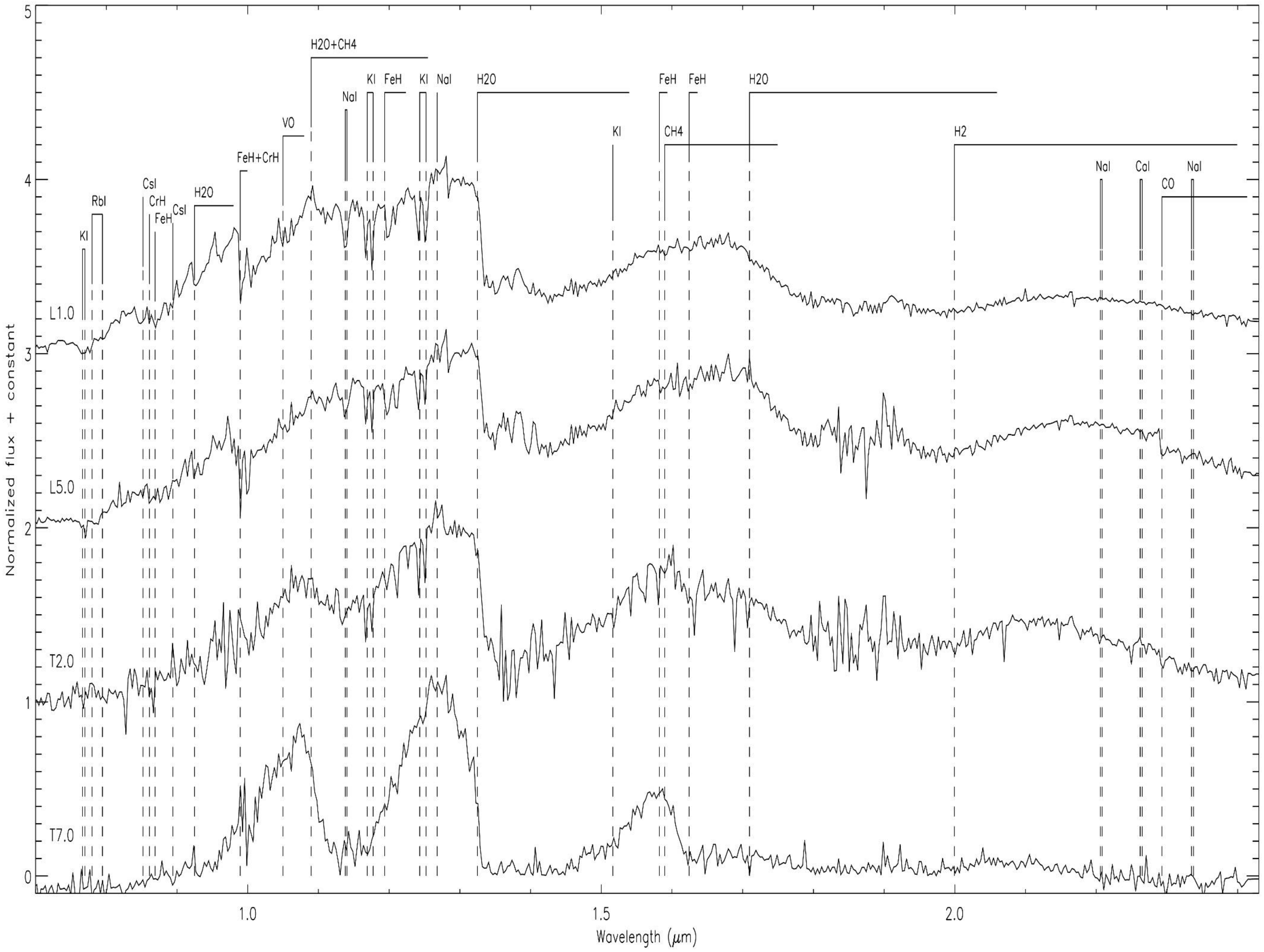
- J <= 18.1
- Y-J >= 0.8
- z-J >= 2.4 and J-K >= 1.0

  OR

  z-J >= 2.9 and J-K < 1.0
- i-z > 2.0
- i-J > 4.7
- z-K > 3.5 and J-K < 1.0

We followed-up 189 candidates with Xshooter (63 published in Day-Jones et al. 2013)




H2O+CH4
KI
RbI
CsI
CrH
FeH
CsI
H2O
FeH+CrH
VO
NaI
KI
FeH
KI
NaI
H2O
KI
FeH
FeH
CH4
H2O
H2
NaI
CaI
CO
NaI
L1.0
L5.0
T2.0
T7.0
5
4
3
2
1
0
Normalized flux + constant
1.0
1.5
2.0
Wavelength (μm)

Constraining the IMF and formation history

To compare our sample to the simulations we need to:

1) Determine the T_{eff} of the targets (i.e. their spectral types);

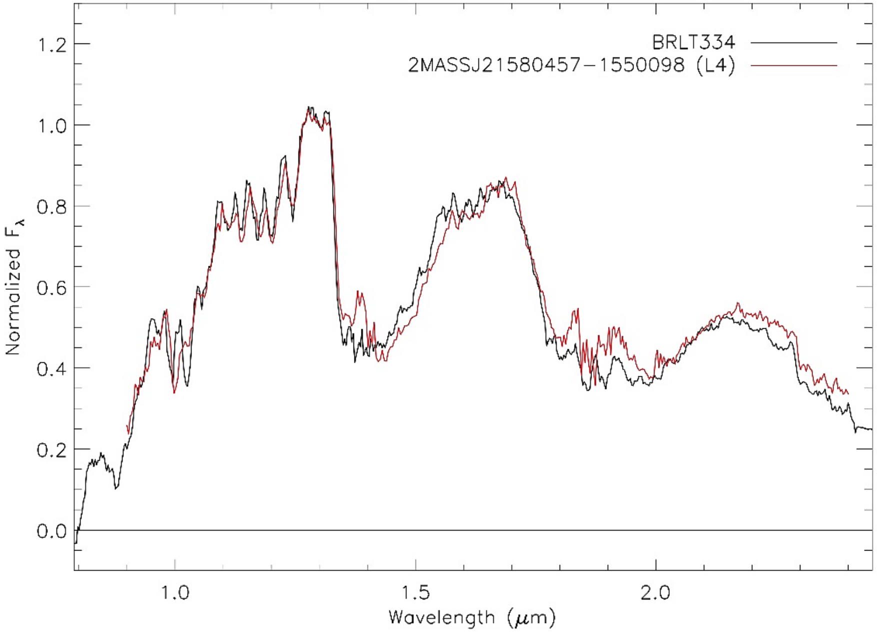
2) Determine the volume sampled (i.e. calculate the distance to our targets);

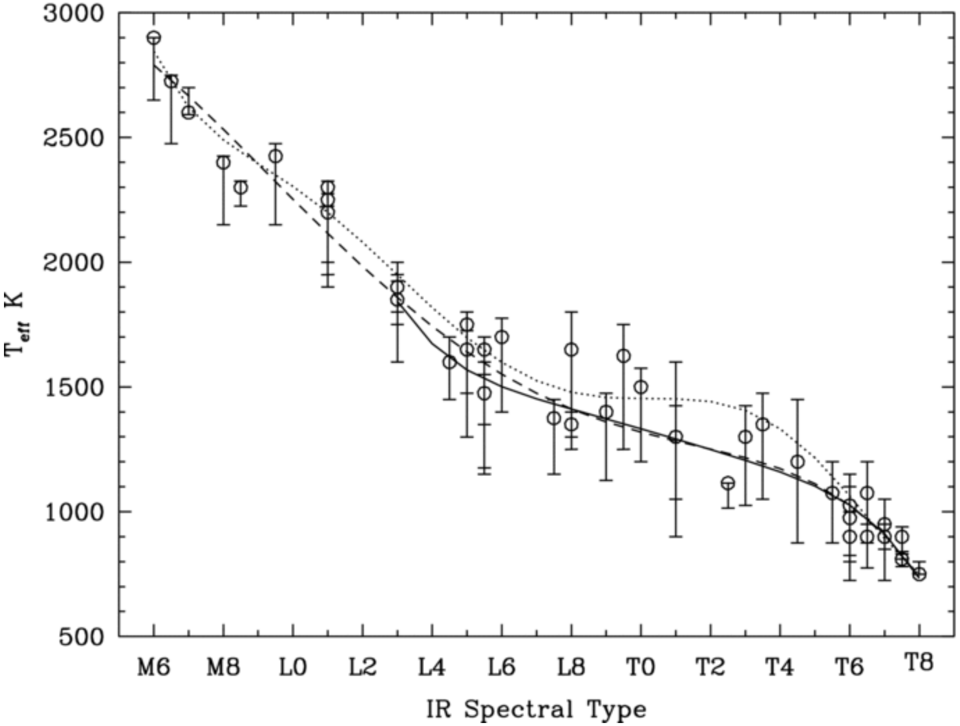
3) Check the completeness of the sample;

4) Correct for binarity, Malmquist bias, etc...

Step 1: determine T_{eff}

The spectral types of the objects were determined via comparison with spectroscopic standards.



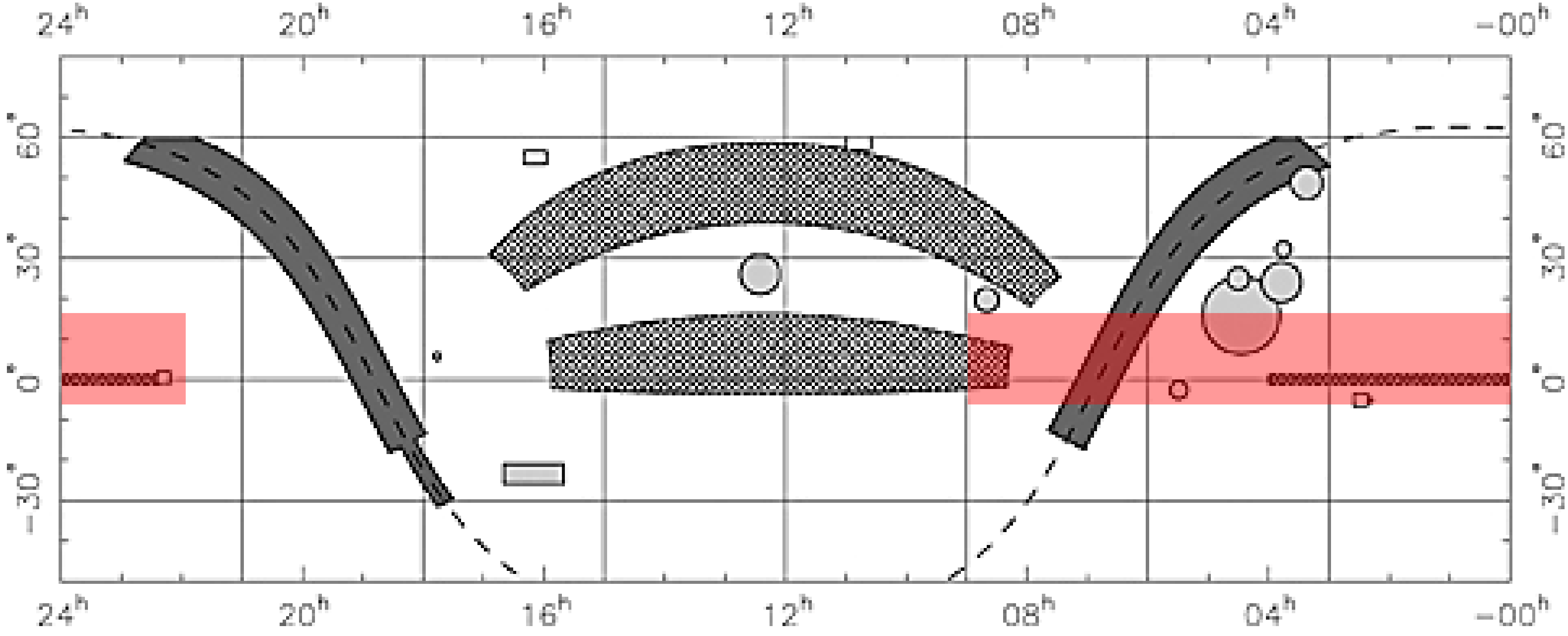


The spectral types were converted into T_{eff} using the Stephens et al. 2009 (ApJ, 702, 154) relation.

Step 2: determine the volume sampled

The spectroscopic follow-up is completed for 22h < RA < 9h and -3 < Dec < +19, corresponding to an area of ~670 deg^2, containing 80 objects.

The distance to the targets was estimated using the photometric distance calibration from Marocco et al. 2010 (A&A, 524, A38).



Step 3: check completeness

We checked the completeness of our sample using a control sample.

We took all the known L and T dwarfs from dwarfarchives.org, and cross-matched with UKIDSS and SDSS to obtain *ugriz* and MKO YJHK photometry.

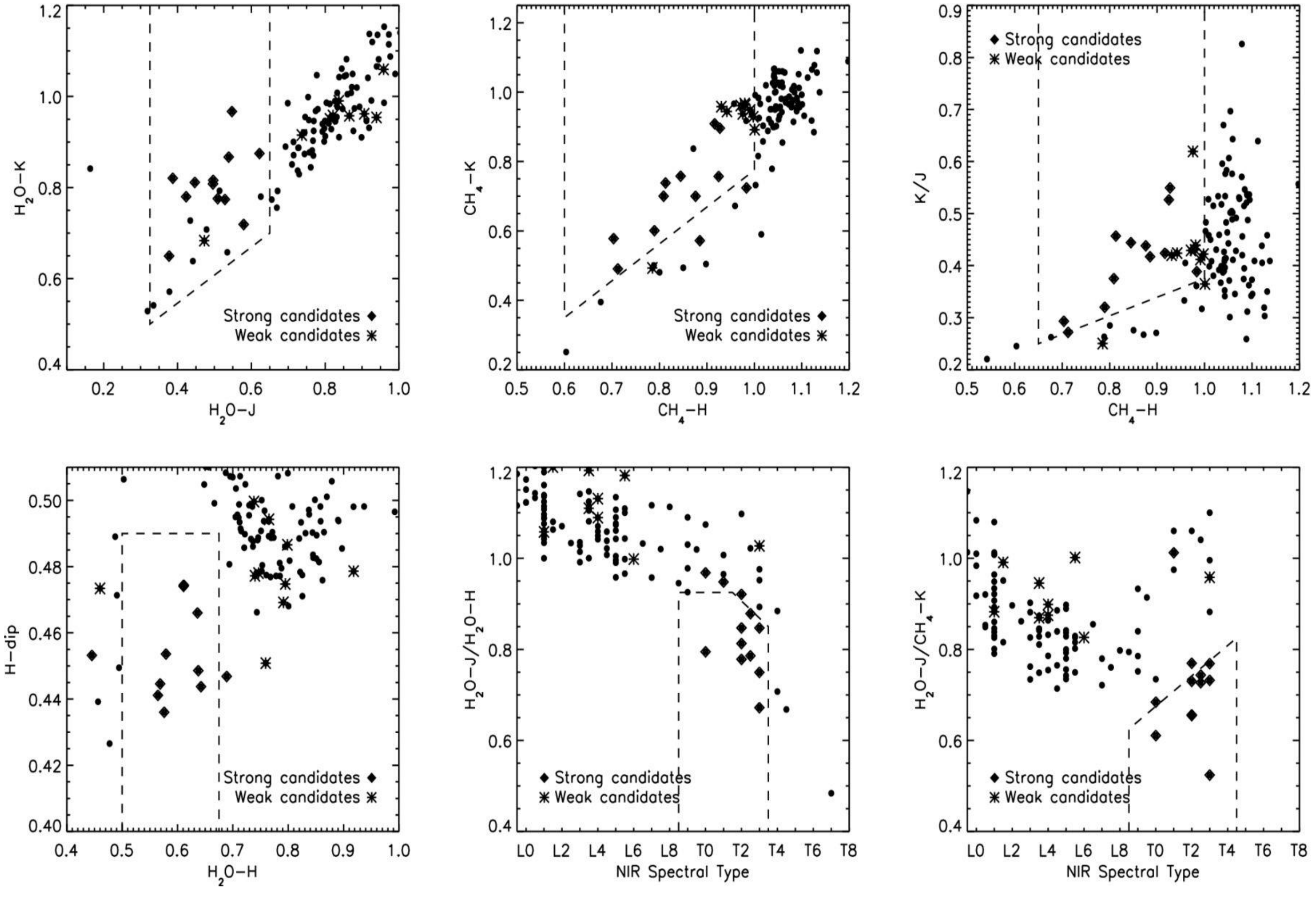
Then we applied our selection criteria to the control sample.

Applying our selection criteria we retrieve 88% in the L4-L6 range, 94% in the L7-T0, and 99% in the T1-T4 range.

Step 4: correct for binarity & biases

Unresolved binaries can be identified using their spectral indices. The criteria are defined in Burgasser et al. 2010 (ApJ, 710, 1142)

We identified 37 binary candidates

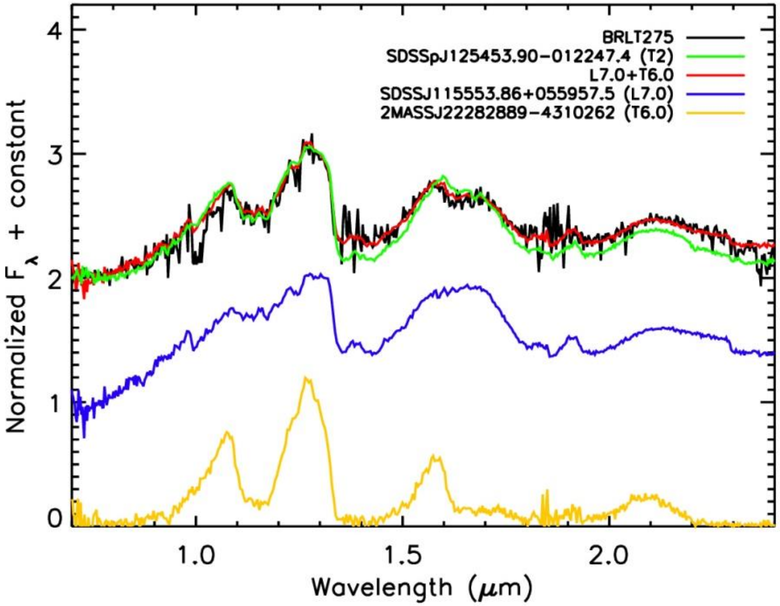


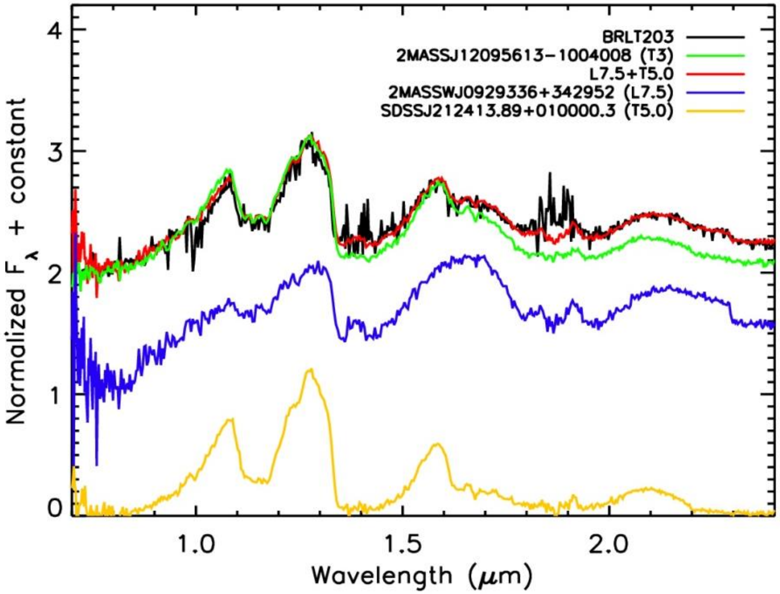
(Day-Jones, Marocco, et al. 2013, MNRAS, 430, 1171)

Step 4: correct for binarity & biases

The spectral types of the components can be determined via spectral deconvolution.

The results of the deconvolution are tested against the results of the templates fitting using an F-test.





19 of the 37 candidates passed this second selection. Need AO follow-up!

If confirmed, *BF* ~ 10%

Step 4: correct for binarity & biases

Our technique is only sensitive to non-equal spectral type binaries. We still need to correct for equal spectral type binaries.

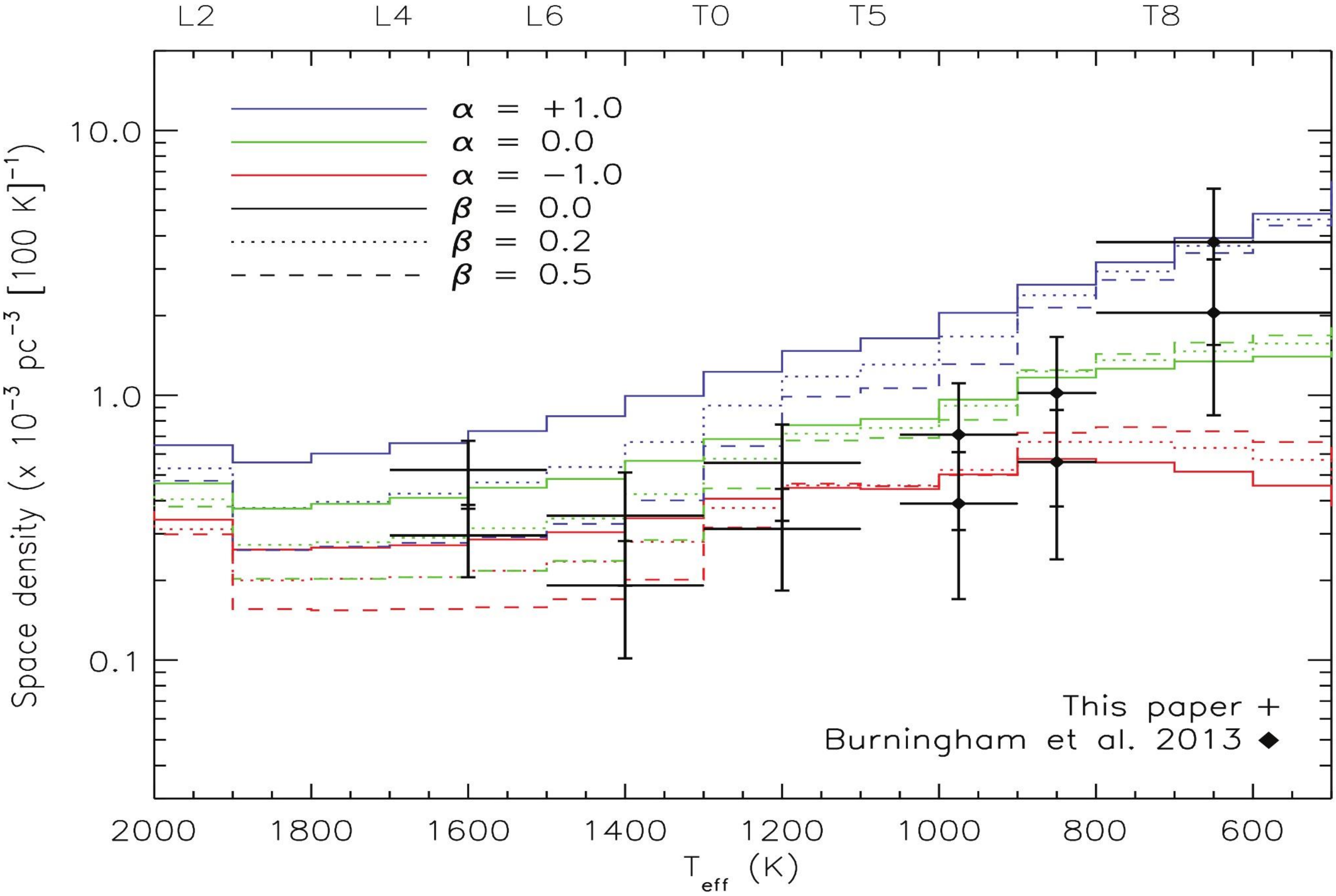
To do that we follow Burgasser et al. 2003 (ApJ, 586, 512)

$$f_{excl} = \frac{\gamma - 1}{\gamma + \frac{1}{BF} - 1}$$

Where $\gamma = 2\sqrt{2}$ for equal spectral type binaries, and *BF* is the "true" binary fraction.

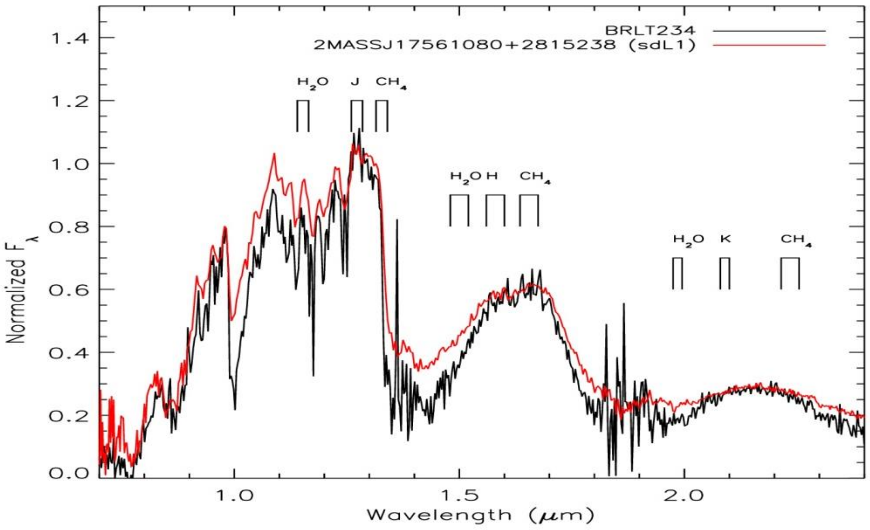
PROBLEM: BF is unconstrained. In the literature 5% < *BF* < 45%

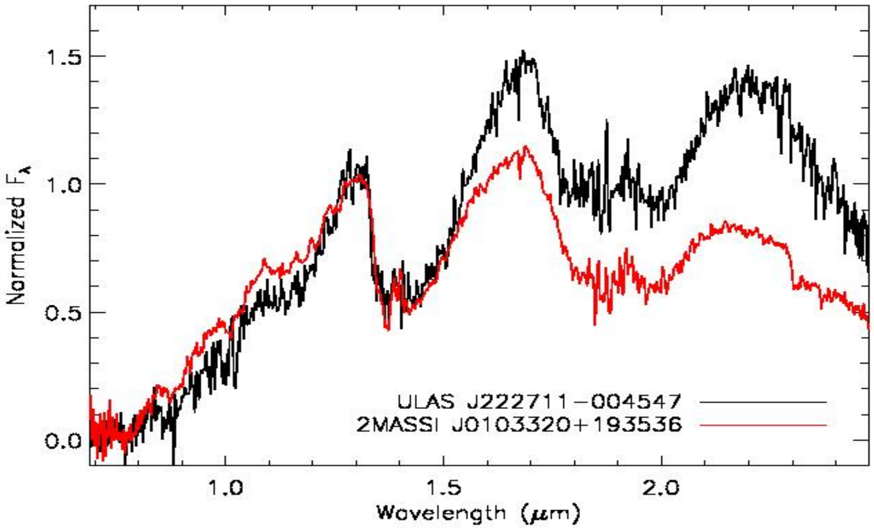
Results

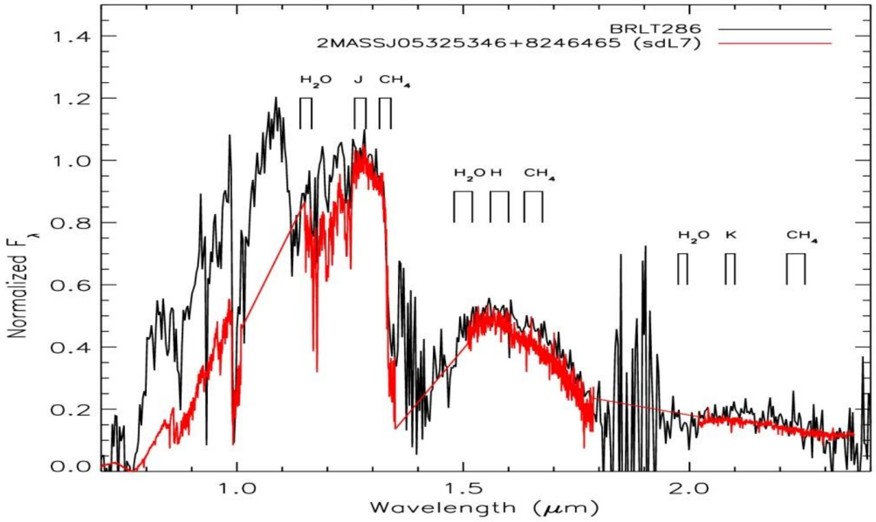

L2
L4
L6
T0
T5
T8
α = +1.0
α = 0.0
α = −1.0
β = 0.0
β = 0.2
β = 0.5
10.0
1.0
0.1
Space density (x 10^{-3} pc^{-3} [100 K]$^{-1}$)
2000
1800
1600
1400
1200
1000
800
600
T_{eff} (K)
This paper +
Burningham et al. 2013 ◆

Peculiar objects

The wide wavelength coverage of Xshooter is ideal to identify peculiar objects, i.e. BDs that are bluer/redder than the spectroscopic standards.



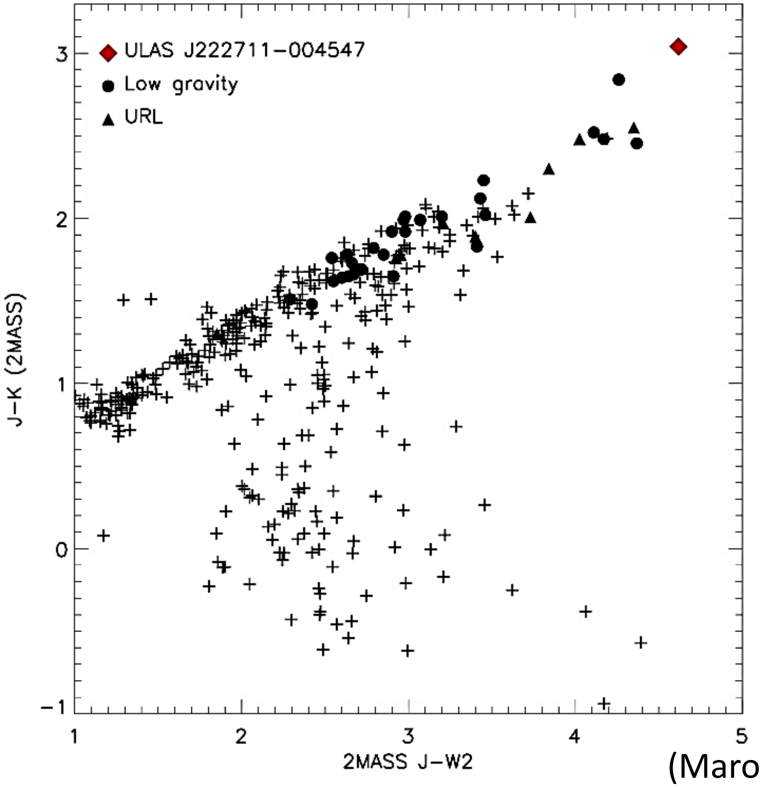


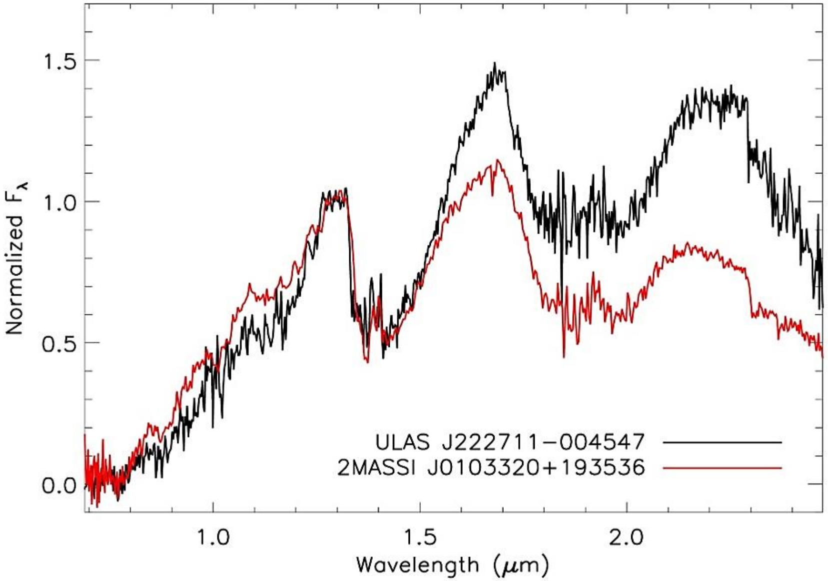


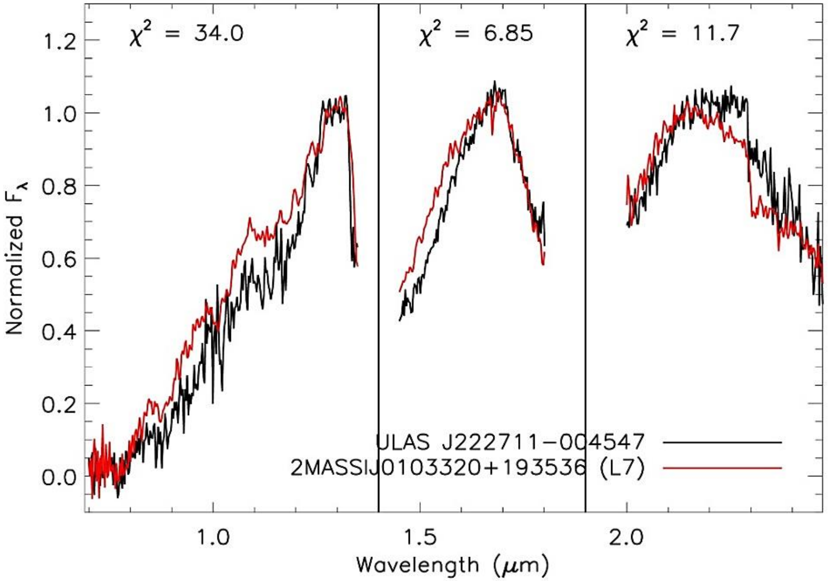
ULAS J222711-004547

One of the reddest BD known. Its colours (and spectrum) look very similar to those of gas giant exoplanets.

Not associated to any young moving group. The extreme red colours are caused by dust.







(Marocco et al. 2014, MNRAS, 439, 372)

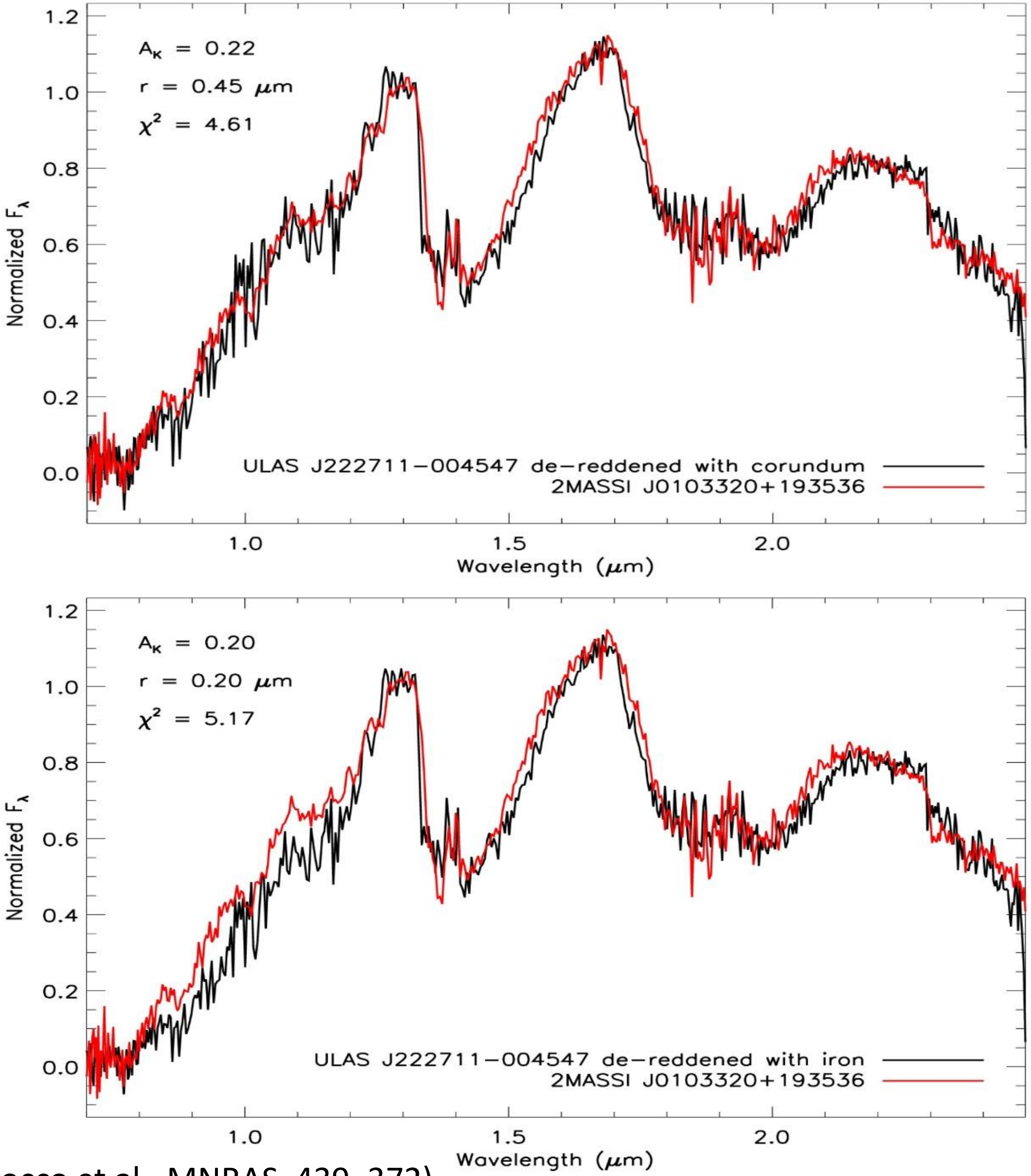
ULAS J222711-004547

The main dust species in L dwarfs are thought to be corundum (Al_2O_3), enstatite ($MgSiO_3$) and iron (e.g. Morley et al. 2012).

We derived extinction curves for these 3 species for a range of grain sizes (r = 0.05 to 1.00 µm) and applied them to the spectrum of ULAS 2227-0045.

Corundum and enstatite give good results for r = 0.40-0.55 µm, iron requires smaller grains (~0.20 µm).

First constrain on grain size!



(Marocco et al., MNRAS, 439, 372)

Summary

- The PARSEC program is on track and already producing results (PM catalogue, T_{eff} vs SpT calibration);

- The L-T transition regime is the place to look to constrain IMF and BR. But we need to constrain the BF first!

- We have identified a sample of unresolved binary candidates, that can be used to determine the binary fraction;

- Red L dwarfs can be used to constrain the typical grain size of the dust particles in the atmosphere of BDs.

Future work

- Parallaxes for the full PARSEC sample will be available in ~6 months, and will allow us to refine the T_{eff} vs SpT relation AbsMag vs SpT relations;

- Complete the spectroscopic follow-up (if telescope time granted!) to update the space densities with the full sample;

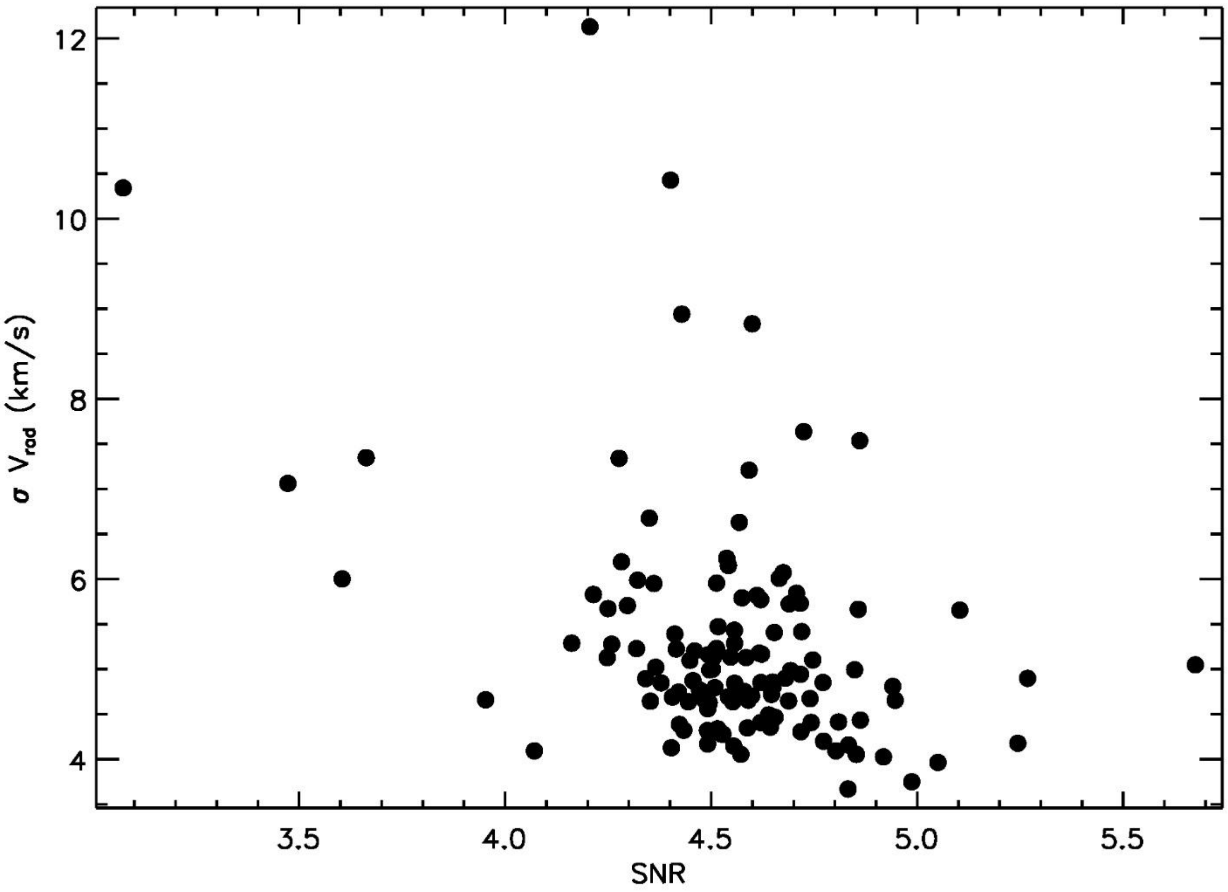
- Follow-up of the binary candidates to constrain the IMF;

- Extend and refine the dust analysis to other L and T dwarfs;

Future work – RV of Gaia BDs

Gaia is up and working. It will provide parallaxes with a precision of ~0.1-0.3 mas and tangential velocities with a precision of ~10-30 m/s for ~500 L0-L5 dwarfs. **We need radial velocities!**

Using Xshooter we can achieve a precision of ~1 km/s.



Thank you!