# Brown dwarf census with the Dark Energy Survey year 3 data and the thin disk scale height of early L types

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Abstract:

We present a catalogue of 11,745 brown dwarfs with spectral types ranging from L0 to T9, photometrically classified using data from the *Dark Energy Survey* (DES) year 3 release matched to the *Vista Hemisphere Survey* (VHS) DR3 and *Wide-field Infrared Survey Explorer* (WISE) data, covering ~2,400 deg2 up to i=22.

The classification method follows the same photo-type method previously applied to *SDSS-UKIDSS-WISE* data. The most significant difference comes from the use of DES data instead of SDSS, which allow us to classify almost an order of magnitude more brown dwarfs than any previous search and reaching distances beyond 400 parsecs for the earliest types.

Next, we also present and validate the `GalmodBD` simulation, which produces brown dwarf number counts as a function of structural parameters with realistic photometric properties of a given survey. We use this simulation to estimate the completeness and purity of our photometric LT catalogue, as well as to compare to the observed number of LT types.

We put constraints on the thin disk scale height for the early L (L0-L3) population to be around 450 parsecs, in agreement with previous findings.

For completeness, we also publish in a separate table a catalogue of 20,863 M dwarfs that passed our colour cut with spectral types greater than M6. Both the LT and the late M catalogues are found at *https://des.ncsa.illinois.edu/releases/other/y3-mlt*.

Context:

**Ultra-cool dwarfs** are mostly sub-stellar objects (brown dwarfs, BDs) with very cool (T < 2,300 K) atmospheres with spectral types later than M7, including the L, T and Y sequences.

BDs have **very low luminosity**, especially the older or lower mass ones. Their mass function, star formation history (SFH) and spatial distribution are still poorly constrained, and the evolutionary models still lack details, especially the lowest-masses and old ages.

The era of **digital wide-field imaging surveys** has allowed the study of brown dwarfs to blossom, with thousands now known in the solar neighbourhood. But this collection is heterogeneous and very shallow and therefore, not suitable for large-scale statistical analysis of their properties.

**In this paper**, we follow the photo-type methodology of *Skrzypek et al. (2015)* to find and classify L and T dwarfs in the DES + VHS + AllWISE system. We can go to greater distances due to the increased depth in the DES optical bands i,z in comparison with SDSS while maintaining high completeness in the infrared bands, needed for a precise photometric classification.

In fact, the **optical bands can drive the selection of L dwarfs**, as demonstrated here, improving upon previous photometric BDs searches. In the case of T dwarfs, the infrared bands are the limiting ones, and therefore, our sample will have a similar efficiency in that spectral regime in comparison with previous surveys.

Description:

The **classification methodology** can be summarized in three steps:

1) **A photometric selection in colour space** (*i-z*), (*z-Y*), (*Y-J*) is done using DES + VHS + AllWISE data.

2) **A spectral photometric classification is performed** by comparing observed colours in *i, z, Y, J, H, K, W1, W2* to a set of colour templates for various spectral types, ranging from M6 to T9. These templates are calibrated using a sample of spectroscopically confirmed ultra-cool dwarfs (MLT).

3) **We remove possible extragalactic contamination** with the use of a galaxy template fitting code, in particular, we use `Lephare` photo-z code. The number of extragalactic contaminants is small and agrees well with the result obtained by an independent method using morphologic information.

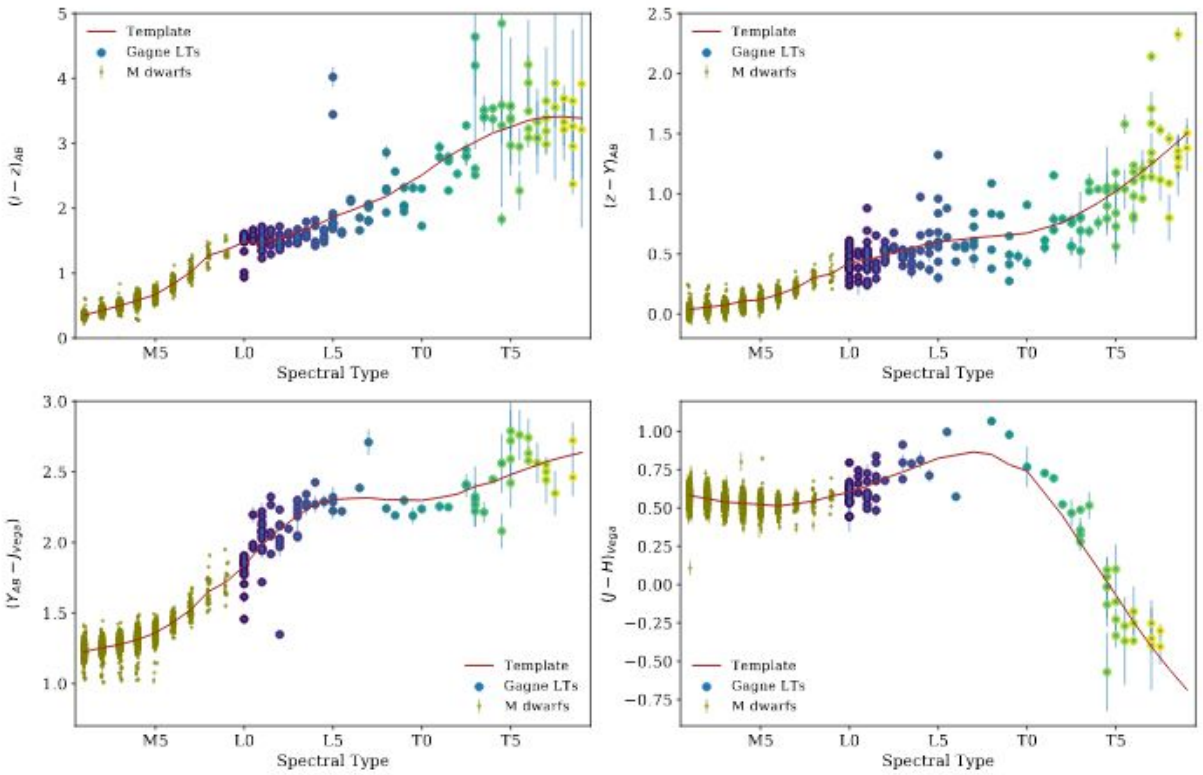
**After completion of a homogeneous sample of LT dwarfs, we proceed to measure the thin disk scale height (h_z).**

**Unfortunately, current simulations present many inconsistencies with observations and are not trustworthy.** Therefore, we also introduce a new simulation which computes expected number counts of LT dwarfs and creates synthetic samples following the properties of a given survey. We have called it `GalmodBD`.

**Finally, we can compare the output of the simulation for different formation scenarios, to the number of BDs found in the sample footprint, placing constraints on h_z and other fundamental parameters.**

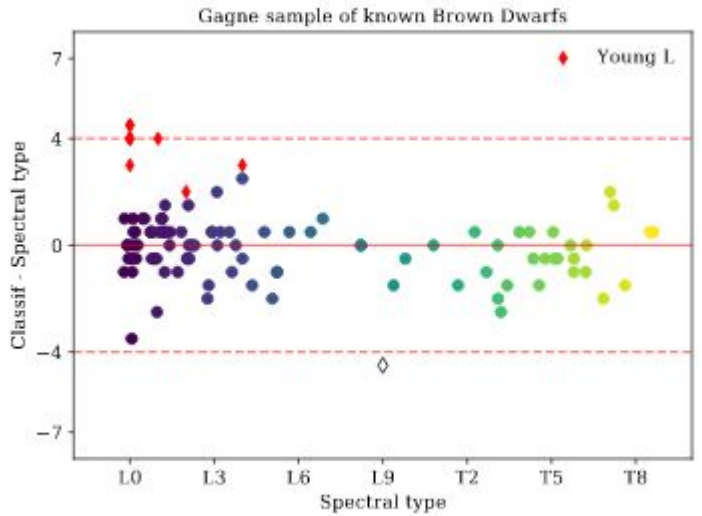
## Results:

### Creation of empirical templates

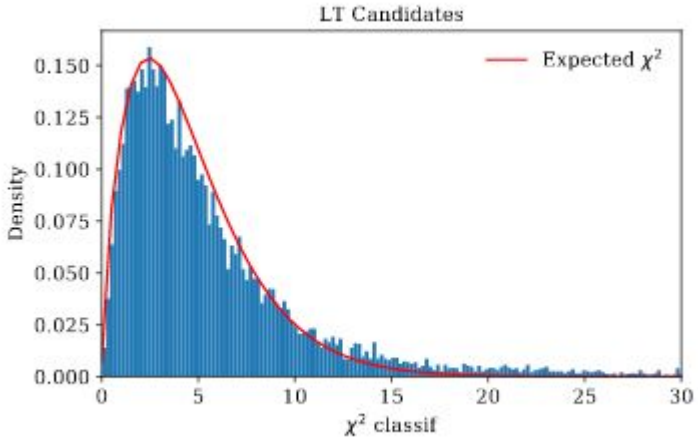



In this figure we show the color distribution of known BDs as a function of spectral types. Also, in brown, we show the estimated color-type template used to classify the target DES + VHS + AllWISE sample.

## Performance of the method:

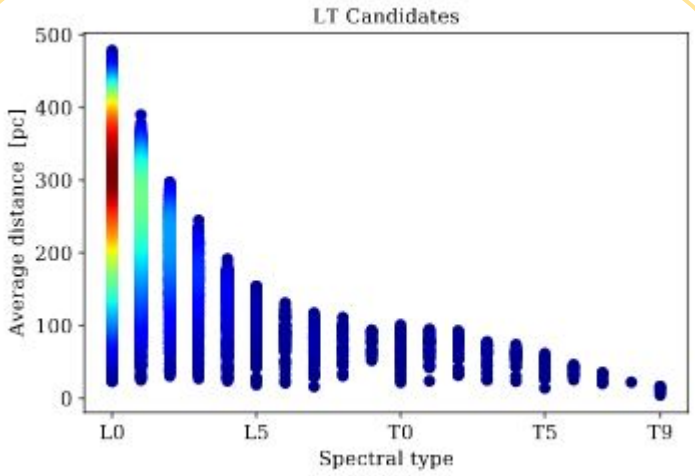



We validate the spectral classification methodology in the same sample of known BDs, recovering their spectral type with precision




Once we run the method in our target sample, the wellness of the fit is in agreement with the theoretical expectation

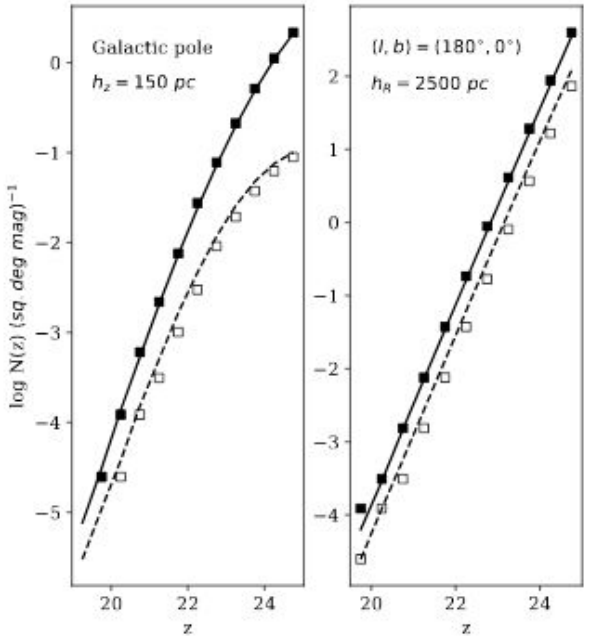
## Catalog properties:




In this figure we show the BD distance distribution as a function of spectral type for our target sample.

Most of our sample compromises L0 and L1 types at a distance of ~300 parces, but reaching distances > 400 parsecs for the L0 types.

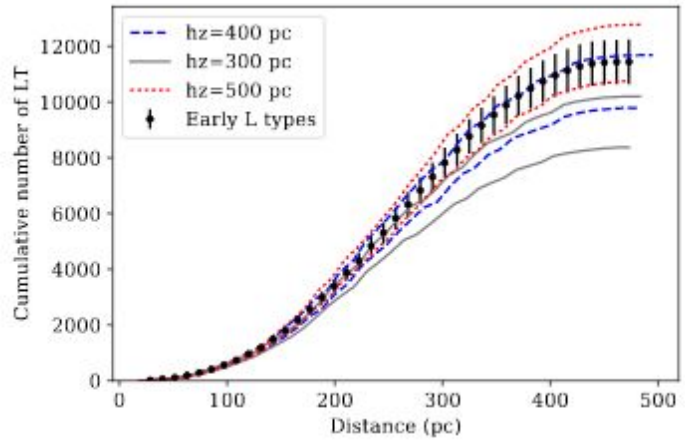
## GalmodBD simulation:




Left: Star counts as a function of *z* band towards the Galactic Pole using a single disk model with scale height h_z =150 pc. The open symbols are differential counts and the filled symbols are cumulative counts.

Right: Same as in the previous panel, but now towards the Galactic anticenter, for a model with a single disk with horizontal scale length h_R =2.5 kpc.

## Thin disk scale height:




Comparison of the number counts of early L types (L0-L3) with three models of the thin disk scale height. In Grey we show models with a scale height similar to that for M dwarfs with h_z=300 pc, in dashed blue, models with h_z =400 pc and in red, models with h_z =500 pc.

For each model we show two estimates, one where n_thick=5% (lower limit) and another where n_thick=20% (upper limit).

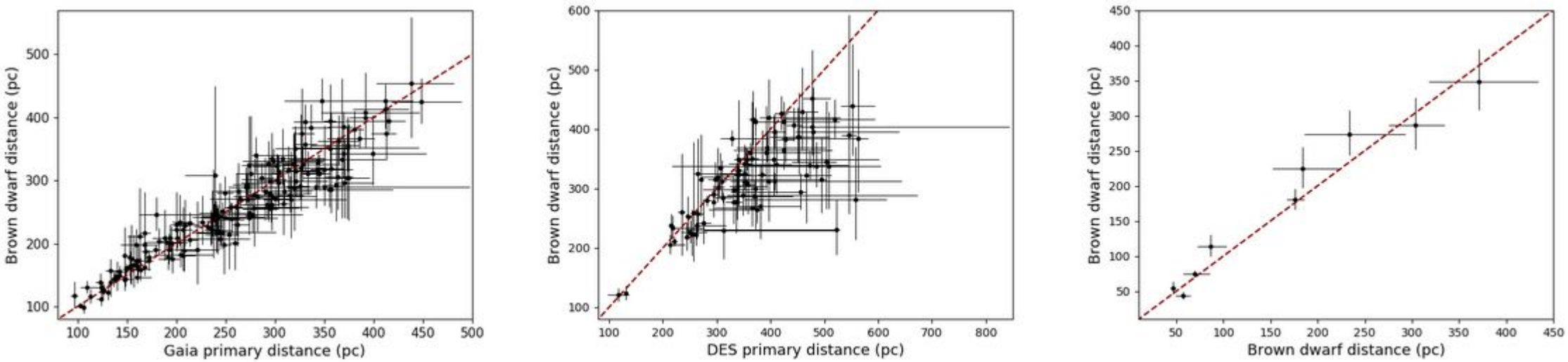
Impact and prospects:

**Publication**: Carnero Rosell et al. (2019).
*Monthly Notices of the Royal Astronomical Society*, Volume 489, Issue 4, Pages 5301–5325.

**Public data:** ***https://des.ncsa.illinois.edu/releases/other/y3-mlt***

Follow-up projects: https://arxiv.org/abs/2001.11015 (Submitted to MNRAS)

**L and T dwarfs in wide binary and multiple systems using Dark Energy Survey DR1 and Gaia DR2 data (dal Ponte et al. 2020)**




Using the L and T dwarf sample presented in Carnero Rosell et al. 2019, we search for wide binary systems composed of an L or T dwarf companion to main sequence stars in the Gaia DR2 and DES DR1 data. We also search for systems composed of two ultracool dwarfs.