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Hubble Space Telescope WFC3 observations of L and T dwarfs

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Abstract. We used HST/WFC3 observations of a sample of 35 nearby (<30 pc) late L- and T-type field brown dwarfs to examine the frequency and properties of multiple systems across the L dwarf/T dwarf transition, and search for cooler companions. The observations aim to address two of the most outstanding problems in low-temperature brown dwarf astrophysics today: the mechanism for cloud depletion across the L/T transition, and the multiplicity statistics of brown dwarfs as they relate to formation mechanisms. The targets were characterized using F110W, F127M, F139M and F164N filters, from which we derived color-spectral type calibrations to identify well-resolved companions. Tightly-separated companions were searched for using a double-PSF fitting algorithm. We also compared our detection limits based on simulations to other prior HST/WFPC2 and HST/NICMOS programs. Neither new wide or tight companions were identified. We use our results to add new constraints to the binary fraction of L/T transition systems and the Y dwarf companion rate.

1. Introduction

Multiplicity statistics are useful for testing different formation scenarios for VLM stars and brown dwarfs (BDs). While the binary fractions of the solar-type stellar systems is ~ 65% (Duquennoy & Mayor 1991) and early-type M stars is ~ 30–40% (Reid & Gizis 1997; Delfosse et al. 2004), measurement of multiplicity statistics in BDs have inferred fractions of 15-30% (Allen 2007; Burgasser 2007). suggesting a different formation mechanism. The majority of the ~ 100 VLM pairs known to date, have been uncovered with high angular resolution Hubble Space Telescope (HST) and/or ground-based adaptive optics imaging programs. These studies have revealed that BD systems have typical mass ratios $M_2/M_1 \geq 0.8$ and typical separations $a < 20$ AU (Bouy et al. 2003, Burgasser et al. 2003, Martín et al. 2003, Allen 2007). These statistics make BDs

Send offprint requests to: M. Aberasturi distinct from stars, although there may be selection biases for close separation and small mass ratios. Beyond statistical information, orbit determinations and consequent dynamical masses of individual systems are of crucial importance for testing and calibrating evolutionary and atmospheric models (Dupuy & Liu 2012). The transition between the L and T spectral classes is of particular interest in the context of BD multiplicity, as this phase marks a dramatic change in the cloud structure and atmospheric properties of BDs over a narrow $T_{\rm eff}$ shift. This phenomenon is reflected in a major redistribution of the emergent flux producing bluer infrared colors ($J-K$ ~2 to 1 mag) and an increase in 1 μm flux density, the so-called J-band bump. Remarkably, some studies have shown evidence of enhancement in multiplicity at the L/T transition, possibly related to the rapidity of the transition (Burgasser 2007). All of these studies can be advanced by increasing the population of known brown dwarf binary systems. To do this, we undertook two parallel programs using the IR channel of Wide Field Camera 3 (WFC3) installed in the Hubble Space Telescope.

2. Observations

WFC3 is a 1024x1024 pixels array with an angular resolution 0″.13 and a field of view 123″ x 136″. We used the F110W, F127M, F139M and F164N filters for our observations. The sources were observed as part of two $HST(WFC3)$ programs, one to study multiplicity at the L/T transition (11631) and one targeting T5 to T8.5 dwarfs to search for Y dwarf companions (11666).

3. WFC3 Photometry

We used Sextractor (Bertin & Arnouts 1996) to measure the photometry in our final calibrated images with a background annulus of 25 pixels (3″.25) and a 6 pixel aperture (0″.78). In Fig. 1, we show the colors of our targets and background sources. While the latter have blue colors, our targets follow a clear trend towards redder colors. On the bottom we have compared F127M-F164N and F127M - F139M color vs. spectral type, where SpT(L0) = 0, SpT(T0) = 10 and SpT(Y0)=20. A linear fit for F127M-F139M:

$$SpT = 1.56 - 6.25\,(F127M - F139M) \qquad (1)$$

And a quadratic fit for F127M-F164N:

$$SpT = 13.22 - 5.32\,(F127M - F164N) - 1.55\,(F127M - F164N)^2 \qquad (2)$$

4. WFC3/HST PSF Fitting Analysis

One of the main goals of this study is to identify binary systems in the sample. To do this, we performed a PSF-fitting algorithm similar to that described in Burgasser et al. (2003). To assess the statistical significance of each fit, we calculated the one-side F test. Taking account the χ^2 and the degrees of freedom in the PSF fitting, the F test allows us to identify which target has significantly greater probability of being fit with a binary model. We require a probability greater than 90% to identify a binary system. Neither wide nor tight companions were detected.

5. Searching limits

Our null discovery rate compared to prior HST surveys is due to the coarser pixel scale and lower angular resolution of the WFC3 IR channel; for comparison, the pixel scale of NICMOS NIC1 and WFPC2 is 3 times finer. In total, only 20% of known binaries could be discovered with WFC3, primarily due to resolution limits. WFC3 has greater sensitivity, so we could detect fainter companions at separations greater than 0″.325 but those systems appear to be rare.

To constrain the overall binary fraction of our sample taking into account these instrumentation limitations, we performed a multi-step Monte Carlo simulation to (1) calculate the detection and false positive rates as a function of separation and relative magnitude for each source in the F127M filter; and (2) determine the fraction of binaries that would have been detected around each source assuming separation and mass ratio distributions from Allen (2007) and all possible orbit orientations.

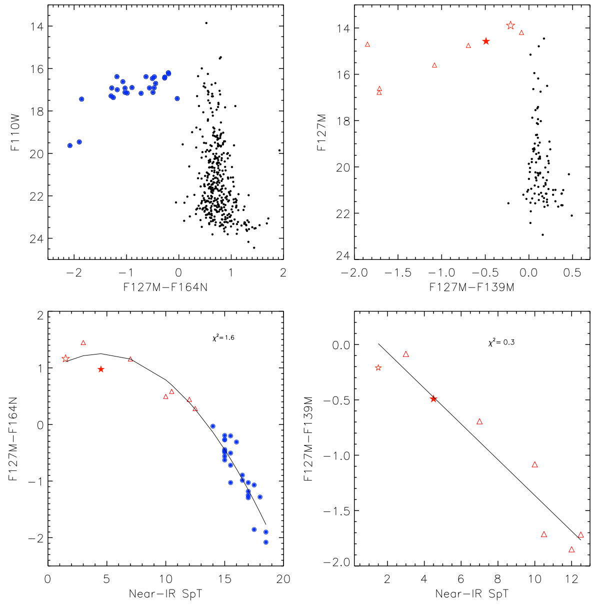

Fig. 1. Segregation for L and T dwarfs with WFC3 photometry. Color vs. color and color vs. NIR SpT for 11666 (full circles) and 11631 (triangles) programs, with the know binary system 2MASS J1520-4422AB highlights (stars). Background sources are represented with dots.

If all our systems had binaries, we would have detected 13.8 companions, implying a 1σ (3σ) binary fraction limit of $< 12\%$ ($< 36\%$). Note that these limits take into account selection biases but are highly dependent on the assumed properties of the underlying binary population.

6. Conclusions

– We have characterized 35 brown dwarfs using for WFC3/HST.
– We have produced two new color vs. spectral types relations for brown dwarfs with spectral types between L0 and T9.
– Using a forward modeling technique, we determine a binary fraction limit of $< 12\%$. We can conclude that WFC3 is more sensitive than NICMOS and WFPC2, but its lower resolution makes it not suitable to discover close BD binary systems.

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