# Optical photometry of brown dwarfs with the telescopes of Rozhen NAO

D. Dimitrov
Institute of Astronomy and NAO, Bulgarian Academy of Sciences
dinko@astro.bas.bg
(Conference talk)

**Abstract.** The obtained optical ($V$ and $I$) photometry of several known brown dwarfs (BDs) demonstrates the possibility for observations of BDs with the telescopes at Rozhen NAO. Criteria for searching for brown-dwarf candidates are derived on the base of statistical analysis. Observations of three arbitrary sky fields and applying of the selection criteria lead to finding of 14 BD candidates. Their spectral types are predicted on the base of the established statistical relations.
**Key words:** ultra-cool dwarfs, brown dwarfs, optical photometry, $JHK$ 2MASS photometry

### Оптична фотометрия на кафяви джуджета с телескопите на НАО Рожен

Динко Димитров

Получената фотометрия в оптичния диапазон (във $V$ и $I$ филтри) на няколко известни кафяви джуджета потвърждава възможността да се наблюдават такива обекти с телескопите на НАО Рожен. На базата на статистически анализ са изведени критерии за търсене на кандидати за кафяви джуджета. Наблюдавани са три произволни звездни площадки, в които са открити 14 кандидати за кафяви джуджета, използвайки изведените статистически критерии. Техният спектрален клас е предсказан на базата на емпирично изведени зависимости.

## Introduction

Our knowledge on the bottom of the Main-sequence as well as on the low-mass stellar and sub-stellar population of the Solar neighborhood increased considerably during the last decade. Several hundreds ultra-cool dwarfs (called brown dwarf, BD) were found within $\sim 100$ pc. As a result two new classes L and T were added to the spectral type classification (Kirkpatrick 2005; Kirkpatrick et al. 1999; Martin et al. 1999).

The first L dwarf was discovered in 1988 (GD165 B; Becklin & Zuckerman 1988) while the first T dwarf was found in 1995 (Gl229 B; Nakajima et al. 1995).

The effective temperatures of the brown dwarfs are below those of the coolest M dwarfs and their masses are in the range between those of the lowest-mass stars and the highest-mass planets. Thus the central temperature of the brown dwarfs are not high enough for stable hydrogen burning but it is supposed that they have been undergone short periods of primordial deuterium burning during the early stage of their evolution.

The brown dwarfs are extremely faint in the optical and to date they have only efficiently been identified based on their colors at the red optical

(RO) $0.6 - 1.0\mu$m wavelengths and at the near-infrared (NIR) $1.0 - 2.5\mu$m wavelengths. Hence the most fruitful way to search for BDs is to use the data of the huge surveys at these ranges: Two Micron All Sky Survey (2MASS at NIR; Skrutskie et al. 2006; e.g., Kirkpatrick et al. 1999, 2000; Burgasser et al. 2002, 2003, 2004; Cruz et al. 2003; Tinney et al. 2005; Kendall et al. 2007a; Kendall et al. 2003; Looper et al. 2007), Sloan Digital Sky Survey (SDSS at RO; York et al. 2000; e.g., Fan et al. 2000; Leggett et al. 2002; Kendall et al. 2007b; Chiu et al. 2006), Deep Near-Infrared Survey (DENIS at NIR; Phan-Bao et al. 2008; Kendall et al. 2004), Canada-France Brown Dwarf Survey (CFBDS at RO; e.g., Delorme et al. 2008) and UKIRT Infrared Deep Sky Survey (UKIDSS at NIR; e.g., Lawrence et al. 2007; Chiu et al. 2008; Pinfield et al. 2008).

A large number of L and T dwarfs (602 L-type and 155 T-type) were identified in these uniform and well-characterized data sets in the last decade (by 2010 June, see http://www.DwarfsArchives.org for the full list). It allows detailed investigations of these sub-stellar objects (masses, luminosity functions, multiplicity, etc.)

The main goal of this article is to present the possibilities for observations of brown dwarfs in the optical region with the telescopes of the National Astronomical Observatory (NAO) at Rozhen.

## 1 Our observations of known brown dwarfs

In order to check the possibility for optical photometry of sub-stellar objects using the telescopes of NAO we observed a sample of L and T dwarfs from the database DwarfsArchives.org.

Our CCD photometry of the known L dwarfs (as well as of M and L dwarf candidates) in $V$ and $I$ bands was carried out with the 60-cm Cassegrain telescope equipped with the FLI PL09000 CCD Camera (3056 × 3056 pixels, 12 $\mu$m pixel). The field of view of this equipment is 17.1 × 17.1 arcmin with the scale of 0.334 arcsec per pixel. The exposure times were relatively short – 120 sec in order to escape the considerable tracking errors.

The CCD photometry of the two known T dwarfs was gathered with the 2-m Ritchey-Chrétien telescope equipped with two-channel focal reducer FoReRo-2 (Bonev 2004; Jockers et al. 2000) and CCD camera PI VersArray (512 × 512 pixels, 24 $\mu$m pixel). The resulted field of view was 7.6 × 7.6 arcmin.

All images were flat fielded and dark subtracted (bias substraction for VersArray camera) using standard IDL procedures (adapted from DAOPHOT). The series of frames for each individual object were alained and combined after reduction procedure. To measure instrumental magnitudes, we used aperture with radius of 5 pixels and background ring located between 8 and 12 pixels. Field stars with USNO-B1.0 $I$ band magnitudes were used for transition from the instrumental system of each telescope to standard photometric system.

Table 1 gives information about known brown dwarfs selected for observations by our telescopes and Table 2 presents the journal of our observations. Figures 1-2 illustrate the detection of the first four of the list and show the

fields of 2.5 × 2.5 arcmin around them. In this way we demonstrated the possibility for observations of BDs by our telescopes.

Only the last object, ULAS J133553.45+113005.2, did not be detected by us. This ultra-cool T9 dwarf ($T_{\rm eff} \simeq 550$ K) is proposed to be a prototype of new spectral type Y0 (Delorme et al. 2008; Legget et al. 2009). We suppose that we didn't manage to detect it due to the short exposure time for such type of objects – 2 × 20 min as well as to relative bad weather conditions (seeing of about 2.″5).

**Table 1.** The parameters of observed known brown dwarfs

| No | Star Name | $\alpha$ [2000] | $\delta$ [2000] | $I$ [mag] | $J$ [mag] | $J-K$ [mag] | Sp Type |
|---|---|---|---|---|---|---|---|
| 1 | 2MASS J16580380+7027015 | $16^{\rm h}58^{\rm m}03^{\rm s}.80$ | $+70°27'01.''5$ | 16.46 | 13.28 | 1.37 | L1 |
| 2 | 2MASS J16262034+3925190 | $16^{\rm h}26^{\rm m}20^{\rm s}.34$ | $+39°25'19.''1$ | 16.68 | 14.44 | -0.03 | sdL4 |
| 3 | 2MASS J15150083+4847416 | $15^{\rm h}15^{\rm m}00^{\rm s}.83$ | $+48°47'41.''6$ | >19.0 | 14.11 | 1.61 | L6 |
| 4 | 2MASS J12060248+2813293 | $12^{\rm h}06^{\rm m}02^{\rm s}.48$ | $+28°13'29.''3$ | 21.30 | 16.54 | 0.72 | T3 |
| 5 | ULAS J133553.45+113005.2 | $13^{\rm h}35^{\rm m}53^{\rm s}.45$ | $+11°30'05.''2$ | >22.0 | 17.90 | -0.38 | T9 |

Reference: 1 – Gizis et al. (2000), 2 – Burgasser (2004), 3 – Wilson et al. (2003), 4 – Chiu et al. (2006), 5 – Burningham et al. (2008)

**Table 2.** Journal of observations of the selected known BDs

| Star | Date | Telescope | Filter | N | Exp | Detections |
|---|---|---|---|---|---|---|
| 2MASS J16580380+7027015 | 2010 April 27 | 60-cm | $V, I$ | 7,5 | 120 | only in $I$ |
| 2MASS J16262034+3925190 | 2010 April 27 | 60-cm | $V, I$ | 7,5 | 120 | only in $I$ |
| 2MASS J15150083+4847416 | 2010 April 27 | 60-cm | $V, I$ | 7,5 | 120 | yes |
| 2MASS J12060248+2813293 | 2010 May 07 | 2-m | $I$ | 2 | 1200 | yes |
| ULAS J133553.45+11300 | 2010 May 09 | 2-m | $I$ | 2 | 1200 | no |

## 2 Criteria for searching for of brown-dwarf candidates

In order to derive criteria for discovery of sub-stellar objects by our telescopes we carried out statistical analysis of the known BDs from the dataset DwarfsArchives.org. Firstly, we choose from all 602 L dwarfs those that have the three $JHK$ colors in 2MASS dataset. After that we established that only 180 BDs from the last sample have the needed $I$ magnitudes in USNO-B1.0 catalogue. Finally we removed several of these 180 BDs from our statistical

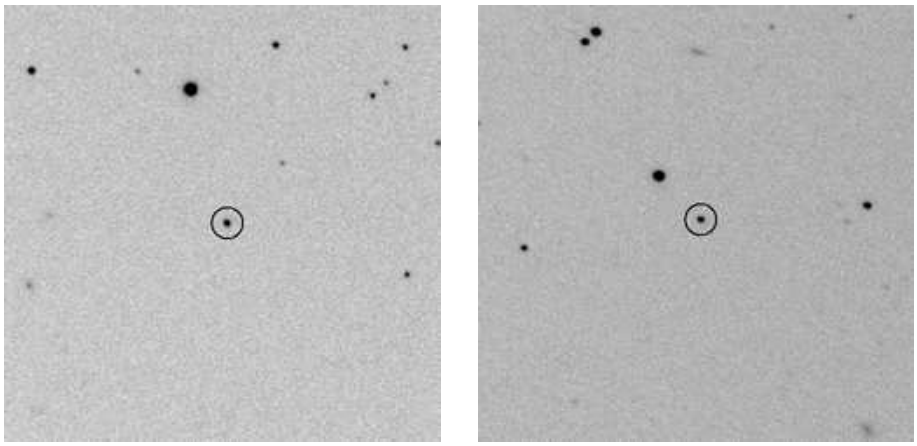

**Fig. 1.** Fields around the observed L dwarfs 2MASS J16580380+7027015 (left) and 2MASS J16262034+3925190 (right)

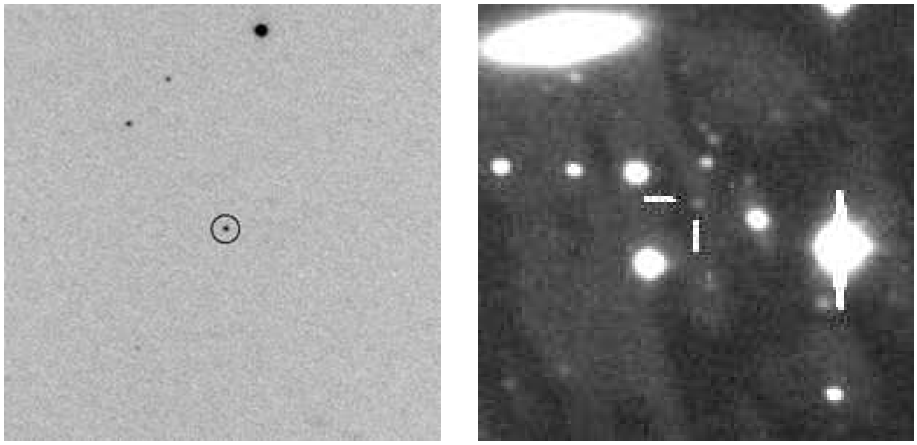

**Fig. 2.** Fields around the observed L dwarf 2MASS J15150083+4847416 and T dwarf 2MASS J12060248+2813293

sample due to their neighborhood with bright stars and suspected unreal colors. As a result our statistical sample consists of 163 BDs.

We quantized the spectral types M7.0, M7.5, M8.0 ... L6.0 attributing them the numbers $Sp$ which values are respectively 0.0, 0.5, 1.0 ... 9.0.

Figure 3 reveals the statistical diagrams $(I-K)$–Spectral type and $(J-K)$–Spectral type and Color–Color diagram $(J-H)$–$(H-K)$ built on the base of our sample from 163 BDs.

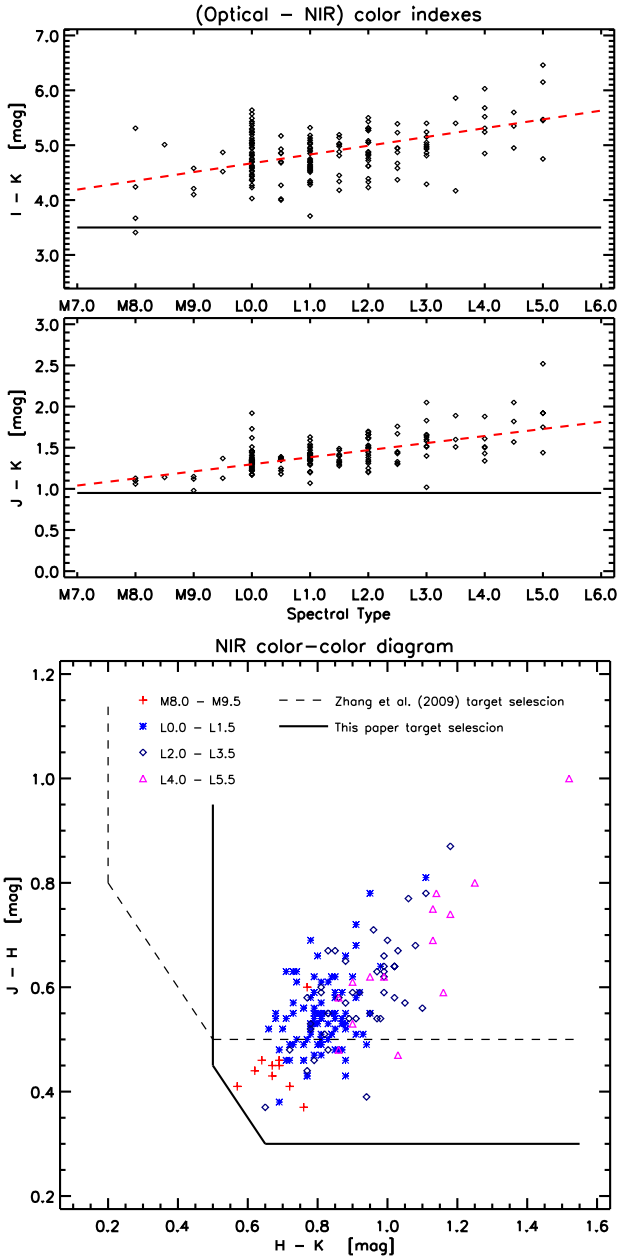


**Fig. 3.** Top: Color – Spectral type diagrams; Bottom: Color – Color diagram. The red dashed lines present linear fits (see eq. **??** and **??**). Black solid lines present the derived selection criteria (eq. **??**–**??**).

The two Color–Spectral type diagrams are described by linear fits (dashed lines):

$$I - K = 4.19 + 0.163 \times Sp \tag{1}$$

$$J - K = 1.04 + 0.086 \times Sp \tag{2}$$

By analogy with similar studies (Zhang et al. 2009; Kendall et al. 2007a; Metchev et al. 2008) we derived the following selection criteria for detection of BDs based on optical and NIR color indices (Fig. 3):

$$I - K \geq 3.5, \tag{3}$$

$$J - K \geq 0.95, \tag{4}$$

$$J - H \geq 0.30, \tag{5}$$

and

$$H - K \geq 0.50. \tag{6}$$

## 3 Delection of brown-dwarf candidates by our observations

We made $V$ and $I$ band photometry of three arbitrary fields on April 29 2010 using 60-cm telescope at NAO. The exposures were 2 min and 8 images of each field for the two filters were obtained. The coordinates of the image centers are respectively: $\alpha = 14^{\rm h}41^{\rm m}28\overset{\rm s}{.}11$, $\delta = +72^\circ42'32\overset{''}{.}7$ in constellation Ursa Minoris, $\alpha = 20^{\rm h}29^{\rm m}19\overset{\rm s}{.}1$, $\delta = +18^\circ09'32\overset{''}{.}6$, and $\alpha = 20^{\rm h}28^{\rm m}10\overset{\rm s}{.}0$, $\delta = +18^\circ09'40\overset{''}{.}2$ in constellation Delphinus.

The astrometric solutions for $I$ band frames were performed using the software MaxIM DL (PinPoint Astrometry code). Bright USNO-B1.0 stars were used as referent points. 3390 stars were detected on the three fields that were matched with the 2MASS objects. It should be noted that we have used a matching radius of $5''$ to provide that ultra-cool dwarfs with high proper motion would be also matched.

Applying consequently the criteria (4), (5), (6) and (3) we found 14 BD candidates on the three observed fields that are listed in Table 3. Their positions are marked by large black triangles on the color – magnitude and color–color diagrams for the observed fields (Fig. 4).

The last column of the Table shows the predicted spectral types of our BD candidates derived on the statistical relations (eq. **??** and **??**). Future spectral observations are necessary to confirm these predictions.

**Table 3.** The parameters of observed BDs candidates

| No | Star Name | $\alpha$ [2000] | $\delta$ [2000] | $I$ [mag] | $J$ [mag] | $J-K$ [mag] | Predicted Sp Type |
|---|---|---|---|---|---|---|---|
| 1 | 2MASS J20285479+1801586 | $20^h28^m54^s.79$ | $+18°01'58''.6$ | >19.00 | 14.98 | <1.06 | blended? |
| 2 | 2MASS J20283771+1802017 | $20^h28^m37^s.71$ | $+18°02'01''.7$ | >19.00 | 16.55 | <2.02 | galaxy? |
| 3 | 2MASS J20285049+1808101 | $20^h28^m50^s.49$ | $+18°08'10''.1$ | >19.00 | 16.53 | <1.52 | L0.5–L3.5 |
| 4 | 2MASS J20293607+1817358 | $20^h29^m36^s.07$ | $+18°17'35''.8$ | >19.00 | 16.34 | 1.13 | M7.0–L0.0 |
| 5 | 2MASS J20291053+1803208 | $20^h29^m10^s.53$ | $+18°03'20''.8$ | 18.87 | 16.46 | <1.34 | M8.5–L2.5 |
| 6 | 2MASS J20285329+1810200 | $20^h28^m53^s.29$ | $+18°10'20''.0$ | 18.66 | 16.26 | <1.31 | M8.0–L2.0 |
| 7 | 2MASS J20291049+1808405 | $20^h29^m10^s.49$ | $+18°08'40''.5$ | 18.46 | 16.56 | <1.75 | L2.0–L5.5 |
| 8 | 2MASS J20280481+1804357 | $20^h28^m04^s.81$ | $+18°04'35''.7$ | >19.00 | 16.65 | 1.29 | M8.0–L2.0 |
| 9 | 2MASS J20292409+1806089 | $20^h29^m24^s.09$ | $+18°06'08''.9$ | 18.90 | 16.92 | 1.56 | L0.5–L3.5 |
| 10 | 2MASS J20290994+1804292 | $20^h29^m09^s.94$ | $+18°04'29''.2$ | 18.60 | 16.51 | <1.41 | L9.5–L3.0 |
| 11 | 2MASS J20292696+1814270 | $20^h29^m26^s.96$ | $+18°14'27''.0$ | 18.74 | 16.50 | 1.26 | M8.0–L2.0 |
| 12 | 2MASS J20293533+1815115 | $20^h29^m35^s.33$ | $+18°15'11''.5$ | 18.22 | 15.87 | 1.11 | M7.0–L0.0 |
| 13 | 2MASS J20283732+1809558 | $20^h28^m37^s.32$ | $+18°09'55''.8$ | 18.04 | 16.06 | <1.47 | L0.0–L3.0 |
| 14 | 2MASS J20282386+1816244 | $20^h28^m23^s.86$ | $+18°16'24''.4$ | >19.00 | 16.69 | <1.13 | M7.0–L0.0 |

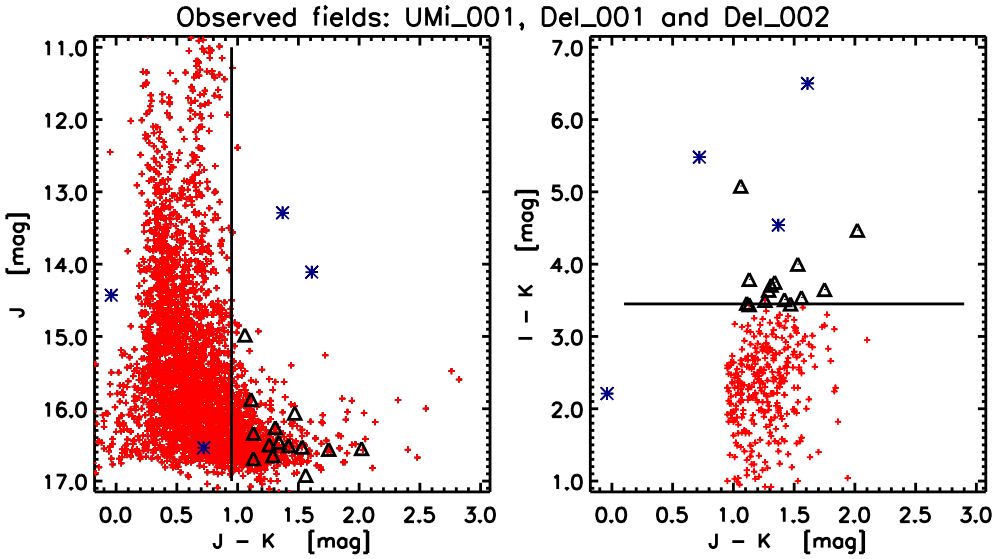


**Fig. 4.** Color – magnitude (left) and color–color (right) diagrams for observed test fields. The solid lines present derived selection criteria (eq. **??** and **??** respectively), the observed known L and T dwarfs from Table 1 are marked by asterisks while our BDs candidates are signed by triangles.

## 4 Conclusion

This study allows to derive the following conclusions:

1. Optical photometry in $I$ band of bright M and early L-type brown dwarfs can be obtained using our 60-cm Cassegrain telescope.
2. Optical photometry in $I$ band of relatively faint M and L-type BDs as well as of bright early T-type BDs can be obtained with our 2-m RRC telescope.
3. The detection of T3 dwarf 2MASS J12060248+2813293 was successful thanks to the new control system (Bonev 2010; Bonev & Dimitrov 2010) as well as to the using of autoguiding equipment of the 2-m telescope.

Based on optical and NIR color indexes a simple selection criteria (eq. **??**-**??**) can be derived. These relations can be applying to the programme of searching for new BDs candidates with Rozhen's telescopes.

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**Fig. 5.** Dragomir Marchev and Tanyu Bonev in the Conference

**Fig. 6.** Borislav Borisov gives a talk in the Conference

**Fig. 7.** Ilian Iliev at the opening of the Conference