Mon. Not. R. Astron. Soc. **000**, 000–000 (0000) Printed 13 April 2011 (MN LATEX style file v2.2)

# The discovery of the T8.5 dwarf UGPS J0521+3640

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13 April 2011

**ABSTRACT**

We have carried out a search for late-type T dwarfs in the UKIDSS Galactic Plane Survey $6^{th}$ Data Release. The search yielded two persuasive candidates, both of which have been confirmed as T dwarfs. The brightest, UGPS J0521+3640 has been assigned the spectral type T8.5 and appears to lie at a distance of 7–9 pc. The fainter of the two, UGPS J0652+0324, is classified as a T5.5 dwarf, and lies at an estimated distance of 28–37 pc. Warm-*Spitzer* observations in IRAC channels 1 and 2, taken as part of the GLIMPSE360 Legacy Survey, are available for UGPS J0521+3640 and we used these data with the near-infrared spectroscopy to estimate its properties. We find best fitting solar metallicity BT-Settl models for $T_{\rm eff} = 600$K and 650K and $\log g = 4.5$ and 5.0. These parameters suggest a mass of between 14 and 32 $M_{Jup}$ for an age between 1 and 5 Gyr. The proximity of this very cool T dwarf, and its location in the Galactic plane makes it an ideal candidate for high resolution adaptive optics imaging to search for cool companions.

**Key words:** surveys - stars: low-mass, brown dwarfs

## 1 INTRODUCTION

The growing sample of very cool T dwarfs (e.g. Warren et al. 2007; Burningham et al. 2008; Delorme et al. 2008; Burningham et al. 2009; Delorme et al. 2010; Goldman et al. 2010; Lucas et al. 2010; Mainzer et al. 2011) is providing a crucial test bed for atmospheric model grids that span the stellar, substellar and planetary regime (Marley et al. 2002; Saumon & Marley 2008; Allard et al. 2010a). A number of recent discoveries (e.g. Folkes et al. 2007; Artigau et al. 2010) including the very cool and nearby T dwarf UGPS J0722-0540 (Lucas et al. 2010) demonstrate that despite the technical challenges associated with identifying rare red objects in the Galactic plane, it is a feasible region in which to identify such targets. Nearby T dwarfs in the Galactic plane offer a number of advantages that make them ideal for detailed study. In addition to their relative brightness compared to more distant sources, the greater likelihood of proximity to stars bright enough to act as natural guide stars or tip-tilt stars for laser guide star observations make cool brown dwarfs in the Galactic plane ideal for high-resolution imaging campaigns aimed at identifying cool substellar neighbours and dynamical benchmark systems (e.g. Liu et al. 2008; Dupuy et al. 2009b,a).

In this Letter we present the results of a new search of the UKIRT Infrared Deep Sky Survey (UKIDSS; Lawrence et al. 2007) Galactic Plane Survey (GPS; Lucas et al. 2008) $6^{th}$ Data Release for nearby late-type T dwarfs which allows for candidates in the colour range $-0.1 < H - K < +0.1$ that were excluded by the search reported in Lucas et al. (2010) .

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## 2 CANDIDATE SELECTION

Late T dwarfs have a fairly wide spread of near infrared colours that includes objects with $(J-H) > 0$ or $(H-K) > 0$. A quite restrictive selection ($(J-H) < -0.2$, $(H-K) < -0.1$) was employed to detect UGPS 0722-0540 in order to minimise the number of false positive candidates with colours similar to normal stars. Inspection of the two colour diagrams in figure 9 of Burningham et al. (2010) shows that T8.5 and T9 dwarfs typically have $(H-K) \approx 0$ and $(J-H) < -0.2$. A query of the $6^{th}$ UKIDSS GPS Data Release at WFCAM Science Archive (Hambly et al. 2008) showed that the number of candidates in the gpsSource catalogue is increased only modestly if the $(H-K)$ colour selection is relaxed to $(H-K) < +0.1$, provided that all the other selection criteria employed in Lucas et al. (2010) remain in place. The number of candidates requiring visual inspection rises much more rapidly if this colour cut is relaxed further, or if the $(J-H)$ selection is relaxed.

We therefore searched the colour space $-0.1 < (H-K) < +0.1$, $(J-H) < -0.2$ for additional late T dwarfs. We note that this search would miss unusually red objects such as the T8.5 dwarfs ULAS J1302+1308, and Ross 458C which have $(H-K) = 0.32$ and 0.11 respectively. In other respects the search was identical to that carried described in Lucas et al. (2010), to which the reader is referred for an explanation of the logic behind the selection criteria.

This selection yielded 12 candidates. Two of these, UGPS J0521+3640 and UGPS J0652+0324, passed visual inspection of the FITS images and have no optical counterpart in either the IPHAS survey (Drew et al. 2005) or the POSS USNO-B1.0 archive. These two were therefore selected for spectroscopic observation. An additional search was run that removed the requirement for the coordinate shifts between the three passbands to be smaller than $0.3''$ and included all sources with $H-K < 0.1$ mag that satisfy the other criteria above. This search produced only 3 additional candidates, all of which were identified as image defects upon inspection of the FITS images.

## 3 OBSERVATIONS

The near-infrared discovery images of UGPS J0521+3640 were obtained on $25^{th}$ October 2007, whilst UGPS J0652+0324 was observed on $29^{th}$ October 2007. Follow-up imaging to measure proper motions was obtained use the Near Infrared Camera Spectrometer (NICS) on the National Telescope Galileo (TNG) on La Palma during the nights of $8^{th}$ February and $28^{th}$ January 2011 respectively. The data were processed using the standard NICS pipeline[1]. Additional WFCAM (Casali et al. 2007) imaging for both targets was obtained on $21^{st}$ November 2010 and further images were obtained for UGPS J0521+3640 on $2^{nd}$, $18^{th}$ and $19^{th}$ February 2011. The WFCAM data were processed using the standard pipeline (Irwin et al. 2004). The $x, y$ coordinates of the targets in all frames were converted to the standard coordinate system of the discovery frames using a simple linear model. The relative proper motion for all objects were found from linear fits to the standard coordinates at the different epochs. We were unable to determine a self-consistent motion for UGPS J0652+0324 from the 3 epochs of data available. A correction to an absolute system was estimated from the median difference between measured relative proper motions and published values of PPMXL (Roeser et al. 2010) objects in the field. The derived proper motion for UGPS J0521+3640 was corrected for an assumed parallax of 125mas. The UKIDSS coordinates and proper motions are given in Table 1. The Simbad and SuperCOSMOS (Hambly et al. 2001) databases were searched for targets to which UGPS J0521+3640 may be a common proper motion companion, but no viable candidates were identified.

Warm-Spitzer IRAC [3.6] and [4.5] imaging of the region around UGPS J0521+3640 was obtained as part of the GLIMPSE360 legacy program[2]. The [3.6] data were obtained on $31^{st}$ October 2009, with AORkey 32886784; the [4.5] data on $30^{th}$ October 2009, with AORkey 32912896. The frame time in both cases was 12s. The post-basic-calibrated-data (pbcd) mosaics generated by version 18.18.0 of the Spitzer pipeline were used to obtain aperture photometry. The photometry was derived using a $3.6''$-radius aperture, and the aperture correction was taken from the IRAC handbook[3]. UGPS J0521+3640 is currently close enough to a bright star ($36''$ North-NorthWest) that care had to be taken with subtraction of the sky background. The choice of sky background was investigated and found to lead to an uncertainty of the same size as that indicated by the noise statistics in the pbcd uncertainty image. The error quoted in Table 2 is the result of adding these random errors in quadrature to the 3% error that accounts for systematic effects due to calibration uncertainties and pipeline dependencies.

Near-infrared spectroscopy of UGPS J0521+3640 and UGPS J0652+0324 was obtained using the Gemini Near InfraRed Spectrograph (GNIRS; Elias et al. 2006) mounted on the Gemini-North telescope. UGPS J0521+3640 was observed on the night of $30^{th}$ December 2010 with a total integration time of 24 minutes. UGPS J0652+0324 was observed on the night of $26^{th}$ December 2010 with a total integration time of 40 minutes. The targets were observed in cross-dispersed mode capturing the full 0.8–2.5µm region with a $0.68''$ slit delivering a resolving power of R$\sim$ 1200. The data were reduced using GNIRS routines in the Gemini IRAF package (Cooke & Rodgers 2005), using a nearby F star in each case for telluric correction. The telluric standard spectrum was divided by a blackbody spectrum of an appropriate $T_{\rm eff}$ after removing hydrogen lines by interpolating the local continuum. The rectified standard spectrum was then used to correct for telluric absorption and to provide relative flux calibration. The overlap regions between the orders in the $Y$,$J$ and $H$ bands agreed well suggesting that the relative flux of the orders is well calibrated. The resulting $YJHK$ spectra are shown in Figure 1.

[1] http://www.tng.iac.es/news/2002/09/10/snap/

[2] http://www.astro.wisc.edu/sirtf/glimpse360/

[3] http://ssc.spitzer.caltech.edu/irac/dh/

| Object | $\alpha$ | $\delta$ | Epoch | Equinox | $\mu_{\alpha\cos\delta}$ / mas yr$^{-1}$ | $\mu_\delta$ / mas yr$^{-1}$ |
|---|---|---|---|---|---|---|
| UGPS J0521+3640 | 05:21:27.27 | +36:40:48.6 | 2007.82 | J2000 | $513 \pm 10$ | $-1507 \pm 10$ |
| UGPS J0652+0324 | 06:52:27.71 | +03:24:31.0 | 2007.83 | J2000 | | |

**Table 1.** UKIDSS discovery coordinates for the targets and the proper motions for UGPS J0521+3640.

| Object | $J_{UKIDSS}$ | $H_{UKIDSS}$ | $K_{UKIDSS}$ | [3.6] | [4.5] | $J-H$ | $H-K$ | $H-$[4.5] |
|---|---|---|---|---|---|---|---|---|
| UGPS J0521+3640 | $16.94 \pm 0.02$ | $17.28 \pm 0.04$ | $17.32 \pm 0.09$ | $15.30 \pm 0.06$ | $13.36 \pm 0.03$ | $-0.34 \pm 0.04$ | $-0.04 \pm 0.1$ | $3.92 \pm 0.05$ |
| UGPS J0652+0324 | $17.24 \pm 0.02$ | $17.50 \pm 0.04$ | $17.52 \pm 0.09$ | | | $-0.26 \pm 0.04$ | $-0.02 \pm 0.1$ | |

**Table 2.** Summary of photometry for UGPS J0521+3640 and UGPS J0652+0324.

## 4 ANALYSIS

### 4.1 Spectral types

We have classified the two T dwarfs presented here following the scheme of Burgasser et al. (2006), with the extension to T9 as discussed in Burningham et al. (2008) . Spectral typing index ratios for the targets presented here are given in Table 3. In Figure 1 we compare our targets to appropriate spectral type templates. Both the spectral typing index ratios and the template comparison suggests a type of T5.5 ±0.5 for UGPS J0652+0324. The spectrum of UGPS J0521+3640 appears to be intermediate between the T8 and T9 spectral type templates 2MASS J0415-09 and ULAS J1335+1130. Its $W_J$ index lies towards the upper end of the range defined for T9 in Burningham et al. (2008), and is most similar to the value found for the T8.5 dwarf Wolf 940B, whilst its $H_2O$–H index has a value towards the lower range of the T8 bracket. The other indices that were defined by Burgasser et al. (2006) are degenerate for types T8 and T9. The $NH_3$–H index, defined by Delorme et al. (2008), does not easily map onto the T dwarf classification system for earlier types since it is degenerate for types ⩽T8 (Burningham et al. 2008). However, its value for UGPS J0521+3640 ($0.597 \pm 0.003$) is intermediate between the values found for T7–T8 dwarfs and those typically seen for T9 dwarfs, suggesting that a later-than T8 classification is justified. Based on these considerations we assign a spectral type of T8.5 ±0.5 for UGPS J0521+3640.

Applying the spectral type vs $M_J$ relations of Marocco et al. (2010), we thus estimate distances of $8.2^{+1.2}_{-1.0}$ pc and $32^{+5}_{-4}$ pc for these objects. The uncertainties on these distances are derived from the uncertainties in the polynomial coefficients quoted by Marocco et al. (2010). We have not included the uncertainty due to our ±0.5 subtype spectral typing precision. For the coolest dwarfs, the spectral type - $M_J$ relation is sufficiently steep that a half subtype uncertainty can have a large effect on the inferred distance. In the case of UGPS J0521+3640 we find that a T8–T9 range in spectral type corresponds to distance bracket of 5.9 – 11.4 pc.

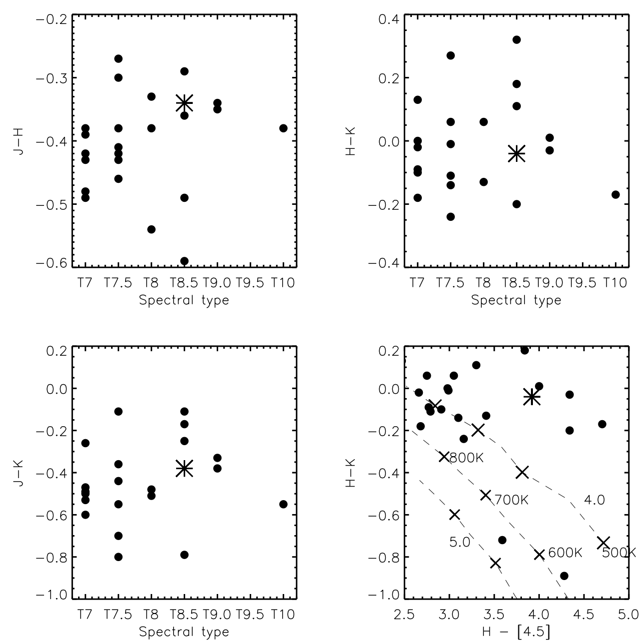


**Figure 2.** Colour versus spectral type plots for T7–T10 dwarfs with MKO photometry, along with a $H-K$ / $H-$[4.5] colour-colour plot shown in the bottom right panel. Synthetic colours for solar metallicity Saumon et al. (2006, 2007) are shown as solid lines with crosses indicating 100K intervals. The lower left line corresponds to $\log g = 4.0$, the middle line $\log g = 4.5$ and the upper right line $\log g = 5.0$. . UGPS J0521+3640 is shown with an asterisk.

### 4.2 Properties of UGPS J0521+3640

In Figure 2 we show the near-infrared colour versus spectral type plots and a $H-K$ / $H-$[4.5] for T7–T10 dwarfs, placing UGPS J0521+3640 in context within the wider sample. Both $H-K$ and $J-K$ colours (the latter often discussed in terms of the $J/K$ ratio) have been suggested as useful metallicity and gravity diagnostics. Poor agreement between the model atmospheres and observations of the flux ratio between the $K$ band and the $J$ and $H$ bands (e.g. Burningham et al. 2009, 2011) preclude their use for making absolute estimates for gravity or metallicity, but they allow useful relative comparisons between objects. The location of UGPS J0521+3640 on the plots in Figure 2 suggests that its metallicity and gravity are within the range of values seen for other T8–T9 dwarfs.

We have estimated the properties of UGPS J0521+3640 by comparison with the latest BT Settl model grid (Allard et al. 2010b) for solar metallicity and a reasonable $T_{\rm eff}$ and gravity range (based on experience of objects of similar spectral type). We have used the same method as described in Burningham et al (2011), which is an adaptation of the Cushing et al. (2008) method for fitting model

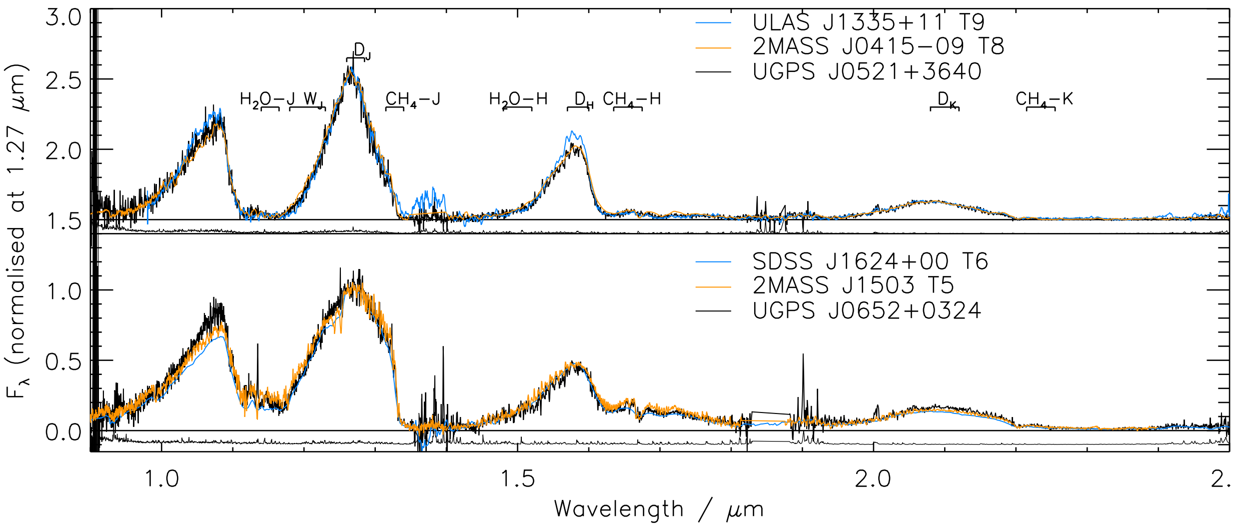


**Figure 1.** GNIRS spectra for the T dwarfs presented here compared to T dwarf spectral type templates taken from Burgasser et al. (2006) and Burningham et al. (2008).

| Object | $H_2O$–J | $CH_4$–J | $W_J$ | $H_2O$–H | $NH_3$–H | $CH_4$–H | $CH_4$–K |
|---|---|---|---|---|---|---|---|
| U0521 | $0.028 \pm 0.001$ | $0.147 \pm 0.001$ | $0.269 \pm 0.001$ | $0.151 \pm 0.002$ | $0.597 \pm 0.003$ | $0.103 \pm 0.001$ | $0.036 \pm 0.002$ |
| | ⩾T8 | ⩾T8 | T9 | T8 | >T8 | ⩾T8 | ⩾ T7 |
| U0652 | $0.199 \pm 0.002$ | $0.361 \pm 0.001$ | $0.491 \pm 0.002$ | $0.325 \pm 0.003$ | $0.671 \pm 0.001$ | $0.362 \pm 0.002$ | $0.182 \pm 0.002$ |
| | T5 | T5/6 | <T7 | T5/6 | <T8 | T5/6 | T5/6 |

**Table 3.** Spectral typing index ratios for UGPS J0521+3640 and UGPS J0652+0324 as defined by Burgasser et al. (2006) and extended to T8+ by Burningham et al. (2008). The $W_J$ ratio was defined by Warren et al. (2007), whilst the $NH_3$–H ratio was defined by Delorme et al. (2008).

spectra that incorporates flux information from photometric data points (e.g our *warm*-Spitzer photometry). The lack of a known parallax for our target means that we can only consider the case of the freely scaled model spectra, and cannot use the bolometric luminosity to better constrain the properties. Prior to fitting the models the target spectrum was placed on an absolute flux scale using the $J$ band photometry. Scaling by the noisier $Y$, $H$ and $K$ photometry provided consistent results.

We find that the goodness of fit statistic, $G$, is minimised for the cases where $T_{\rm eff} = 600$K and $\log g = 4.5$ and $T_{\rm eff} = 650$K and $\log g = 5.0$. These values for $T_{\rm eff}$ are broadly consistent with the location of UGPS J0521+3640 on the $H-K$ / $H-[4.5]$ plot shown in Figure 2, although, as has been noted previously, the models predict colours that are too blue in $H-K$. These properties correspond to a mass of 14 – 32 $M_{Jup}$, and a radius of approximately 1.0 – 0.8 $R_{Jup}$ for ages of 1–5 Gyr on the COND evolutionary model grid (Baraffe et al. 2003), although an age of 10 Gyr and a mass of 35 $M_{Jup}$ would be implied by a moderately higher surface gravity that is not resolved by our model grid. These best fits are found for scaling factors that correspond to distance to radius ratios of $d/R = 8.00$ and 9.78 pc/$R_{Jup}$ respectively. These are consistent with the photometric distances determined in Section 4.1 , with implied distances of 8 pc and 7.8 pc for the inferred radii of each case. This suggests that the distance derived for the T8.5 classification in Section 4.1, without the inclusion of the ±0.5 subtype uncertainty, of $8.2^{+1.2}_{-1.0}$ pc is a reasonable best-estimate for the distance to UGPS J0521+3640.

At this distance, the proper motion of UGPS J0521+3640 ($\mu_{\alpha \cos \delta} = 513$ mas yr$^{-1}$, $\mu_\delta = -1507$ mas yr$^{-1}$) corresponds to a tangential velocity, $V_{tan} = 60$ kms$^{-1}$. This is at the upper end of the distribution for T dwarfs reported by Vrba et al. (2004), implying that this source is unlikely to be very young (e.g. $<$ 1Gyr), and supporting our estimated age range of 1–5 Gyr.

## 5 SUMMARY

We have searched the 6$^{th}$ data release of the UKIDSS GPS for late type T dwarfs and have identified two such objects with types T5.5 and T8.5. The T8.5 dwarf, UGPS J0521+3640, appears to lie at distance of less than 10 pc, and as such is an ideal candidate for high resolution imaging searches for cool companions and detailed characterisation. We have used archival warm-*Spitzer* observations and the latest BT Settl model grid to estimate that UGPS J0521+3640 is cooler than 700K, with best fitting models at $T_{\rm eff} = 600$ and 650K.

## ACKNOWLEDGEMENTS

We thank our colleagues in the GLIMPSE360 team for providing this deep panoramic Legacy dataset, which complements the UKIDSS GPS excellently. We thank Barbara Whitney, Brian Babler and Robert Benjamin for a helpful discussion of the Spitzer photometry. Based on observations made under project A22TAC_96 on the Italian Telescopio Nazionale Galileo (TNG) operated on the island of La Palma by the Fundacin Galileo Galilei of the INAF (Istituto Nazionale di Astrofisica) at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias. Based on observations obtained via program GN-2010B-Q-41 at the Gemini Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the NSF on behalf of the Gemini partnership: the National Science Foundation (United States), the Science and Technology Facilities Council (United Kingdom), the National Research Council (Canada), CONICYT (Chile), the Australian Research Council (Australia), Ministério da Ciência e Tecnologia (Brazil) and Ministerio de Ciencia, Tecnología e Innovación Productiva (Argentina). SKL's research is supported by the Gemini Observatory. CGT is supported by ARC grant DP0774000. ADJ is supported by a Fondecyt postdoctorado fellowship, under project number 3100098. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France, and has benefited from the SpeX Prism Spectral Libraries, maintained by Adam Burgasser at http://www.browndwarfs.org/spexprism. JG, GK and BS are supported by RoPACS, a Marie Curie Initial Training Network funded by the European Commissions Seventh Framework Programme. NL acknowledges funding from the Spanish Ministry of Science and Innovation through the Ramón y Cajal fellowship number 08-303-01-02 and the project number AYA2010-19136. The authors wish to recognise and acknowledge the very significant cultural role and reverence that the summit of Mauna Kea has always had within the indigenous Hawaiian community. We are most fortunate to have the opportunity to conduct observations from this mountain.


## REFERENCES


Allard F., Homeier D., Freytag B., 2010a, ArXiv e-prints
—, 2010b, ArXiv e-prints 1011.5405
Artigau É., Radigan J., Folkes S., Jayawardhana R., Kurtev R., Lafrenière D., Doyon R., Borissova J., 2010, ApJ, 718, L38
Baraffe I., Chabrier G., Barman T. S., Allard F., Hauschildt P. H., 2003, A&A, 402, 701
Burgasser A. J., Geballe T. R., Leggett S. K., Kirkpatrick J. D., Golimowski D. A., 2006, ApJ, 637, 1067
Burningham B., et al, 2011, MNRAS in press, ArXiv e-prints 1103.1617
Burningham B., et al, 2008, MNRAS, 391, 320
Burningham B., et al, 2009, MNRAS, 395, 1237
Burningham B., et al 2010, MNRAS, 406, 1885
Casali M., et al, 2007, A&A, 467, 777
Cooke A., Rodgers B., 2005, in Astronomical Society of the Pacific Conference Series, Vol. 347, Astronomical Data Analysis Software and Systems XIV, P. Shopbell, M. Britton, & R. Ebert, ed., pp. 514–+
Cushing M. C., Marley M. S., Saumon D., Kelly B. C., Vacca W. D., Rayner J. T., Freedman R. S., Lodders K., Roellig T. L., 2008, ApJ, 678, 1372
Delorme P., et al, 2010, A&A, 518, A39+
Delorme P., Delfosse X., Albert L., Artigau E., Forveille T., Reylé C., Allard F., Homeier D., Robin A. C., Willott C. J., Liu M. C., Dupuy T. J., 2008, A&A, 482, 961
Drew J. E., et al, 2005, MNRAS, 362, 753
Dupuy T. J., Liu M. C., Ireland M. J., 2009a, ApJ, 692, 729
—, 2009b, ApJ, 699, 168
Elias J. H., Joyce R. R., Liang M., Muller G. P., Hileman E. A., George J. R., 2006, in Presented at the Society of Photo-Optical Instrumentation Engineers (SPIE) Conference, Vol. 6269, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series
Folkes S. L., Pinfield D. J., Kendall T. R., Jones H. R. A., 2007, MNRAS, 378, 901
Goldman B., Marsat S., Henning T., Clemens C., Greiner J., 2010, MNRAS, 405, 1140
Hambly N. C., et al, 2008, MNRAS, 384, 637
Hambly N. C., et al, 2001, MNRAS, 326, 1279
Irwin M. J., Lewis J., Hodgkin S., Bunclark P., Evans D., McMahon R., Emerson J. P., Stewart M., Beard S., 2004, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 5493, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, P. J. Quinn & A. Bridger, ed., pp. 411–422
Lawrence A., et al, 2007, MNRAS, 379, 1599
Liu M. C., Dupuy T. J., Ireland M. J., 2008, ApJ, 689, 436
Lucas P. W., et al, 2008, MNRAS, 391, 136
Lucas P. W., et al, 2010, MNRAS, 408, L56
Mainzer A., et al, 2011, ApJ, 726, 30
Marley M. S., Seager S., Saumon D., Lodders K., Ackerman A. S., Freedman R. S., Fan X., 2002, ApJ, 568, 335
Marocco F., et al, 2010, A&A, 524, A38+
Roeser S., Demleitner M., Schilbach E., 2010, AJ, 139, 2440
Saumon D., Marley M. S., 2008, ApJ, 689, 1327
Saumon D., Marley M. S., Cushing M. C., Leggett S. K., Roellig T. L., Lodders K., Freedman R. S., 2006, ApJ, 647, 552
Saumon D., et al, 2007, ApJ, 656, 1136
Vrba F. J., et al, 2004, AJ, 127, 2948
Warren S. J., Mortlock D. J., Leggett S. K., Pinfield D. J., Homeier D., Dye S., Jameson R. F., Lodieu N., Lucas P. W., Adamson A. J., and 14 co-authors, 2007, MNRAS, 381, 1400