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# A SEARCH FOR WEATHER IN LATE L DWARFS

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RESUMEN

Hemos llevado a cabo un programa de monitorización de 3 enanas marrones de campo con tipos espectrales L tardíos utilizando *Spitzer*/IRAC en 4.5 y 8 $\mu$m. La finalidad de este trabajo es buscar evidencias de la existencia de estructuras irregulares en las fotosferas de estos objetos. El hecho de que dos de los tres objetos estudiados mostraran variaciones en sólo una de las dos bandas sugiere un origen instrumental para las mismas. Sin embargo, dado que los flujos en distintas longitudes de onda provienen de distintas regiones verticales de la atmósfera, nuestras observaciones son consistentes con variabilidad intrínseca del objeto. En cualquier caso, estas observaciones constituyen la búsqueda de variabilidad en el infrarrojo medio más precisa hasta la fecha y nuestra fotometría proporciona límites superiores a la estructura de las fotosferas de estos objetos de transición.

ABSTRACT

We have conducted a photometric monitoring program of 3 field late-L brown dwarfs using *Spitzer*/IRAC 4.5 and 8 $\mu$m bandpasses. The aim of this work is to look for evidences of non-axisymmetric structure in their photospheres. The fact that two out of the three targets exhibit some variations in their light curves in one of the two bandpasses studied suggests an instrumental origin for the detected variations. On the other hand the data may still be consistent with intrinsic variability since the fluxes at different wavelengths come from different vertical regions of the atmosphere. In either case, the present observations provide the most sensitive search to date for structure in the photospheres of late-L dwarfs at mid-IR wavelengths, and our photometry provides stringent upper limits to the extent to which the photospheres of these transition L dwarfs are structured.

*Key Words:* **STARS: INDIVIDUAL (DENIS-P J0255-4700) — STARS: LOW-MASS, BROWN DWARFS — STARS: VARIABLES: OTHER**



## 1. INTRODUCTION

The transition region from the late L dwarfs to the early T dwarfs has always been problematic for brown dwarf atmosphere modelers. There have been many efforts in order to interpret these objects in terms of the atmospheric chemistry but it is still hard to deal with the effect of the condensates. Some of the unanswered questions relate to the fact that early T dwarfs tend to have absolute $J$ magnitudes brighter than later L dwarfs (Vrba et al. 2004), the large dispersion of certain colors as a function of spectral type (Knapp et al. 2004), and the discrepancies between the optical and near-IR derived spectral types of some transition objects (Kirkpatrick et al. 2005). Though some of these issues can be answered with unresolved binaries (Liu et al. 2006), it is also likely true that the mechanism for dust clearing is intimately involved in the explanation of all of these observables. Several mechanisms for dust clearing have been proposed (Tsuji et al. 2003; Burgasser et al. 2002; Knapp et al. 2004) and photometric variability is one observable that may be able to provide constraints on which is the dominant process occurring in very cool atmospheres. These atmospheres are too cool and neutral to support star spots (Mohanty & Basri 2003; Gelino et al. 2002) and thus, if variability exists, it is most likely caused by non-uniform structures in the cloud deck.

Numerous attempts have been made to search for photometric variability in L and T dwarfs, both in the optical and the near-IR, but the intrinsic faintness of the targets in the optical, and second order extinction effects from the Earth's atmosphere in the near-IR, make these kind of studies very difficult. In both cases, the usual single measurement one-sigma uncertainties is of order the amplitude of the quoted variability.

## 2. OBSERVATIONS AND DATA ANALYSIS

Our sample consists of 3 late L field brown dwarfs near the L/T transition. In this communication we focus on one of them, DENIS-P J0255-4700 (hereafter DENIS0255). See Morales-Calderón et al. (2006) for further information on the other objects. DENIS0255 is a well-known L8 brown dwarf at a distance of ~5.0 pc. It is one of the brightest of the

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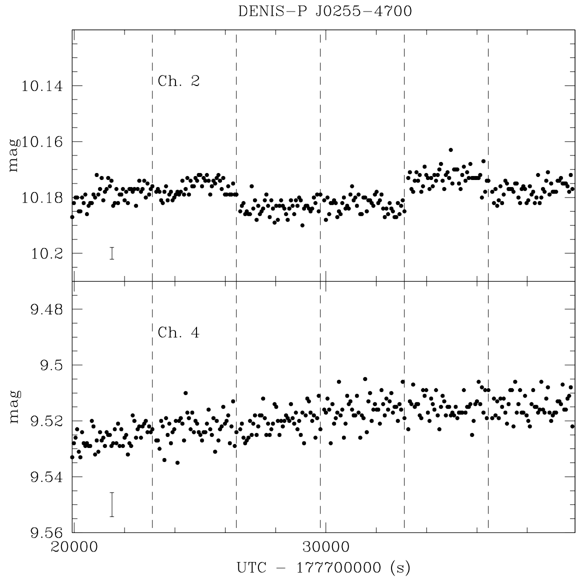


Fig. 1. Initial light curves for DENIS0255. The RMS-uncertainty of a single binned point is represented in the lower left corner of each panel.

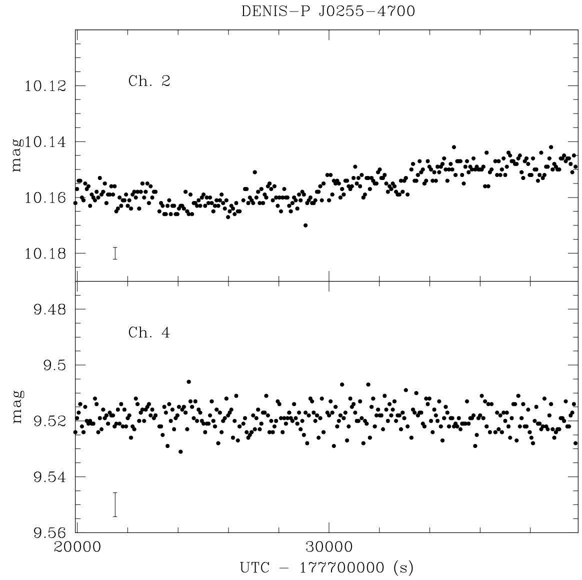


Fig. 2. Final light curves for DENIS0255. The 1$\sigma$ uncertainty per point is represented in the lower left corner of each panel.

so-called L/T "transition" objects, and it has $v \sin i$ of $\sim$40 km s$^{-1}$ (Basri et al. 2000) which corresponds to a rotation period of 3 hours. We have conducted a monitoring program using SPITZER/IRAC 4.5 and 8.0 $\mu$m in staring mode along 6 hours in order to have two whole rotation periods of the object.

Our starting point for the data analysis was the Basic Calibrated Data (BCD) produced by the IRAC pipeline software at the Spitzer Science Center. The finding of a good centroiding and the photometry extraction were performed under IRAF standard procedures. We did not perform differential photometry because, even though the 2MASS $K_s$ magnitudes of the reference objects were comparable to that of our target, their IRAC magnitudes were significantly fainter and therefore their light curves were much noisier. We did use them as control objects, comparing their time series with the science ones.

The time series for the averaged datapoints in both bandpasses can be seen in Figure 1. The upper panel is the light curve at 4.5 $\mu$m, and the lower one is for the 8.0 $\mu$m data. The vertical dashed lines delimit the different Astronomical Observation Request (AOR) used for the observation. In these time series, without any possible corrections applied, we see no evidence of a rotational variability. Upper limits on the intrinsic variability of our target at 4.5 and 8.0 $\mu$m were established as the RMS of the light curves.

The 4.5 $\mu$m data do show photometric variations that happen at AOR boundaries with a maximum amplitude of 1-2%. Each AOR is defined such that it begins with a slew to the target and a re-acquisition by the star-tracker, and we could not eliminate that process. Therefore, a slight repointing of the spacecraft and thus a repositioning of the target on the arrays at the start of each AOR. This movement of the target on the array produced the discontinuities shown in Figure 1. The 8.0 $\mu$m data do not show the same photometric variations as the 4.5 $\mu$m data. Instead, the lower panel in Figure 1 shows a brightening of 1.5% along the whole observation period.

The SSC pipeline is intended to produce fully flux-calibrated images which have had most of the well-understood instrumental signatures removed. However we had to correct our images for the effects present in Figure 1, pixel-phase effect and latent image buildup.

## 3. RESULTS AND DISCUSSION

Figure 2 shows the corrected light curves. The upper and lower panels show the 4.5 and 8.0 $\mu$m data respectively. The RMS-error is represented by an error bar at the lower left corner of each panel. After applying the pixel-phase correction to the 4.5 $\mu$m data, discontinuities between AORs are no longer visible. The photometry was corrected for latent images at 8.0 $\mu$m and now appear flat. Note that the trends in both bandpasses are different and there is a lack of photometric modulation at the expected rotational periods. The RMS of the light curves are 6 and 4 mmag respectively. Therefore, any possible variability on the timescale of 6 hours would be less than these values.

DENIS-P J0255-4700 is one of the best studied objects in the late-L/early-T region. It has been claimed to be variable in the *Ic* band (Koen et al. 2005) but, no signs of variability have been found in any other band.

We used the $\chi^2$ test to determine if our target was variable and it was labeled as variable at 4.5 $\mu$m and, non-variable at 8.0 $\mu$m. The power spectrum of this object shows only one strong peak at 7.4 hr, almost twice the period predicted from the spectroscopic rotational velocity. Hence, the cause of variability would have to be some type of global change in the luminosity of the object which is not modulated on the rotation period. Future observations would be useful in order to determine if any kind of long term variability is present. Another possibility would be that the $v \sin i$ is in error or that our assumed radius is in error. However, recently Zapatero et al. (2006) have derived the same $v \sin i$ with higher accuracy, and DENIS0255 does not show any evidence of lower gravity in its optical spectrum or near-IR colors and thus, nothing indicates that it has a larger than normal radius. Note that our 6 hr of observation do not allow us to see an entire phase and thus, we cannot check the validity of the estimated period.

There are instrumental effects that depend on position on the array (both pixel phase effects and flatfield errors) that affect the measured flux at 4.5 $\mu$m. Those effects are smaller at 8.0 $\mu$m. Therefore, the observed variability could be caused by instrumental remanents.

On the other hand, the fact that we see variations in one bandpass and not in the other is not inconsistent with the hypothesis of real variability arising from clouds. The spectra of L and T dwarfs are sculpted by molecular absorption bands which vary greatly in strength as a function of wavelength. Thus, there is no well defined "photosphere", and the depth from which flux is emitted varies strongly with wavelength. Among the IRAC bandpasses, 3.6 & 4.5 $\mu$m probe most deeply into late L dwarf atmospheres and 5.8 & 8 $\mu$m probe higher, generally above the region cloud models predict is occupied by the iron and silicate clouds (Ackerman et al. 2001; Marley et al. 2006).

## 4. CONCLUSIONS

We have conducted a photometric monitoring program of a late-L brown dwarf with SPITZER/IRAC at 4.5 and 8 $\mu$m with observations that lasted approximately the expected rotational period of the object. This project presents the most sensitive search yet obtained for brown dwarf mid-IR variability. The observational mode selected allowed us to obtain very well-sampled light curves in the time domain and 1$\sigma$ RMS uncertainties of $<$3 mmag and $\sim$6 mmag at 4.5 and 8 $\mu$m respectively. The search was sensitive to the timescale of our observations (6 hours) and hence, larger variability on timescales to which we were not sensitive could be present.

DENIS0255 turned out to be variable at 4.5 $\mu$m with a period of 7.4 hr but not at 8 $\mu$m. If this variability is real and if it is a rotational modulation, its period would be much larger than the expected rotational period and would have a peak-to-peak amplitude of 10 mmag. The cause of variability could be some type of global longer term change in the luminosity of the object which for some reason is not modulated by the rotation period. The fact that some instrumental effects that could affect the photometry at 4.5 $\mu$m were present in DENIS0255 suggests that perhaps the variability is not real. If the variability shown by our targets has an instrumental origin, our non-variable L dwarfs could be either completely covered with clouds or objects whose clouds are smaller and uniformly distributed along its atmosphere. However, since the flux at the two bandpasses arises from different vertical regions in the atmosphere, the different shapes in the light curves are consistent with the hypothesis of variability caused by clouds in the atmosphere of the L dwarf. Whether the detected variation is instrumental in origin or intrinsic to the target, our data place a limit on the amplitude for a true rotational modulation with a period between 20 minutes and 6 hours below 6 and 4 mmag at 4.5 and 8 $\mu$m respectively.

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