A mini-survey for variability in early L dwarfs

F.J. Clarke¹, B.R. Oppenheimer² and C.G. Tinney³

¹Institute of Astronomy, Madingley Road, Cambridge CB3 0HA, UK.
²Department of Astrophysics, American Museum of Natural History, New York, NY 10024, USA
³Anglo-Australian Observatory, PO Box 296, Epping, NSW 2121, Australia
fclarke@ast.cam.ac.uk, bro@amnh.org, cgt@aaepp.aao.gov.au

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ABSTRACT
We report differential I-band photometry of four early L-dwarfs obtained to study variability. We detect variability on the timescale of hours in two objects, 2M0746425+200032 (at a level of 0.007 mag – 6.5 sigma) and 2M1108307+683017 (0.012 mag – 5 sigma). We also place upper limits of 0.02 mag (1 sigma) on the variability of two others.

Key words: techniques: photometric — stars: low mass, brown dwarfs

1 INTRODUCTION
The recently categorised L-dwarfs (Kirkpatrick et al. 1991) have rapidly become an important part of stellar astrophysics. L-dwarfs lie below M-dwarfs in terms of their temperatures, and their spectra are dominated by molecules such as TiO, FeH and CrH. Dust formation also plays a very significant role in the atmospheric physics of early L-dwarfs (by L5-7, the major dust species have begun to settle below the photosphere). The physics of dust formation is a complicated subject, but one which is critical to our understanding of L dwarfs. Variability studies give us a tool to probe the sub-global differences in the composition of the atmosphere. Other processes, such as the flaring seen in M dwarfs, may also contribute to variability in L dwarfs.

In this paper we report time-series photometry of four field L-dwarfs. Two objects, 2MASS1108307+683017 and 2MASS0746425+200032 are found to be variable at the level of 0.012 mag (5σ) and 0.007 mag (6.5σ) respectively on the timescale of hours. We did not detect any variability above this level were removed from the analysis below.

In some science frames, the peak counts in a few pixels of similar magnitude. The chip was also binned where possible to further reduce overheads, such that we collected images at 2 minute intervals on average. All observations were made through the I-band filter where the photon count from the extremely red L dwarfs is maximised. Calibration frames, consisting of bias frames, dome and sky flats were obtained for all chip configurations. A log of observations, including window sizes and chip binning, is given in table [1].

Data were reduced with IRAF [2]. Ten bias frames were median combined, and this was then subtracted from all data and flat field frames. An average normalised flat field was then constructed from sky flats. We divided the science data by the appropriate flat field. This provided images flattened to the 0.25% level. Fringing is visible at the ~1% level on the scale of ~10''. We could not remove this, as we did not obtain enough pointings to build a fringe map.

During the first night’s observing, we discovered PFCam’s shutter was working incorrectly, with only one blade of the traveling shutter system functioning. As the travel time of the blade is on the order of the milliseconds, a part in 10⁶ for most science frames, this contributes negligibly to the photometric errors. The effect is however apparent in short (0.5-4s) dome flats. For these frames, we fitted the gradient with a linear function, and subtracted the fit.

In some science frames, the peak counts in a few pixels approached the full-well depth of the CCD (65536 ADU). We obtained data to test the linearity of the chip, and found it to be linear to ~60000 ADU. Any frames with peak counts above this level were removed from the analysis below.

Photometry was performed with the APPHOT package within IRAF. We determined the FWHM for each frame

1 The Image Reduction and Analysis Facility (IRAF) is distributed by NOAO, which is operated by AURA, Inc., under contract to the NSF.
within an observing sequence, and picked an aperture \( \sim 1.5 \times \) larger than the average FWHM for that sequence. This aperture was used on all frames within that sequence. Magnitudes and errors were calculated from the fluxes given by APHOT in the manner described by Everett & Howell (2001) including an estimate of informal errors from fringing and imperfect flatfield correction. An ensemble of bright stars were combined to give a zero-point magnitude for each frame \( (m_{\text{ens}}) \), which was then subtracted from the measured magnitude of the target \( (m_{\text{tar}}) \) to build a differential lightcurve. Hence, an increase in \( \delta (m_{\text{tar}}-m_{\text{ens}}) \) represents a dimming of the object. A selection of comparison stars (not included in the ensemble stars) were also analysed to ensure any variability detected is intrinsic to the target. In no case did any of the ensemble stars display any variability.

3 RESULTS

3.1 2MASSJ1108307+683017

2M1108+6830 is an L1 dwarf. Gizis et al. (2000) report an H-\( \alpha \) equivalent width of 7.8\AA, which they suggest indicates it is possibly an older member of the stellar population, rather than a youthful brown dwarf. We observed 2M1108 for 4.5 hours with a sampling rate of 2 minutes (100s integrations). To obtain sufficient ensemble stars (at least 3), we used a field of 5.1’×5.1’ with 2x2 pixel binning (Figure 1). Figure 2 shows the resulting I band lightcurves for 2M1108 and a comparison star (which was not part of ensemble stars). It is clear from this figure that 2M1108 becomes \( \sim 0.012 \) mag fainter during the last 1.5 hours of observation, whilst the comparison star stays constant to within \( \pm 0.003 \) mag throughout the observation. The standard deviation of the binned comparison lightcurve is 0.0025 mag. Our detection of variability in the binned lightcurve is therefore significant at the 5\( \sigma \) level. There may be a slight brightening in 2M1108 just before it fades (AJD≈6.03), but this is detected only at the 2\( \sigma \) level due to an increase in noise in this region.

Although the comparison star shows no variability, we must consider the possibility that 2M1108’s variability is caused by second order colour effects (see Young et al. (1991) for a full discussion). The L dwarfs have much redder spectral energy distributions than the ensemble stars, and hence have a longer effective wavelength in the I filter. This means the L dwarfs have a smaller effective extinction coefficient, which would manifest itself as an apparent brightening in the differential lightcurve with increased airmass. However, the data exhibit the opposite behaviour, since the observation started at an airmass of 1.15 and ended at 1.3. The detected dimming of 2M1108 we see is therefore unlikely to be caused by airmass effects.

The H-\( \alpha \) emission from 2M1108 implies chromospheric activity. However, it is not clear if the variability we detect is related to this. The variability may alternatively be due to photospheric features (magnetic spots or dust clouds) which modulate the brightness as the object rotates. There is no periodic signal in our data, but our temporal sampling clearly does not cover a sufficient range to exclude this possibility. Based on \( v \sin i \) measurements (Basri et al. 2000), we expect the typical rotation period of an L dwarf to be on the order of 6-12 hours.

3.2 2MASSJ0746425+200032

2M0746+2000 is in fact a close (0.22”) binary of roughly equal mass (Reid et al. 2001). We do not resolve the binary in our observations, and therefore refer to the whole system as 2M0746 rather than either individual component. We discuss how this may effect our results later.

2M0746 has a spectral type of L0.5. Schweitzer et al. (2001) detect no H\( \alpha \) in its spectra, and therefore estimate a minimum mass of \( \sim 0.06 M_\odot \) for each component. Due partly to its binary nature, 2M0746 is one of the brightest known L dwarf systems, having an I band magnitude of 15.2. It also lies in a rich stellar field, making it an ideal target for accurate differential photometry. We observed this target for nearly 6.5 hours with a sampling rate of 1-2 minutes. Changes in seeing required us to adapt our observing strategy (to avoid saturating the target). The majority of the usable images measure 2.2’×2.2’, and contain the target and 4 bright comparison stars (Figure 2). These stars are also visible in all previous configurations used on this object.

The derived I band lightcurves are shown in Figure 3. 2M0746 shows variability in two of the three configurations. In the second configuration (AJD=5.64-5.70), 2M0746 brightens (\( \delta m \) decreases) by \( \sim 0.01 \) mag while the comparison stays constant to within 0.005 mag. However, due to the increased noise in this configuration, this is only significant at the 2\( \sigma \) level. During the third configuration (AJD=5.70-5.89), 2M0746 fades by \( \sim 0.007 \) mag around AJD=5.78 before returning to its original brightness. The comparison object is constant to \( \sim 0.002 \) mag, and its binned lightcurve has a standard deviation of 0.0011 mag. Our detection of variability in the third configuration is therefore significant at the 6.5\( \sigma \) level.

It is possible that the brightening we see from 5.66 to 5.7 is analogous to the brightening from 5.78 to 5.82. This
Table 1. Log of observations obtained with PFCam on the 3-m Shane Telescope at Lick Observatory. Object names starting with 2M come from the 2MASS survey (Kirkpatrick et al. 1999). D0909-0658 was discovered by the DENIS survey (Delfosse et al. 1997).

| Object          | Date  | Start UT | End UT | # Frames | Exp time (s) | CCD configuration | Window size | binning |
|-----------------|-------|----------|--------|----------|--------------|-------------------|-------------|---------|
| 2M0746+2000     | 21    | 02:48    | 03:33  | 28       | 45           | 5.1′×5.1′         | 2×2         |         |
| 2M0746+2000     | 21    | 03:33    | 04:55  | 51       | 45-30        | 3.7′×3.7′         | 2×2         |         |
| 2M0746+2000     | 21    | 04:55    | 09:22  | 121      | 120-60       | 2.2′×2.2′         | 1×1         |         |
| 2M1108+6830     | 21    | 09:52    | 14:23  | 119      | 100          | 5.1′×5.1′         | 2×2         |         |
| D0909-0658      | 23    | 07:51    | 08:20  | 6        | 300          | 2.2′×2.2′         | 2×2         |         |
| D0909-0658      | 23    | 09:53    | 11:57  | 26       | 300-200      | 2.2′×2.2′         | 2×2         |         |
| 2M1146+2230     | 23    | 12:11    | 14:20  | 22       | 300          | 2.2′×2.2′         | 2×2         |         |

Figure 1. Finder chart for all four targets, indicating the position of the target and the comparison stars (marked with arrows). Note the difference in scale of the 2M1108+6830 field.
Figure 3. I band lightcurve of 2M0746425+200032 (upper panel) and an apparently invariant comparison star (lower panel). Individual measurements are shown as narrow lines, with the lightcurve averaged into 20 minute bins shown with thick crosses. 2M0746 clearly changes in brightness (dims) by $\sim 0.007$ mag on the timescale of 3 hours while the comparison star stays constant to $\sim 0.002$ mag. The dashed vertical lines at times 5.64 and 5.70 indicate the changes in chip configuration (Table 1). Each configuration has a different zeropoint, and all three have been individually mean subtracted. Differences between the configurations are therefore not significant.

Figure 4. Lightcurve of D0909571-065806 (upper panel) and the comparison star indicated in Figure 1 (lower panel). There is no significant variability from the target, with the scatter in both lightcurves at the level of $\sigma_t = 0.02$ mag.

Figure 5. Lightcurve of 2M1146345+223053 (upper panel) and the comparison star (lower panel) denoted in figure 1. Both lightcurves are consistent with non-variability within the errors. This gives an upper limit of $\sigma_t < 0.02$ mag for the variability of 2M1146 over $\sim 2$ hours.

3.3 DENIS0909571-065806

Martin et al. (1999) classify D0909-0658 as an L0 dwarf. Figure 4 identifies it along with the comparison star whose lightcurve is plotted in Figure 4. Seeing on this night was $\sim 2$ arcsec poorer than the first night, requiring longer (300s) exposures to obtain the necessary signal to noise ratio. D0909-0658 was observed in two batches, separated by $\sim 90$ minutes. Figure 5 shows no significant indication of variability either between or within the two sequences. We therefore place an upper limit on the variability of D0909-0658 of $\sigma_t < 0.02$ mag (1 sigma) on the timescale of 0.5-4 hours.

3.4 2MASS1146345+223053

2M1146+2230 is actually a close equal brightness binary with a separation of 0.3" (Koerner et al. 1999). Schweitzer et al. (2001) have detected Li in the combined spectrum of 2M1146, confirming its status as a brown dwarf binary with each component having M$<0.06M_\odot$. In addition, an earlier type background star is located 1" away from the binary (Kirkpatrick et al. 1999). The seeing during our observations (3 arcsec) did not allow us to resolve the binary or to detect the background star.

Bailer-Jones & Mundt (2001) have previously made a marginal detection of variability in this object at the level of $\sim 0.015$ mag. Poor seeing did not allow us to reach this level of accuracy. The lightcurve (Figure 5) shows 2M1146 is consistent with being non-variable at the noise level of $\sim 0.02$ mag (1 sigma) during our observations.

4 CONCLUSIONS

We have detected variability in time series I band observations of two field L dwarfs (2M0746425+200032 and 2M1108307+683017), and placed upper limits on the variability of two more (2M1146345+223053 and D0909571-065806). The cause of variability is unclear, but it may be due to inhomogenous structures within the photosphere. In the case of 2M0746+2000, weak evidence exists for a periodicity of $\sim 3$ hrs. This could be explained by a photospheric feature and a 3 hour rotation period.
In now seems clear that a significant fraction of, if not all, L-dwarfs are variable at the 1-2% level, and that very few have much larger variability (Clarke, Tinney & Covey 2002, Bailer-Jones & Mundt 2001, Martin, Zapatero Osorio & Lehto 2001). In this study, both stars for which we obtained photometry better than 1% exhibited variability. Future surveys for variability in L-dwarfs require a photometric precision better than 0.5%.

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