VARIABILITY AND ROTATION OF ULTRA COOL DWARFS

C.A.L. Bailer-Jones

Max-Planck-Institut für Astronomie, Königstuhl 17, 69117 Heidelberg, Germany

Abstract

Over the past few years monitoring programs have shown ultra cool dwarfs (UCDs) to be photometrically variable. Of the 60 sources monitored in the field and some 120 monitored in clusters, about 40% show variability in both cases. For mid to late M dwarfs in young (<100 Myr) clusters, this variability is generally periodic with amplitudes of up to a few tenths of a magnitude and periods of between a few hours and several days. For older field dwarfs (covering late M, L and T types) this variability is often nonperiodic with smaller amplitudes (up to 0.1 mag in I) and timescales of order hours. The former may be attributed to the rotational modulation of magnetically-induced photospheric spots, as seen in higher mass T Tauri stars. The nonperiodic variability, on the other hand, may be caused by a rapid evolution of surface features (which 'mask' the otherwise observable rotational modulation). This could be related to the formation and dissipation of inhomogeneities in dust clouds in the photospheres of UCDs.

Key words: brown dwarfs – ultra cool dwarfs – atmospheres – variability

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Work over the past few years by several groups has shown strong evidence for low amplitude photometric variability in both field and cluster very low mass stars and brown dwarfs (collectively, *ultra cool dwarfs*, or UCDs). An example light curve and power spectrum is shown in Fig. 1.

For the field UCDs, variability timescales are typically of order a few hours with amplitudes of between 0.01 and 0.08 mags in the I band. Fig. 2 shows the variability detection amplitudes and upper limits as a function of spectral type. There is no particular correlation, also not with the amplitudes against spectral type.

In several cases, the variability in UCDs has been found to be non-periodic. This is curious, as in many cases the monitoring surveys would have been sensitive to expected UCD rotation periods (see Fig. 3). Bailer-Jones & Mundt (2001) interpreted this with a *masking hypothesis*: If surface evolve on a timescale shorter than the rotation period, these will obscure a regular modulation of the light curve.

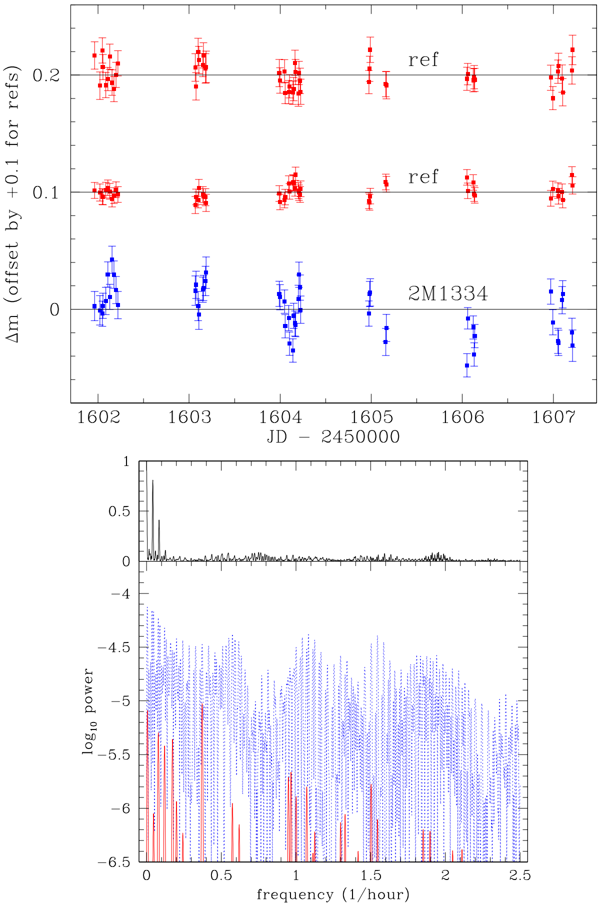

Figure 1. The top panel shows the differential light curve of a field L dwarf (bottom) and two (of many) reference stars (top two). The bottom panel shows the corresponding periodogram for the L dwarf, with the raw, or dirty periodogram in blue (dashed) and the CLEANed periodogram in red (solid). The window function is shown above.

An analysis of the literature shows that UCD variability is quite common. I have collated these results into Tables 1 and 2 for field UCDs and cluster UCDs respectively. My literature search tries to include all relevant work in the refereed literature as of mid 2004. All surveys are in the I-band, except Enoch et al. 2002 (K band), Bailer-Jones & Lamm 2003 (J and K bands) and Tinney & Tolley 1999 (two narrow bands). The issue of a detection or

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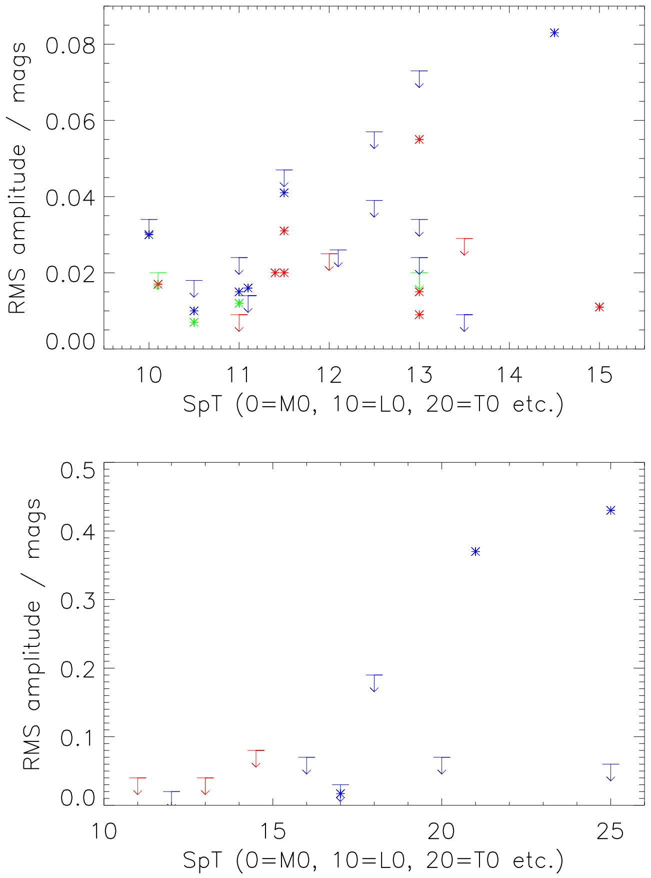

Figure 2. Variability detection amplitudes (stars) and upper limits (arrows) as a function of spectral type and magnitude for field UCDs. The data are taken from five works in the literature: Bailer-Jones & Mundt (2001) [red], Clarke et al. (2002) [green], Gelino et al. (2002) [blue] (I-band surveys, upper panel); Bailer-Jones & Lamm (2003) [red] and Enoch et al. (2002) (K-band surveys, lower panel).

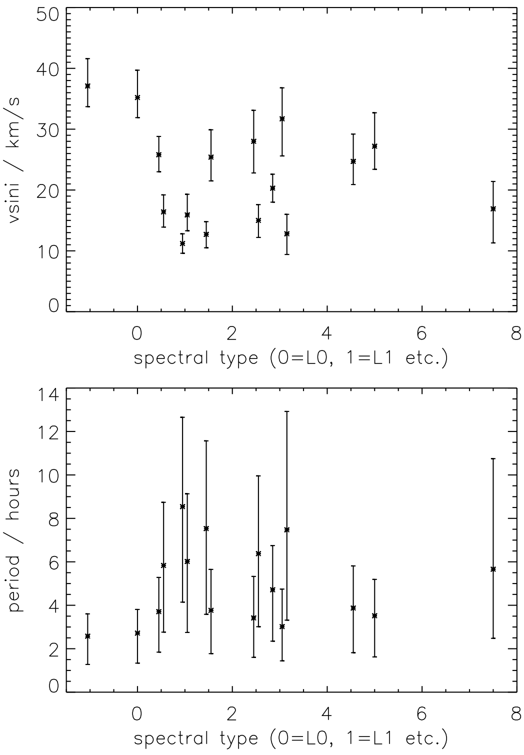

Figure 3. Bailer-Jones (2004) determined the projected rotation velocities ($v \sin i$) of 16 field UCDs using VLT/UVES. The top panel shows these to be rapid rotators (the error bars show the maximum uncertainties, not the 1σ ones). Adopting a radius of $0.1\,R_\odot$ for UCDs, these are converted into expected periods, maximum rotation periods and 90%-confidence limits for the minimum periods, plotted in the bottom panel. From this, claimed photometric periods in the literature could be confirmed or refuted. In one case these data permit a determination of the lower limit of a UCD radius as $0.097 \pm 0.007\,R_\odot$.

non-detection is somewhat arbitrary for marginal cases, as it depends on the statistical test and threshold used. As far as is possible, I have converted values to a common 99% confidence level for variability detection. One must obviously be very careful in comparing results from different surveys, as they differ in their sensitivity limits, target selection, spectral types etc. Keeping this in mind, it appears that both cluster and field UCDs show a similar variability fraction of 30–40% down to optical and near infrared amplitudes greater than 0.5–1%. However, cluster UCDs are more likely to show periodic variability – presumably a rotational – whereas the field UCDs often display non-periodic variability. Thus while both sets are rapid rotators, it seems that surface features evolve more rapidly on field UCDs.

There are at least two plausible candidates for causing the variability. The first is cool, magnetically-induced spots. This is an attractive explanation for cluster UCDs: as these are young, they may show activity with spots appearing in analogy to weak-lined T Tauri stars. However, Gelino et al. (2002) and Mohanty et al. (2003) have argued against the presence of spots at these very low temperatures because of the neutrality of the photosphere and thus a weak coupling between the gas and any magnetic field. A second explanation is dust clouds. Dust is known to form at these low temperatures. Rapid rotation and convection could give rise to complex atmospheric dynamics, possibly accounting for the non-periodic variability seen in field L and T dwarfs.

I have made initial attempts to predict and observe the spectroscopic signatures of different types of spot and cloud patterns (Bailer-Jones 2002), as shown in Figs. 4 and 5. To test these predictions, I obtained time-resolved differential spectrophotometric observations of one field L1.5 dwarf. Spectra were obtained relative to a reference star observed simultaneously in the slit (see Fig. 6). There is no strong evidence for variability in any *single* band,

Table 1. Variability detections and non-detections in field ultra cool dwarfs, taken from the literature. The three columns show: the number of variables; the number of non-variable; the variability fraction (of the total). These are summed at the bottom (the total percentage is calcuated from the other two totals). Numbers may deviate slightly from those published as I have attempted to adopt a common 99% confidence level for detecting variability.

Reference	#var	#non	fraction
Bailer-Jones & Mundt 2001	8	3	73%
Bailer-Jones & Lamm 2003	0	3	0%
Clarke et al. 2002a	2	2	50%
Clarke et al. 2002b	1	0	100%
Enoch et al. 2002	3	6	33%
Gelino et al. 2002	6	12	33%
Koen 2003	3	9	25%
Martin et al. 2001	1	0	100%
Tinney & Tolley 1999	1	1	50%
TOTAL	25	36	41%

Table 2. As Table 1, but for UCDs in clusters. The name of the cluster is given in the second column: P=Pleiades, S=σ Orionis, C=Chamaeleon I. Because the number of non-detections in Scholz & Eislöffel (2004b) is not entirely clear, and because these figures would dominate the sum, these results have been excluded from the total (but are included in the totals shown in parentheses).

Reference		#var	#non	fraction
Joergens et al. 2003	C	5	5	50%
Bailer-Jones & Mundt 2001	P	1	4	20%
Scholz & Eislöeffel 2004a	P	12	14	46%
Terndrup et al. 1999	P	2	6	25%
Bailer-Jones & Mundt 2001	S	3	3	50%
Caballero et al. 2004	S	11	17	39%
Scholz & Eislöeffel 2004b	S	(23)	(72)	(24%)
Zapatero Osorio et al. 2003	S	1	0	100%
TOTAL		35 (58)	49 (121)	42% (32%)

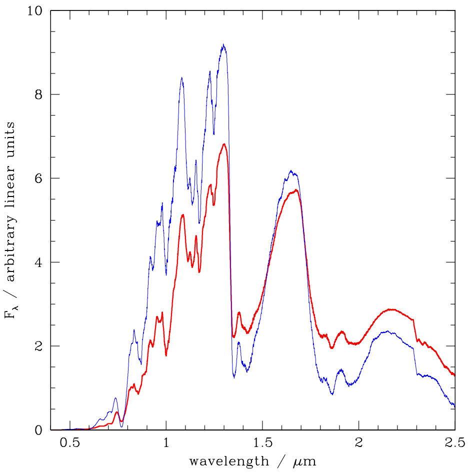

Figure 4. Model DUSTY (red/thick) and COND (blue/thin) spectra from Allard et al. (2001) for a UCD with $T_{\rm eff} = 1900$ *K.*

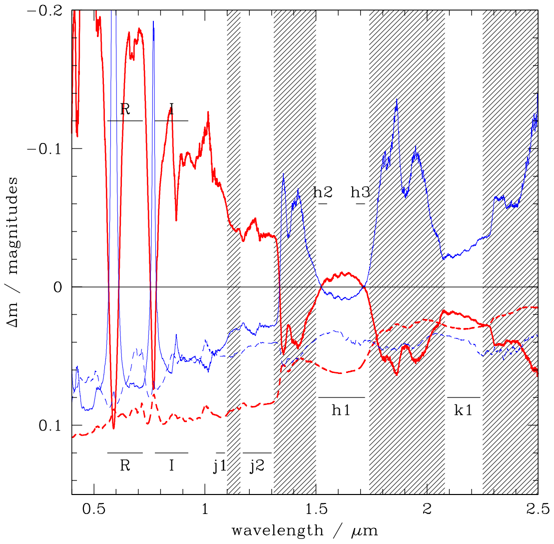

Figure 5. Predictions of the change in the spectrum of a UCD due to the formation of a cloud or spot with a 10% filling fraction (Bailer-Jones 2002). The four lines shown are for: COND cloud on a DUSTY atmosphere (thick/red solid line) and 200 K cooler spot on a DUSTY atmosphere (thick/red dashed line); DUSTY cloud on a COND atmosphere (thin/blue solid line) and 200 K cooler spot on a COND atmosphere (thin/blue dashed line).

but there is evidence for colour-correlated variability (Fig. 7). Adopting a dusty atmosphere with $T_{\rm eff} = 1900$ K, this limits coherent clear clouds to a coverage of no more than 10–15% and 200 K cooler spots to a 20% coverage.

Ongoing work is aimed at better characterizing UCD variability and achieving higher sensitivity. Recent observations have been obtained of several UCDs (see Fig. 8). I am also extending this work to field M dwarfs and T dwarfs. Other useful observational signatures include polarimetry and high resolution monitoring of line profiles (Doppler imaging).

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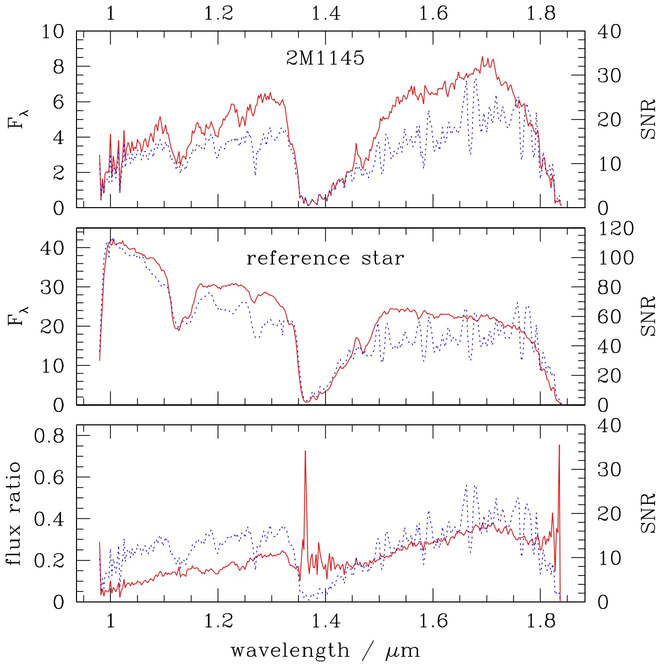

Figure 6. Near infrared spectra of the L1.5 dwarf 2M1145 (top), the reference star observed in the same slit (middle) and their relative spectra (bottom) used to monitor for variability independently of atmospheric effects. The red (solid) lines show the flux (left scale) and the blue (dashed) lines the SNR (right scale). See Bailer-Jones (2002).

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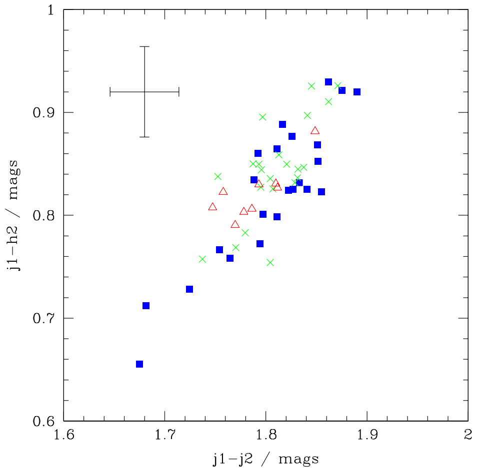

Figure 7. Colour correlated variability in 2M1145 (see Fig. 6). The bands are defined in Fig. 5.

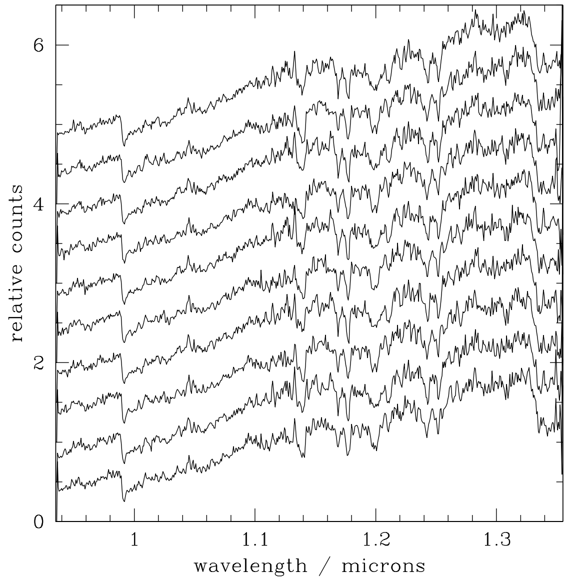

Figure 8. A sequence of ten relative spectra (from a total of 60) for the L2V target SSSPM J0828-1309. Time increases from bottom to top in steps of about four minutes and each relative spectrum has been offset from the previous by 0.5. One can see variability at various places, e.g. around the NaI doublet at 1.138μm and 1.141μm (which coincides with a water band) and the KI doublet at 1.168μm and 1.177μm.