

OBSERVATION OF R-BAND VARIABILITY OF L DWARFS

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ABSTRACT

We report, for the first time, photometric variability of L dwarfs in R band. Out of three L1 dwarfs (2MASS 1300+19, 2MASS 1439+19, and 2MASS 1658+70) observed, we have detected R band variability in 2MASS 1300+19 and 2MASS 1439+19. The objects exhibit variability of amplitude ranging from 0.01 mag to 0.02 mag. Object 2MASS 1658+70, turns out to be non-variable in both R and I band. However, more observations are needed to infer its variability. No periodic behaviour in the variability is found from the two L1 dwarfs that are variable. All the three L1 dwarfs have either negligible or no H_α activity. In the absence of any direct evidence for the presence of sufficiently strong magnetic field, the detection of polarization at the optical favors the presence of dust in the atmosphere of L dwarfs. We suggest that the observed R band photometric variability is most likely due to atmospheric dust activity.

Subject headings: stars:atmosphere — stars: low-mass, brown dwarfs

1. INTRODUCTION

L dwarfs are ultra-cool objects with effective temperature ranging between 2200 K and 1400K. They are characterized by the presence of condensates in their atmosphere. Due to incomplete gravitational settling, dust in the atmosphere of L dwarfs could be detectable in the optical. Dust cloud can play a potential role in making the object variable. Time-resolved photometric variability of a large number of L dwarfs has been reported by Bailer-Jones & Mundt (2001a,b), Martin, Osorio, & Lehto (2001), Gelino et al. (2002), Clarke, Oppenheimer

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& Tinney (2002a), Osorio, Caballero, Bejar & Rebolo (2003), Bailer-Jones & Lamm (2003). However, all these observations were made in the I and J bands. Clarke, Tinney & Covey (2002b) reported variability from ultra-cool dwarfs by using a non-standard filter with the effective wavelength similar to that of I band. Enoch, Brown & Burgasser (2003) reported evidence of variability in K_s band from a few L and T dwarfs. These investigations provide much insight on the atmospheric activities, especially the presence of dust clouds.

Sengupta & Krishan (2001) argued that the presence of dust could give rise to a detectable amount of linear polarization in the optical from L dwarfs. This was observationally verified by Menard, Delfosse & Monin (2002) who detected non-zero linear polarization at red ($0.768 \mu\text{m}$) from a few L dwarfs. In the absence of any direct evidence of sufficiently strong magnetic field, observation of linear polarization strongly favours the presence of dust in the atmosphere of L dwarfs and single dust scattering model could explain the observed polarization (Sengupta 2003). It should also be mentioned here that rigorous theoretical analysis (see Burrows et al. 2001 and references therein; Tsuji et al. 2004) of the continuum spectra implies the presence of dust in the visible region of L dwarfs.

Detection of non-zero polarization at the optical band that may arise from dust scattering urges the necessity of investigating R band variability by dust activity in L dwarfs. In the present letter we, for the first time, report differential photometric variability in R band from a few L dwarfs. The results could be a good complement to the polarization observations as dust clouds play a crucial role in both cases. A detailed theoretical investigation on polarization by single dust scattering of L dwarfs with fixed rotational velocity (Sengupta & Kwok 2004) shows that the degree of linear polarization peaks at L1 spectral type. This motivates us to concentrate on the observation of L1 dwarfs. We have detected photometric variability from two L1 dwarfs. In the next section we describe the observation and data reduction procedure followed. The results are presented and discussed in section 3 followed by conclusions.

2. OBSERVATION AND DATA REDUCTION

The photometric observations of selected L dwarfs were carried out during 2004 January – June using the 2-m Himalayan Chandra Telescope (HCT) of the Indian Astronomical Observatory (IAO) at Hanle, India, using the Himalaya Faint Object Spectrograph Camera (HFOSC), equipped with a SITe 2×4 K pixel CCD. The central 2×2 K region used for imaging corresponds to a field of view of $10 \text{ arcmin} \times 10 \text{ arcmin}$ at $0.296 \text{ arcsec pixel}^{-1}$. More details on the telescope and the instrument may be obtained from <http://www.iap.res.in/~iao>.

We selected the targets from published spectroscopically determined L dwarfs, specifically selecting those objects that have negligible or no H_α effective line-width. This avoids the contribution of H_α line variability to the atmospheric variability in the R band and hence any variability observed could be attributed more convincingly, to the presence of dust clouds. Table 1 presents the name, position, and the R and I magnitudes of those objects.

Several exposures with times of 10 minutes and 5 minutes were obtained in the R and I bands respectively. The central wavelengths of the R band filter and the I band filter used are 0.6 and 0.805 micron respectively. To minimize the effect of improper flat fielding and any systematic error spatially associated with the chip, we tried to confine the L dwarf to a particular CCD pixel in all the frames. The observations were carried out during dark moon period, and uninterrupted observations of a single object were obtained over 3 to 7 hours during different nights. The full width at half maximum (FWHM) of the stellar profile was found to be about 1.5 to 1.8 arc-seconds. The observing log is given in the Table 2. The basic image processing such as bias subtraction and flat fielding were done in the standard manner using the various tasks available within IRAF. Atmospheric extinction and transformation coefficients were obtained from observation of photometric standard stars (Landolt 1992). The I frames were affected by CCD fringing due to night sky emission lines. Fringe correction was applied to all the I frames using a master fringe frame created by observing several blank night sky fields.

The stellar magnitudes at varying apertures were then obtained using the IRAF task *phot*. Since accurate sky background estimation is very crucial to faint object photometry, the sky value was iteratively estimated by examining the growth curves of isolated stars so that the growth curves were neither monotonically decreasing (underestimated sky) nor increasing (overestimated sky). Furthermore, the magnitudes of L dwarfs and faint stars were first determined at the aperture having highest S/N and then aperture correction was made to the aperture size $4 \times FWHM$ using the correction term obtained from bright isolated stars. The standard R and I magnitudes of L dwarfs and the field stars were determined using system transformation coefficients.

Differential photometry was performed following the ensemble photometry technique (Gilliland & Brown 1988; Everett & Howell 2001). From the average flux of the few fairly bright stars we determined the ensemble reference magnitude, iteratively rejecting stars that were found to have either a systematic variation or large errors. The differential magnitude of L dwarfs with respect to the ensemble magnitude was then computed using the relation

$$\Delta m_{i,b} = \bar{m} - m_{i,b}, \quad (1)$$

where \bar{m} is the ensemble magnitude and $m_{i,b}$ is the magnitude of L dwarfs.

While analyzing the differential photometric data of L dwarfs, a linear variation with respect to airmass was noticed. This trend appears to be an effect of the second order extinction coefficient. The spectral type of the observed ultra-cool dwarfs were L1 whereas our ensemble references were found to be near spectral type G. Therefore, within our observing band they would have very different effective wavelengths. In order to check how severe the second order extinction effect would be, we first determined the effective wavelengths of the L dwarfs and G type reference stars using equation:

$$\lambda_{eff} = \frac{\int \lambda F_{\lambda} S_{\lambda} d\lambda}{\int F_{\lambda} S_{\lambda} d\lambda} \quad (2)$$

where F_{λ} is spectral energy distribution and S_{λ} is system response. The L dwarf and reference star spectra were retrieved from digital spectral libraries (Martin, Delfosse & Basri 1999; Le Borgne et al. 2003). The computed effective wavelengths for L dwarf and G type star are 6308 Å and 7148 Å respectively. The average spectroscopic extinction at IAO are 0.081 *mag* and 0.04 *mag* at these two wavelengths. The difference of these two extinction values is nothing but the second order extinction correction at the unit airmass i.e. $k''_R \Delta(R - I)$. The observed color difference ($R - I$) of L dwarf and G type reference star was found to be 2.1 *mag* and that predicts $k''_R \approx -0.02$ *mag*. The second order extinction coefficient was independently estimated using the observations of the photometric standards and found to be $k''_R \approx -0.02$, similar to the above estimation. The second order extinction correction was made to each observed L dwarf data using the relation

$$(\Delta m_{i,b})_o = \Delta m_{i,b} - k''_R \Delta(R - I) X_i \quad (3)$$

where X_i is airmass of the frames.

3. RESULTS AND DISCUSSIONS

The light curves of the three L1 dwarfs observed are presented in figure 1 and in figure 2. Figure 1 shows the light curves of 2MASS 1300+19 and 2MASS 1439+19 in *R* band, while figure 2 shows the light curves of 2MASS 1658+70 in both *R* and *I* bands. The light curves in *R* band for all the three objects indicate a possible variability.

In order to verify any variability, we employ the procedure given by Martin et al. (2001). In figure 3a-e, we show the standard deviation, σ_R with respect to the standard *R* magnitudes of all the field stars for different fields at different nights along with that for the three targets. Figure 3a-d show that although the programme stars 2MASS 1300+19 and 2MASS 1439+19 lie at the variable side of the σ_R vs the *R* magnitude diagram, no overwhelming evidence for

variability in any of the two objects is found. On the other hand Figure 3e shows that the programme object 2MASS 1658+70 lies at the non-variable side of the diagram for 19 May implying no variability in R band. A similar inference can be made from the other observing nights for R band as well as for the I-band observation of the same object.

From figure 3a-e, we notice that for the same field there are very less variation of systematic error at different nights. Also, for different fields the relation between σ_R with standard R magnitudes and its 1σ scatter do not change significantly. In order to have objects well distributed across the entire magnitude range we combine the different fields. This should provide a statistically more reliable result for the σ_R vs R magnitude relationship. The result with combined fields is presented in figure 3f. For this case, the relation between σ_R vs standard R magnitudes can be written as

$$\sigma_R = 0.712139 - 0.0854801 R + 0.00256972 R^2 \quad (4)$$

with a scatter of 0.004 (1σ). However, the results do not differ from that obtained by using the individual fields. The objects 2MASS 1300+19 and 2MASS 1439+19 are found to be nearly 2σ and 1σ away from the mean relation respectively.

On the other hand, if we determine the systematic error from the relation between σ_R vs standard R magnitude and consider its large 1σ error as well, the systematic error becomes about double the photometric error which is calculated using ensemble references and program star photometric errors. Even if we add the scatter due to color effect, such a large error is not expected. However, if we discard the objects that are fairly out of fit in figure 3(f) as well as having systematic trend in their light curve and consider rest of the field objects instead, the scatter of distribution of error reduces to 0.002 (1σ). Consequently, the objects 2MASS 1300+19 and 2MASS 1439+19 are found to be situated at about 5σ and 3σ away from the mean relation respectively. Therefore, our analysis implies variability of 2MASS 1300+19 and 2MASS 1439+19 in R band.

The statistical significance of the observed variability is also checked by computing the χ^2 by using the formula:

$$\chi^2 = \sum_{i=1}^n \left(\frac{\overline{\Delta m_b} - \Delta m_{i,b}}{\sigma_{i,b}} \right)^2 \quad (5)$$

where n is the number of observed data points and $\sigma_{i,b}$ is the error associated with the L dwarfs at their respective magnitudes, as obtained from the standard deviation versus standard magnitudes relation given by equation (4). However, it is worth mentioning that the ratio between the variance of L dwarf data and the variance read from the fitted curve may not have a χ^2 distribution and hence it should be considered as an assumption. Table 2

gives the results for each object for individual nights of observation, the number of good frames taken for final analysis, number of references taken to make the mean standard, the standard deviation of the points from the mean level (σ_{rms}), the average σ_{rms} used for χ^2 test and the probability that the L dwarf is variable (p). The L dwarfs 2MASS 1439+19 and 2MASS 1300+19 indicate variability with about 99% probability for all the observed nights. Note that $\sigma_{i,b}$ are calculated from the σ_R vs R magnitude relation by considering all the field stars including those that show systematic trend in their light curve.

A period analysis program based on the widely used Scargle formalism (Scargle 1982) was used to search for any periodicity in our time series photometric data. However, we have not obtained any significant periodicity in the variations from either L dwarfs.

The third object, 2MASS 1658+70, does not show any variability both in R and I bands. However an inspection of the light curves (see figure 2) of the 20th of May and the 16th of June although look like scatter plot, there is a systematic trend in the light curves of the 19th and the 21st May 2004 suggesting a possibility of variation. Further, Gelino et al (2002) reported this object to be variable in I band. It is therefore possible that the variability in this object is transient due to the dust-active variation. More observations with improved temporal coverage are required to establish the variable nature of 2MASS 1658+70.

4. CONCLUSIONS

R band differential photometry of three L1 dwarfs 2MASS 1300+19, 2MASS 1439+19, and 2MASS 1658+70 are presented here. The first two objects show variability. However, no periodicity in the variation is obtained in any of these objects. The light curves indicate transient activity of short time scale. Since rotationally related variability should show rather smooth light curves, any co-relation with the rotation of the objects is unlikely. The third object, 2MASS 1658+70, which was also observed in the I band does not show any variability either in the R or in the I band although it was reported to be a variable in the I band by Gelino et al. (2002). The light curves of this object presented here, however, provide an indication of possible flux variation. More observations of this object are required before its variable nature can be established.

The observation of linear polarization in the red by Menard, Delfosse & Monin (2002) favours the presence of dust cloud in the atmosphere of L dwarfs. The synthetic spectra of L dwarfs also favours the presence of dust in the atmosphere. We propose that the photometric variability in the R band reported here arises due to the dust activity in the atmosphere.

On the other hand, if the variability observed is due to the dust activity, then we predict

non-zero polarization from L1 dwarfs at R band by dust scattering. However, photospheric variability, if caused by dust cloud, needs sufficiently optically thick dust layer. In an optically thick medium, polarization would arise by multiple scattering of photons. It is known that multiple scattering reduces the degree of polarization as compared to that by single scattering mechanism (Sengupta 2001, 2003). Hence, a variable L dwarf should show less amount of polarization as compared to that of non-variable or weakly variable objects which might have optically thin dust layer.

Further observations of L dwarfs of different spectral types and in both *R* and *I* bands could tell if there is any co-relation in the variability at *R* and *I* bands with the spectral type, which in turn could provide significant insight on the distribution of dust in the atmosphere of L dwarfs.

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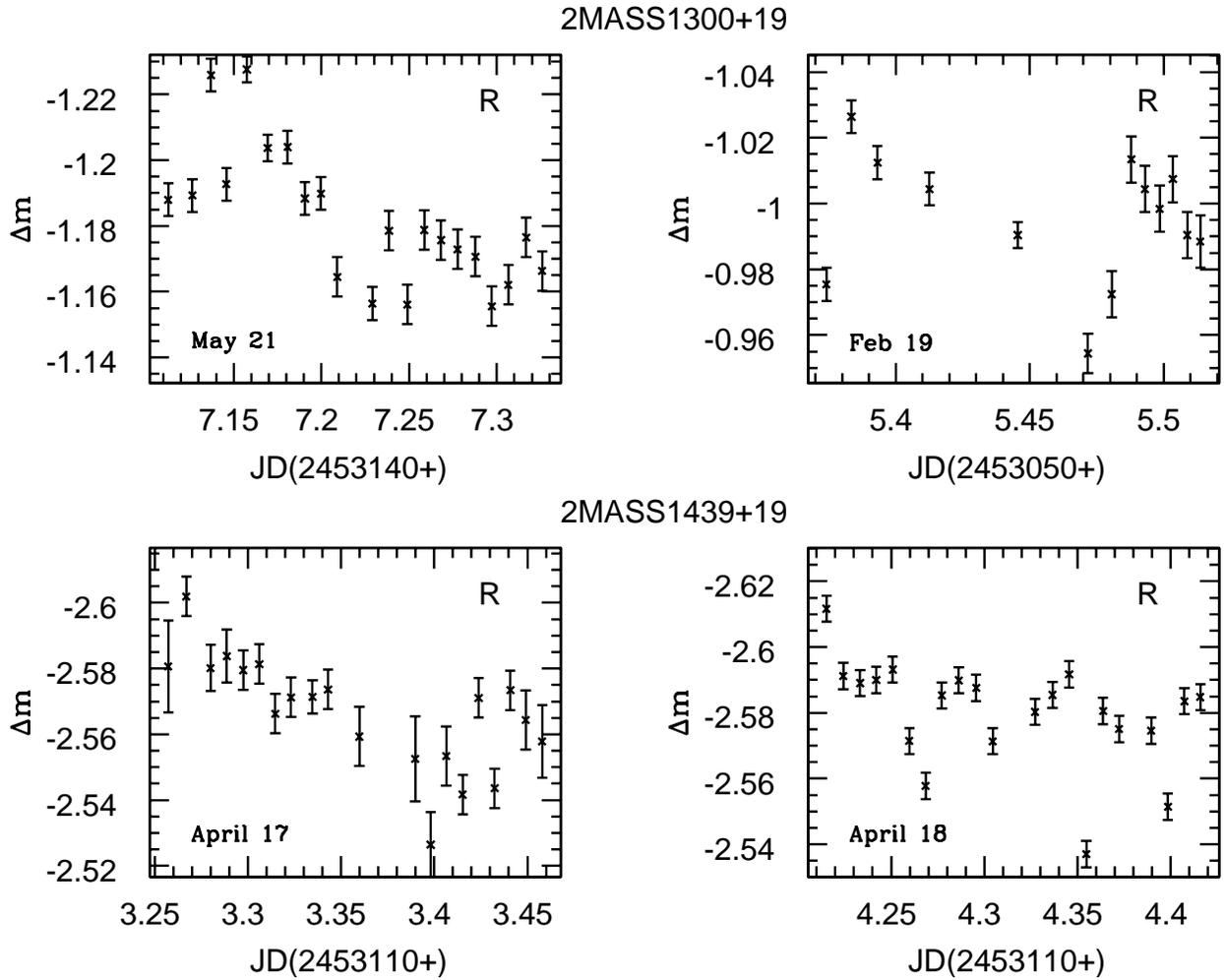


Fig. 1.— The *R* band light curves of L1 dwarfs 2MASS1300+19 (top) and 2MASS1439+19 (bottom) obtained on different nights.

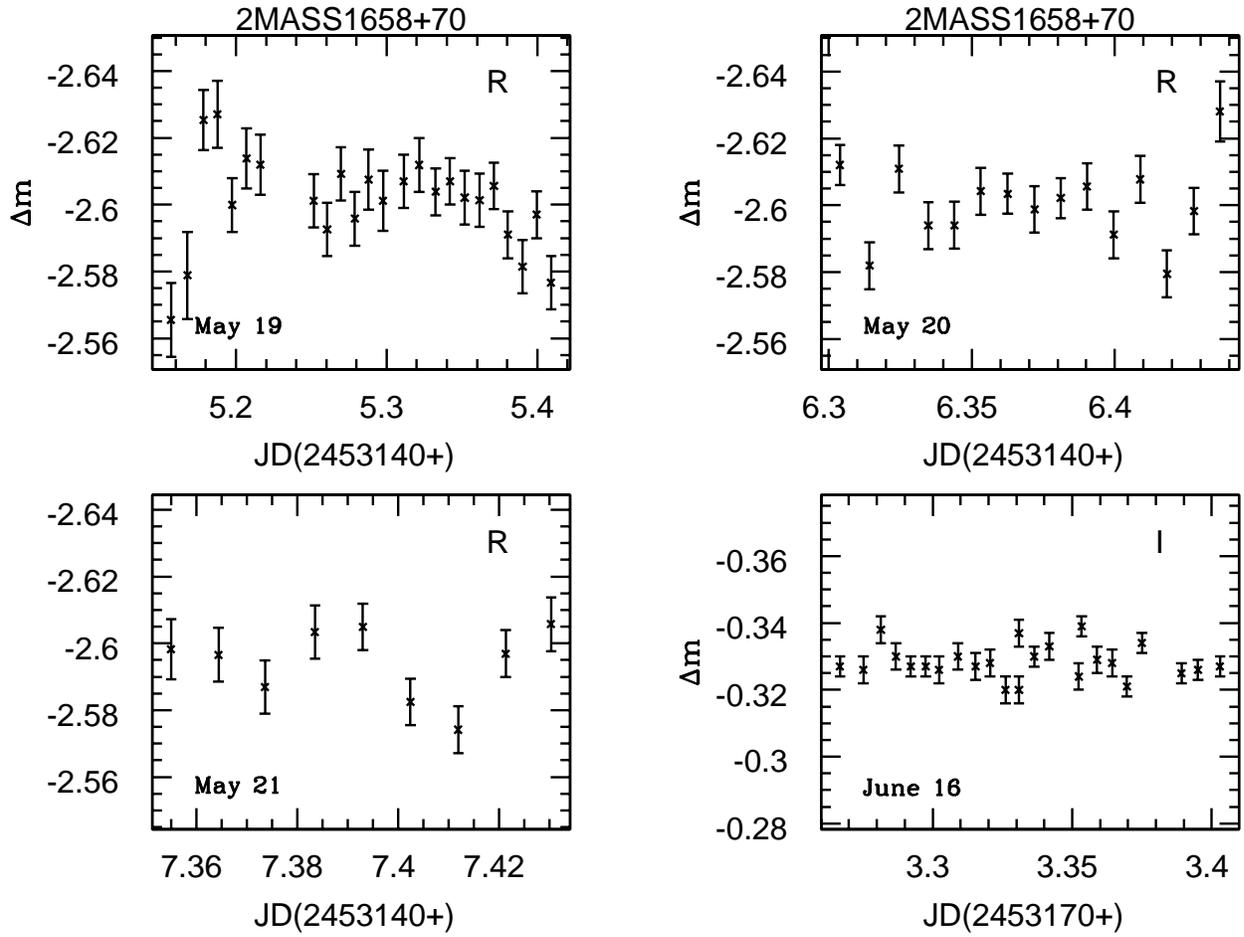


Fig. 2.— The *R* and *I* band light curves of the L1 dwarf 2MASS1658+70 obtained on different nights.

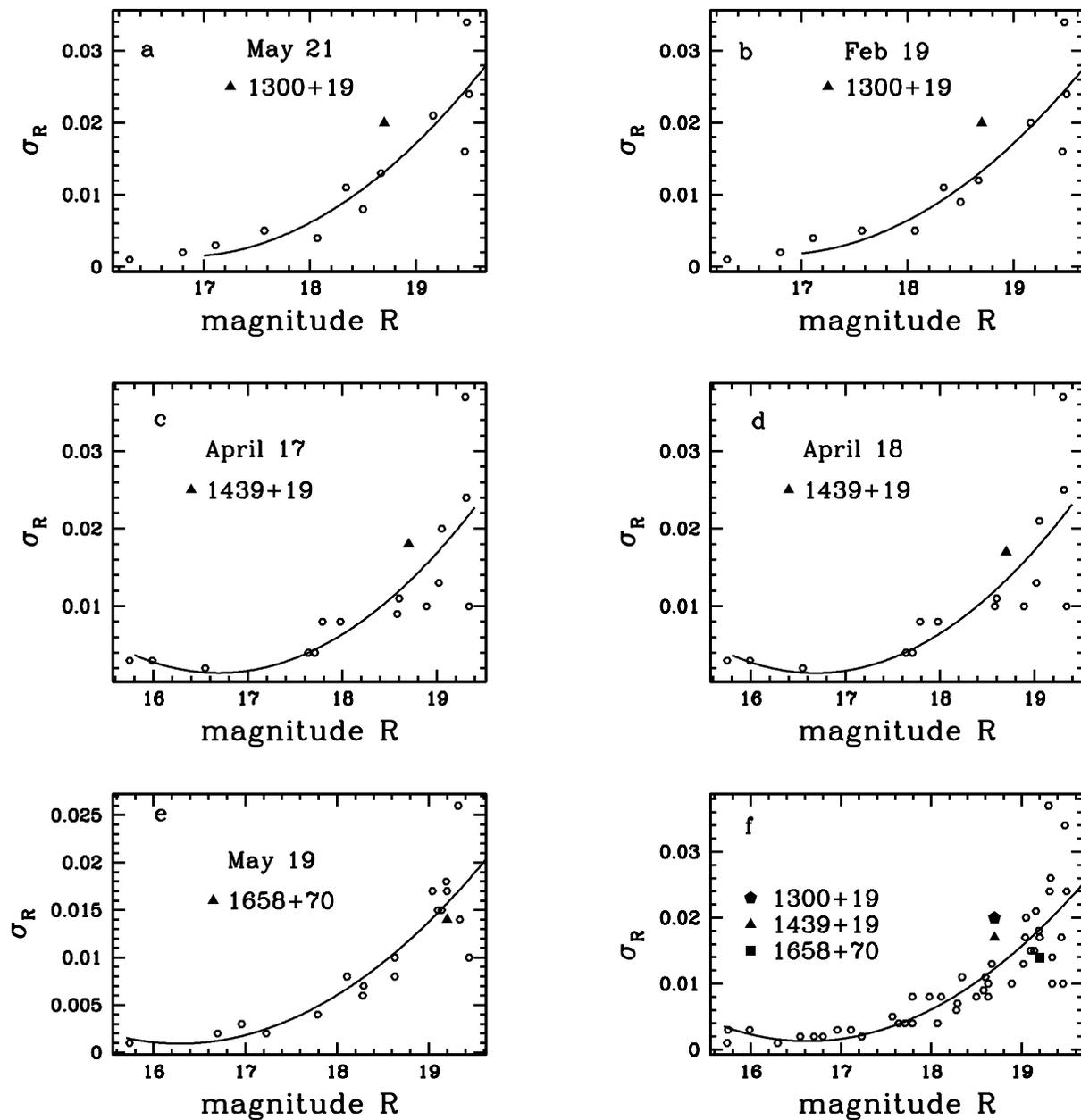


Fig. 3.— Standard deviation (σ_R) versus R band magnitudes for the field stars for three different fields for individual nights. A second-order polynomial fit to the σ_R is shown as a continuous curve. The σ_{rms} on each night for all the three L1 dwarfs are also shown as filled symbols. The result with combined data of May21, April 17 and May 19 is given in plot f.

Table 1: BASIC DATA OF VARIABLE L1 DWARFS.

Name	RA(2000)	DEC(2000)	<i>R mag</i>	<i>I mag</i>	H_α Emission
2MASS 1300+19	13 00 42.5	+19 12 35	18.7	16.0	...
2MASS 1439+19	14 39 28.4	+19 29 15	18.7	16.0	< 0.03
2MASS 1658+70	16 58 03.7	+70 27 01	19.2	16.6	...

Table 2: Observing log and results

Name	Dates	Frames (Used/Total)	Ref. stars	Filter	σ_{rms} ^a of L dwarfs	σ_{rms} ^b used in χ^2	p(%)
2MASS1300+19	19/02/04	13/15	5	R	0.019	0.012	>99.0
2MASS1300+19	21/05/04	21/24	5	R	0.020	0.012	>99.0
2MASS1439+19	17/04/04	20/24	5	R	0.017	0.012	>99.0
2MASS1439+19	18/04/04	21/24	5	R	0.016	0.012	>98.5
2MASS1658+70	19/05/04	24/25	5	R	0.014	0.018	10.1
2MASS1658+70	20/05/04	15/15	5	R	0.012	0.018	4.5
2MASS1658+70	21/05/04	9/9	5	R	0.011	0.018	6.1
2MASS1658+70	16/06/04	24/24	3	I	0.005	0.007	3.1

^a σ_{rms} about the mean differential magnitude of the L dwarf.

^b σ_{rms} used in χ^2 test, obtained from standard deviation (σ_R) vs. standard R magnitudes relation.