Imaging Polarimetry of Cool Atmospheres: 2MASS J02411151-0326587

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Abstract:

Our recent polarimetric photometry of several field, L-type, brown dwarfs suspected to be young (<300 Myr) yielded one object, 2MASS J02411151-0326587 (L0), with a high degree of linear polarization in the J band (Zapatero-Osorio et al. 2011). Here, we present new imaging polarimetry observations of this target taken with the LIRIS instrument at the 4.2-m William Herschel Telescope (WHT) on La Palma island (Spain). We find that the degree of linear polarization has changed. Different scenarios will be discussed to account for the previous and new polarimetric data.

Introduction, Observations & Methodology:

Some field brown dwarfs, suspected to be young, show near and mid-infrared excesses that cannot be explained by simple models (Marley et al. 2010). Many scenarios have been proposed to try to explain this feature such as low gravity (Cruz et al. 2009), excess metallicity, the presence of unusual condensate properties in their atmospheres, and/or the presence of a warm dusty disk/envelope (see Zapatero Osorio et al. 2011, Z2011). Polarimetric measurements have the potential to shed light on many fundamental processes in ultra-cool atmospheres, which are hardly constrained by other observing modes (Goldman et al. 2009).

To discern the best explanation for the reddish nature of some of these young field brown dwarfs, our group obtained polarimetric photometry using LIRIS (Manchado et al. 2004) on the WHT (Z2011). We found that one L0-type dwarf, 2MASS J02411151-0326587 (J0241-0326) had significant linear polarization in the *J*-band (1.2 μm). Here, we report new polarimetric observations taken with the same instrumental configuration as in Z2011 on two different occasions during the last few months of 2011. Data were acquired using two angles of the telescope rotator (0º and 90º) and a pattern of 9 dithers across the detector (for proper sky background subtraction).

The four images of J0241-0326 obtained through the LIRIS polarimetric optics (which includes two Wollaston prisms and an aperture mask of 4´ x 1´ in size) is illustrated in Figure 1.

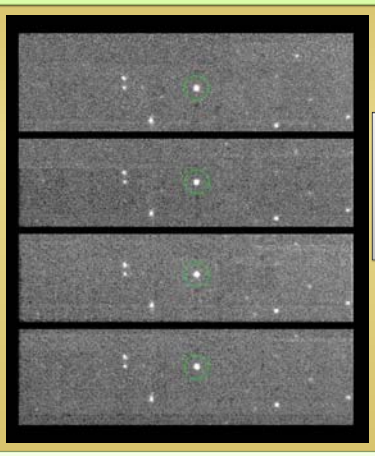
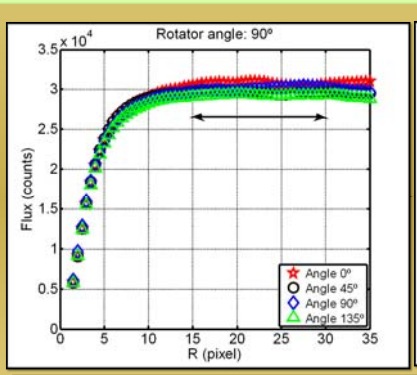


Figure 1. Polarimetric frame of J0241-0326 (object inside the green circle, East up, North on the right) using LIRIS on the WHT. The four polarimetric vectors are from top to bottom: 0º, 90º, 135º, and 45º. Each strip is 4´ x 1´ in size.



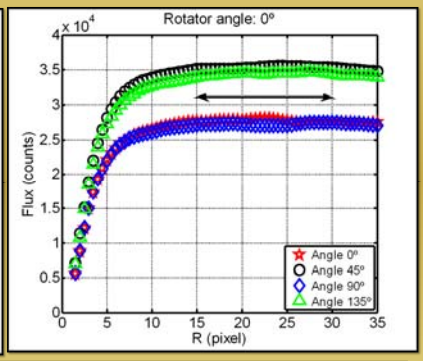


Figure 2. Flux radial profiles of J0241-0326 using the task PHOT within IRAF. The plots illustrates the target flux inside different apertures of radius *R* from the target photometric centroid. The arrow shows the interval of photometric apertures used to derive the mean target fluxes.

As we are interested in the degree of linear polarization we derived the normalized Stokes parameters, *q* and *u*, using the "flux ratio" method (Z2011, and references therein). The mathematical equations are as follows:

Flux Ratio Method: $$R_q^2 = \frac{i_{0,0}/i_{90,0}}{i_{0,90}/i_{90,90}} \quad , \quad R_u^2 = \frac{i_{45,0}/i_{135,0}}{i_{45,90}/i_{135,90}} \quad , \quad q = \frac{R_q - 1}{R_q + 1} \quad , u = \frac{R_u - 1}{R_u + 1} \qquad (1)$$

Polarization determination: $$P = \sqrt{(q - q_{ins})^2 + (u - u_{ins})^2} \quad , \quad \theta = 0.5 \tan^{-1}\left(\frac{u}{q}\right) - \theta_0 \qquad (2)$$

Where $i_{vector,rot}$ stands for the flux corresponding to a given polarization vector (0º, 45º, 90º, and 135º) observed at a particular position of the telescope rotator (0 or 90º), q_{ins} and u_{ins} stands for polarization induced by the telescope + instrument configuration, and θ_0 is the zero-point offset in the angle of the polarization vibration. These parameters are derived by observing polarized and non-polarized standard polarimetric stars, which were included in our observing campaigns.

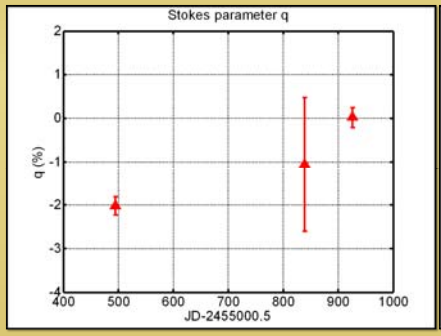
Preliminary Results:

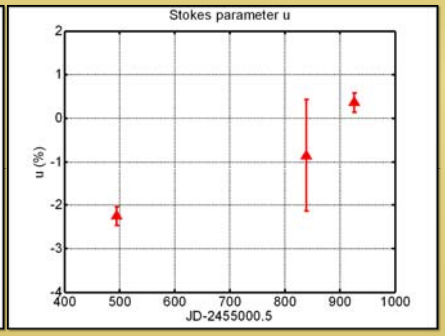
We obtained the mean fluxes for each Wollaston vector by measuring circular aperture photometry (apertures ranging from 3.5 to 6.5 times the FWHM of the data) with the tasks PHOT and IMEXAMINE within the IRAF environment. Typical radial profiles of the target flux counts are shown in Figure 2. In Table 1 we summarize our measurements, including observing date, the Stokes parameters, the polarization degree, the angle of the polarization vibration, and the FWHM of the data.

The Earth atmospheric conditions during the 2011 December observations were photometric. Transparency and seeing were poor during the 2011 October run, with cirrus hampering the observations. Our 2011 October polarimetric measurement thus has a large associated uncertainty.

The evolution of the Stokes parameters and the linear polarization degree of J0241-0326 is displayed in Figure 3. Based on our 3-sigma criterion to claim a detection of polarized light ($P/\sigma \geq 3$), J0241-0326 appears to be unpolarized in 2011 December, in contrast with the early observations of 2010 October by Z2011. Therefore, it appears that the polarization properties of this brown dwarf have changed with time.

There is an extended convergence to the picture that the atmospheres of L dwarfs are characterized by clouds, formed principally of silicate, oxide and iron grains. These clouds of grains can induce polarization but models predict that this polarization lies below 1%. Other mechanism that can produce a higher degree of polarization is the presence of dusty disks/envelopes. Polarimetric variability is expected in both scenarios. More polarimetric measurements are needed to constrain the actual origin of the polarization in J0241-0326.





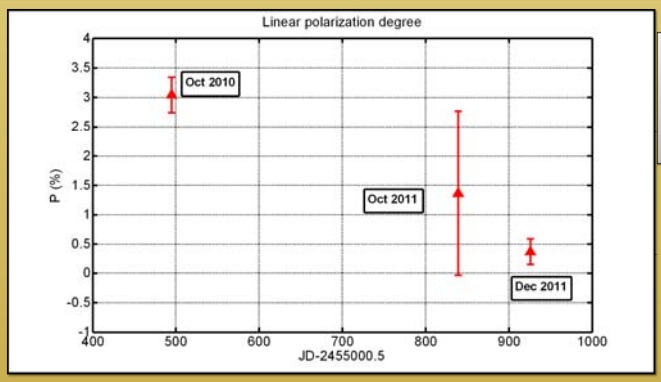


Figure 3. Evolution of the Stokes parameters *q*, *u* and the degree of linear polarization for the L0 brown dwarf J0241-0326.

Date	q (%)	u (%)	P (%)	θ (º)	FWHM (“)
2010 Oct 26	-2.03 ± 0.21	-2.26 ± 0.21	3.04 ± 0.30	110 ± 10	2.2
2011 Oct 5	-1.1 ± 1.5	-0.9 ± 1.3	1.3 ± 1.4	109 ± 29	1.0
2011 Dec 31	0.02 ± 0.23	0.36 ± 0.22	0.36 ± 0.22	---	1.1

Table 1. Results for J0241-0326 using the “Flux Ratio Method”

Future Work:

We will keep observing J0241-0326 in coming polarimetric campaigns with the WHT (near-infrared) and VLT (optical) telescopes. These observations may provide evidences to explain the causes of the observed polarimetric variability.

Also, we have an astrometric follow-up program for J0241-0326 and other brown dwarfs, suspected to be young, using the 3.5-m telescope on the Calar Alto Observatory (Almería, Spain), and the 2.5-m NOT on La Palma Island (Spain). Based on 5 epochs of observations conveniently distributed within a 2-yr time, we estimate a preliminary distance of ≥ 60 pc for J0241-0326, in agreement with Cruz et al. (2009) determination.

References:

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