STUDYING BROWN DWARF DUST CLOUD DISTRIBUTION THROUGH POLARISATION

E. González[1], B. Goldman[1, 2], M. R. Zapatero Osorio[3], V. J. Sánchez Bejar[4], T. Henning[5] and J. Pitann[6]

Abstract. Variations in the cloud cover of brown dwarfs have been detected through photometry monitoring and polarisation observations. This project aims at detecting the time dependence of the polarization for LHS102B, 2MASS J1507−16 and 2MASS J0036+18, which could be then explained by large-scale cloud coverage variations. We have obtained high SNR images with 16 retarder-plate angles using the VLT/FORS2 instrument and reduced the data using the method described in Patat & Romaniello (2006), achieving a level of precision of $\sim 0.04\%$. Our results give evidence of a variation in the polarisation degree in all three targets, and a significant correlation between the flux variability of 2MASS J1507 and the measured polarisation.

Keywords: Brown Dwarfs, Polarimetry, Atmospheres, LHS102B, 2MASS J1507−16, 2MASS J0036+18

1 Introduction

Brown dwarfs (BDs) are compact objects with masses between those of stars and planets. They are not massive enough to sustainably burn hydrogen, and eventually cool down due to the lack of an energy source. Cool BDs host low-temperature atmospheres, favouring molecules over single atoms, and dust grains. Those dust grains may form clouds in their atmosphere, leading to polarised light through scattering and flux variations if the cloud deck is heterogeneous.

Variations in the cloud cover of BDs have been detected through photometry monitoring and polarisation observations. This project aims at detecting the time dependence of the polarisation for 2MASS J00361617+1821104 (L3.5), LHS 102BC (L4.5), and 2MASS J15074769-1627386 (L5), which could be then explained by rotation and large-scale cloud coverage variations. Our sample, located close enough (within 12 pc) that there is no polarisation from interstellar dust, was previously observed in polarisation and showed convincing signs of polarisation variability.

Our goal is to extract new polarimetric information to better understand if the variation of the signal with time can be related to the rotation of the BD.

2 Observations and Data Reduction

Our data consists of unique observations obtained between Oct-2010 and Mar-2011, using FORS2 (ESO 2022), which is mounted on the Cassegrain focus of the 8.2-m ANTU telescope at the ESO VLT in Chile.

When used in the IPOL mode (Imaging POLarimetry), FORS2 works as dual-beam polarimeter. This means that the incident light beam (I) is split by a Wollaston prism (WP) into two perpendicular beams: the ordinary (fo,i) and extraordinary beams (fe,i). In this setup, a rotating half-wave retarder plate (HWP) placed before the WP, allows to measure the intensity of both beams at different angles (θ_i). FORS2 has a FoV of 6.8' x 6.8'

[1] International Space University (ISU), 1 rue Jean-Dominique Cassini, 67400 Illkirch-Graffenstaden, France
[2] Astronomical Observatory of Strasbourg, 11 rue de l'Université, 67000 Strasbourg, France
[3] Centro de Astrobiología (CSIC-INTA), Crta. Ajalvir km 4, 28850 Torrejón de Ardoz, Madrid, Spain
[4] Instituto de Astrofísica de Canarias (IAC), Calle Vía Láctea s/n, 38200 La Laguna, Tenerife, Spain
[5] Max Planck Institute for Astronomy, Königstuhl 17, 69117 Heidelberg, Germany
[6] Space Operations and Astronaut Training (DLR), 82234 Wessling, Germany

imaged into two identical CCD detectors, with a pixel size of 0.25 arcsec with the standard binning of 2x2. For each target, we obtained 16 observations with a different θ_i (step=22.5°), in the I band. The 16-angle set allows to obtain the highest accuracy and to minimise and understand the noise sources (Patat & Romaniello 2006).

We applied the standard calibration process using the associated flat and bias frames, for each night. The photometry phase consists of measuring the flux for both the ordinary and extraordinary beams using aperture photometry. Our analysis shows that the polarisation results are not significantly dependent on the chosen aperture radius. Depending on the observation conditions we selected 4 to 6 pixels (1" to 1".5). Regarding the polarimetry analysis, we followed the steps and formulae presented in Patat & Romaniello (2006).

Uncertainties were estimated at every single step within the process and propagated accordingly. Moreover, we performed the Fourier analysis suggested in Patat & Romaniello (2006) to assess our error results, which can be estimated with the signal included in the harmonics with k= 3, 5-8. The estimated uncertainties were consistent with the systematics obtained through the harmonics power spectrum.

The whole data reduction steps were implemented through an original pipeline developed in Python specifically for this research project, based on the *astropy*, *photutils*, and *ccdproc* packages.

3 Results

We report our measurements in Figs. 1- 3. 2MASS J0036 shows a variation on the polarisation over the three nights (Fig. 1), reaching a significant degree of polarisation (DOP) of (0.26±0.08)% at the end of the first night. In the case of LHS 102BC (Fig. 2), our results also show variations on the polarisation measurements but in this case the highest DOP were obtained in the first two nights (0.18±0.07; 0.15±0.07)%. As to 2MASS J1507 (Fig. 3), the variation in the polarisation shows a peak by the end of the night, with a DOP of (0.25±0.05)%.

In addition, for 2MASS J1507 we performed a variability analysis. Atmospheric models predict that cloud patches that could lead to polarisation would also lead to flux variability. We normalized the sum of the ordinary and extraordinary beam fluxes by the average flux of its reference stars, and compare it with our polarimetry results (Fig. 3). Our results show no significant correlation between the DOP and the flux: r=-0.15 (p-value=0.74).

Furthermore, we compared the results of 2MASS J0036 against other polarisation measurements. The amplitude of variations that we tentatively detected matches with previous observations: (0.199 ±0.028)% in 12/2001 (Ménard et al. 2002) vs. (0.077 ±0.029)% in 08/2005 (Goldman et al. 2009).

In addition, for the same target we looked for photometric variability in the literature, with the intention of understanding the relation between photometry and polarisation variations. Photometric variability has been reported in I band (Croll et al. 2021) as well as radio emission (Berger et al. 2005) but the ∼3h period couldn't be confirmed in our polarimetry observations, as the polarisation peak detected at MJD-5494=0.23d is not observed 3h before, due to a lack of data.

We note that Vos et al. (2017) determined the inclination of 2MASS J0036 and 2MASS J1507 at 51±9deg and 23±2deg resp. A lower inclination, together with a higher rotational velocity, increases the effect of the flattening on the DOP.

4 Conclusions

We tentatively observed a variation of the polarisation degree in all three targets. Yet, we detected significant polarisation measurements in only ≈ 15% of the data points obtained and even then the polarisation significance is low. For 2MASS J1507 we compared the polarisation results with the flux variability and found no correlation.

Over the past decade, there has been a dramatic improvement in the sensitivity of photometric monitoring of BDs and in the understanding of their cloud structure thanks to photometric variability studies (Luna & Morley 2021). Polarimetric measurements of high quality like ours and others (Millar-Blanchaer et al. 2020) provide us with an additional set of constraints related specifically to the dust distribution.

Our analysis puts strong constraints on the level of polarisation in L-type BDs over time and illustrates the difficulty to detect it. However, the degeneracies that affect the polarisation signal can be partly lifted thanks to those independent photometric measurements (Vos et al. 2017), which paves the way for a more accurate interpretation of polarimetric observations of brown dwarfs.

This research is based on observations collected at the European Organisation for Astronomical Research in the Southern Hemisphere under ESO programme 086.C-0812(A/C/D/F), and has made use of the SIMBAD database and VizieR catalogue access tool, both operated and maintained at the CDS, Strasbourg, France.

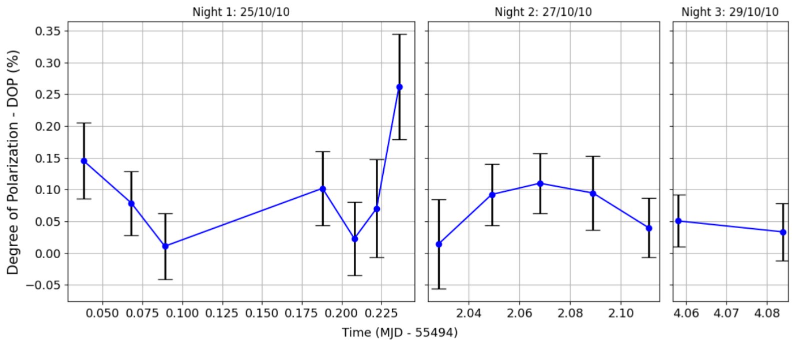

Fig. 1. Polarimetry results for 2MASS J0036

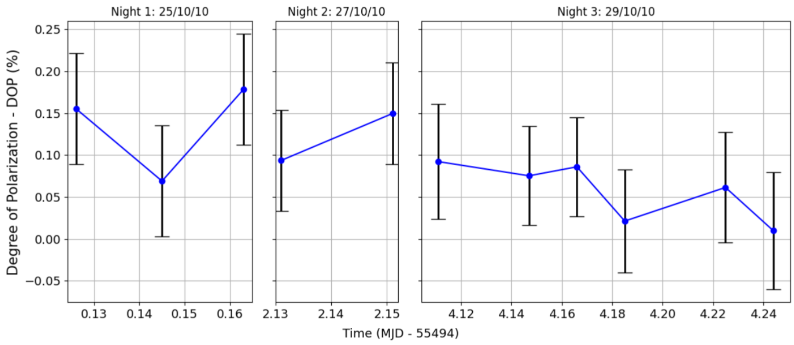

Fig. 2. Polarimetry results for LHS 102BC

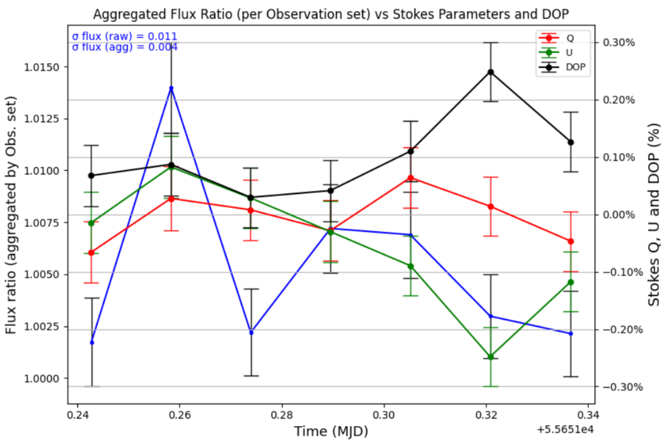

Fig. 3. Polarimetry results for 2MASS J1507 along with flux variability

References

Berger et al. 2005, ApJ, 627, 960

Croll et al. 2021, arXiv preprint arXiv:1609.03586

ESO. 2022, FORS2 FOcal Reducer/low dispersion Spectrograph 2, `https://www.eso.org/sci/facilities/paranal/instruments/fors/overview.html`

Goldman et al. 2009, A&A, 502(3), 929:936

Luna, J. & Morley, C. 2021, ApJ, 920(2), 146

Millar-Blanchaer et al. 2020, ApJ, 894, 42

Ménard et al. 2002, A&A, 396(3), L35:L38

Patat, F. & Romaniello, M. 2006, PASP, 118(839), 146

Vos et al. 2017, ApJ, 842, 78