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Confirming the magnetic field detection at the surface of χ Cyg.

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ABSTRACT

We present spectropolarimetric observations of χ Cygni obtained with Neo-Narval at *Télescope Bernard Lyot* in 2025. We obtained observations across three epochs (2025 Jul, Aug, and Oct) near maximum light to search for magnetic field signatures at the stellar photosphere. We detected a clear circular polarization signal in the 2025 Aug observations (pulsation phases 0.99 to 0.01). We measure a mean longitudinal magnetic field of $B_l = 3.4 \pm 0.6$ G. No detections were obtained for the 2025 Jul and Oct epochs. The pulsation-phase dependence suggests that field detection is tied to specific shock conditions near maximum light.

Keywords: Stellar atmospheres (1584) —

1. INTRODUCTION

The star χ Cygni is a bright AGB variable with a pulsation period of ~ 408 days (N. N. Samus' et al. 2017) and a magnitude peak-to-peak amplitude range of 3.3–14.2 (N. N. Samus' et al. 2017). This large pulsation amplitude is also present in the radial velocity curves, and is associated to strong radiative shocks. A. Lèbre et al. (2014) reported the first detection of a magnetic field in a Mira star. They observed χ Cyg near its maximum light in 2012 (around pulsation phase $\phi = 0.96$) using the Narval optical spectropolarimeter mounted at *Télescope Bernard Lyot* (TBL) in the French Pyrenees. Using the Least Squares Deconvolution (LSD) technique (J.-F. Donati et al. 1997; O. Kochukhov et al. 2010), they detected a weak circular polarization (Stokes V) signature with an amplitude of 2×10^{-5} of the intensity continuum. This signature, only present on the blue side of the blue component of the intensity line, corresponds to a longitudinal magnetic field of 2–3 G at the photospheric level, which they attributed to shock amplification of an underlying stellar magnetic field.

This detection is the only detection of a photospheric magnetic field in a Mira star to date, despite a decade

of monitoring of around ten Mira stars at TBL. In stark contrast, magnetic fields in the circumstellar envelopes of AGB stars are routinely detected through polarization observations of radio masers. SiO maser polarimetry has revealed magnetic fields of several Gauss in the inner circumstellar envelope at a few stellar radii (F. Herpin et al. 2006; L. Marinho et al. 2024), while H₂O and OH masers trace fields extending to hundreds and thousands of stellar radii, respectively (W. H. T. Vlemmings et al. 2006). This discrepancy between the scarcity of spectropolarimetric detections at the photospheric level and the relatively large number of maser-derived magnetic fields challenges our understanding of AGB stars' magnetism.

Here we report new spectropolarimetric observations of χ Cyg obtained with Neo-Narval at TBL in 2025. Following the same data analysis process as described by (A. Lèbre et al. 2014), we also detect a magnetic field at the surface of χ Cyg near maximum light with similar amplitude.

2. DATA AND METHODS

Our observations were acquired in three epochs in 2025 Jul, Aug, and Oct. For each epoch, we observed the star multiple times over several nights. Individual observations were taken with exposure times of 4×19 s. We obtained 177 exposures between 2025 Jul 17–18

(totalling 3.7 hours of integration time), 240 exposures between 2025 Aug 08–16 (5.1 hours), and 131 exposures between 2025 Oct 16–26 (2.8 hours).

Neo-Narval is an echelle spectropolarimeter covering the optical range between 380 – 1050 nm at $R \approx 65000$. Details about Neo-Narval and its data reduction are laid out in A. López Ariste et al. (2022). Reduced data are made publicly available after a 1-year proprietary period in the PolarBase⁵ archive. The data are immediately available at this Zenodo record⁶ (A. Lavail 2025) with other scripts and data (pre-processing scripts, LSD line list, LSD profiles) to reproduce this work.

First, we co-added all individual spectra for each epoch to obtain very-high SNR Stokes I (intensity), V (circular polarization), and N (null polarization) spectra. We then applied the Least Squares Deconvolution (LSD) technique (J.-F. Donati et al. 1997; O. Kochukhov et al. 2010) to the co-added spectra. LSD is a multiline technique that combines information from thousands of spectral lines to produce mean line profiles with significantly enhanced signal-to-noise ratio. The LSD profiles were computed using a line mask appropriate for a star with effective temperature of 3500 K and surface gravity of $\log(g) = 0.5$. We extracted the line list from VALD3 (T. Ryabchikova et al. 2015), kept spectral lines deeper than 20% of the continuum with known Landé factor (g_{eff}). We ended up with a list of 12447 spectral lines, with a mean wavelength of 4888.5 Å, mean g_{eff} of 1.2, and mean depth of 0.59. Our LSD Stokes IVN profiles for Jul, Aug, and Oct are shown in Fig. 1. Our LSD implementation follows (O. Kochukhov et al. 2010).

3. RESULTS AND CONCLUSIONS

We obtain a clear magnetic field detection for 2025 Aug, but no detection for Jul and Oct. Our Jul exposures were taken at pulsation phases ϕ 0.93 – 0.94, Aug exposures at ϕ 0.99 – 0.01, and the Oct exposures at ϕ 0.16 – 0.19.

We measure a mean longitudinal magnetic field $B_l = 3.4 \pm 0.6$ G slightly higher than the 2–3 G reported by (A. Lèbre et al. 2014). This second magnetic field detection at the surface of χ Cyg gives confidence that there is a magnetic field present at peak luminosity and can help inform models of magnetic field formation and amplification on Mira stars, particularly in conjunction with shocks.

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AUTHOR CONTRIBUTIONS

ALa wrote the observing proposal, led the data analysis and the writing of the manuscript. ALAr worked on the instrumentation, data reduction, and participated in the data interpretation. QPe wrote the observing proposal and participated in the data interpretation. PMA planned the observations and participated in the data interpretation. FHe coordinates joint radio observations and helped data interpretation. ALè led the first study of χ Cyg, planned observations, and helped with data interpretation. All co-authors edited the manuscript.

Facilities: TBL(Neo-Narval)

Software: NumPy (C. R. Harris et al. 2020), Matplotlib (J. D. Hunter 2007), astropy (Astropy Collaboration et al. 2013, 2018, 2022), gnu-parallel (O. Tange 2018), SciPy (P. Virtanen et al. 2020)

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⁵ <https://www.polarbase.ovgso.fr/>

⁶ <https://doi.org/10.5281/zenodo.17665025>

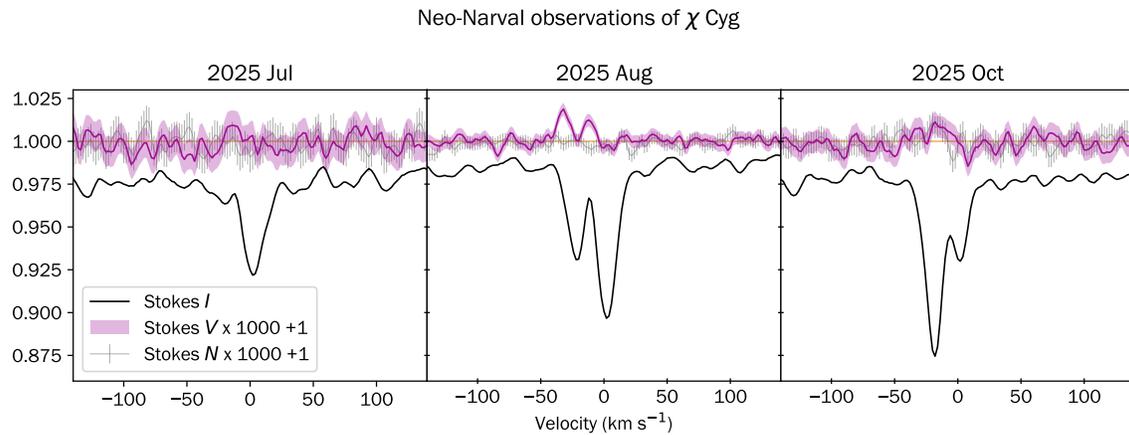


Figure 1. Stokes IVN LSD profiles of χ Cyg obtained with Neo-Narval in 2025. The error bars on Stokes N and the shaded area on Stokes V represent the $1\text{-}\sigma$ confidence interval.

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