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Optical polarimetry studies of white dwarfs

A. Słowikowska[1], **K. Krzeszowski**[2], **M. Żejmo**[2], **D. Blinov**[3,4,5] **and P. Reig**[3,4]

[1] *Toruń Centre for Astronomy, Nicolaus Copernicus University in Toruń, ul. Gagarina 11, 87-100 Toruń, Poland, (E-mail: aga@umk.pl)*

[2] *Janusz Gil Institute of Astronomy, University of Zielona Góra, Szafrana 2, 65-417 Zielona Góra, Poland*

[3] *Foundation for Research and Technology, 711 10 Heraklion, Crete, Greece*

[4] *University of Crete, Physics Department, 710 03 Heraklion, Crete, Greece*

[5] *Astronomical Institute, St. Petersburg State University, Universitetsky pr. 28, Petrodvoretz, 198504 St. Petersburg, Russia*

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Abstract. We present results of the optical linear polarimetric survey of 101 white dwarfs (WDs) performed in R band with the RoboPol polarimeter. Our study shows that highly linear polarized white dwarfs are very rare. Moreover, we found that the median polarization degree of isolated DA WDs and DB WDs are similar, but lower than the median polarization of isolated DC WDs. The DB WDs in binaries seem to be more polarized than binaries containing DA+dM or double degenerated systems (DDSs) with DA component. We also present the measurements of the optical linear polarization of both components in two common proper motion binary systems (CPMBs): WD1336+123 and the Sirius-like system (SLS) WD2129+000. Because the vast majority of WDs have very low polarization degree on the level of less than 0.5%, they can be used as faint linear polarization standards.

Key words: white dwarfs – techniques: polarimetric

1. Introduction

Recently, optical polarimetry studies of astrophysical sources are booming. More and more dedicated polarimeters are built, thus more polarimetric observations are performed. The RoboPol polarimeter dedicated to monitoring the polarization of blazars (Blinov et al., 2016) is a good example. At the same time, polarization observations performed with different telescope classes, from the small to the big, urgently require fainter polarization standards of both types – polarized and zero-polarized. The polarized standards are required to establish the intrinsic depolarization caused by the instrument and zero-point of its position angle (PA), while the zero-polarized standards are necessary to determine the instrumental polarization (e.g. the RINGO3 polarimeter at the Liverpool Telescope, see Słowikowska et al., 2016).

There are more than 23,000 WDs known up to date. For many of them, the spectral type is known. Most WD atmospheres are hydrogen-rich (DA), and almost all others are helium-rich (DB). However, a significant fraction of WDs also contain traces of heavier elements in their atmospheres, and these are labelled with Z for metals or Q for carbon, for example, DZ or DQ. There are also WDs for which the spectrum does not show any strong lines, but their atmospheres are still helium-rich. Such WDs are classified as DC-type WDs.

In 2014 we started a long-term project to measure the linear optical polarization of selected WDs (for the description of the selected sample see Sec. 2 of Żejmo et al., 2017). We aim to perform a statistical analysis of the linear polarization properties of a WD sample and provide observers with a new list of faint linear polarimetric standard sources. In Żejmo et al. (2017) we presented the results of analysis of the optical linear polarization degree of 74 WDs of DA and DC spectral types, both isolated and in binary systems. Their SDSS r magnitudes range from 13 to 17. Almost all measured WDs show low polarization degree (PD $< 1\%$). Only two of them, WD1440−025 and WD2213+317, have PD higher than 1%. Żejmo et al. (2017) claim that the DC-type white dwarfs on average have higher PD (with the median PD of 0.78%) than DA type WDs (with the median PD of 0.36%), but there is no difference between PD of isolated DA type WDs (0.36%) and PD of DA+dM binary systems (0.33%).

Because most of WDs from our sample have low PD and they are well distributed over the sky in the right ascension range from $13^{\rm h}$ to $24^{\rm h}$ and declination from -11° up to 78° , they can be treated as a good set of faint linear polarimetric standard stars. With our sample[1] we increased the low linear polarization standard list (e.g. Fossati et al., 2007) substantially. WDs were, and still are, commonly used as zero-polarization standard stars. Apart from our list, there are eleven well known zero-polarized WDs in the literature. Two of them, namely G 191-B2B (PD=0.09%) and GD 319 (PD=0.045%), were proposed by Turnshek et al. (1990) as the Hubble Space Telescope polarimetric standards. Long-term monitoring of G 191-B2B is presented by Słowikowska et al. (2016). Another nine were proposed by Fossati et al. (2007) as main zero-polarization standards for the FORS1 instrument on the Very Large Telescope. Their goal was to find a group of faint polarized and zero-polarized standards appropriate for telescopes with big mirrors. Their sample consists of 30 stars of different spectral types in the magnitude range from 6 to 14. However, WDs given by Fossati et al. (2007) are in the magnitude range from 11 to 13, with only one exception of 14 mag. Therefore, our list is complementary to Fossati et al. (2007) in respect of the brightness. Seventy WDs extended the existing polarimetric standard lists by a factor of 7. A larger group of zero-polarization standards facilitates the selection of standards at a convenient time of the night and position on the sky.

[1] http://astro.ia.uz.zgora.pl/~chriss/grant/tables_en.html

Additionally, we found that for low extinction values (E(B–V) < 0.04), the best model that describes the dependence of PD on E(B–V) is given by the equation $\mathrm{PD}_{\mathrm{max,ISM}}[\%] = 0.65\ \mathrm{E(B-V)}^{0.12}$. This differs from the Fosalba et al. (2002) equation $\mathrm{PD}_{\mathrm{max,ISM}}[\%] = 3.5\ \mathrm{E(B-V)}^{0.8}$ that was derived from the fit in the E(B–V) range from 0.1 to 1.

2. Observations and data analysis

Our observations were performed at the Skinakas Observatory located in Crete (Greece) in 2014 and 2016. We used the RoboPol[2] linear polarimeter, equipped with two Wollaston prisms and two half-wave plates. It allows to measure the Stokes I, Q, U parameters simultaneously for all stellar objects within $13' \times 13'$ field of view and the scale of $0.435''\ \mathrm{px}^{-1}$ (King et al., 2014). The measurements were performed with an aperture defined as $2.5 \times$ FWHM, where FWHM is an average full width at half maximum of stellar images, which has a median value of $2.1''$(4.0 pixels). All observations with the RoboPol were performed with the R Johnson-Cousins filter. The exposure time was adjusted according to the brightness of each target, as estimated during short pointing exposures.

The data were analysed with the standard RoboPol pipeline (King et al., 2014), whose output gives the normalised Stokes parameters $q = Q/I$ and $u = U/I$ [3]. To account for the instrumental polarization, we measured the polarization degree of 14 zero-polarized standards. The data corrected for instrumental polarization were later used to obtain the PD according to Eq. 1, while the corresponding error (σ_{PD}) is calculated from Eq. 5 in King et al. (2014). For low polarization signal-to-noise ratio (PD / $\sigma_{\mathrm{PD}} < 3$) distribution of the PD is not normal (Gaussian) and the PD values must always be positive so their uncertainties are not symmetric. This introduces a bias into any estimate. To deal with this problem we applied the debias method described by Vaillancourt (2006). Details are given in Sec. 4 of Żejmo et al. (2017).

3. Results

The most intriguing object from our sample is WD1415+234. It shows the highest measured linear polarization in our total sample of 101 WDs measured in 2014 and 2016 and is an isolated DB WD with PD of 2.66% ($\mathrm{PD_c} = 2.56\%$). This value of the PD does not depend on the chosen aperture. A close examination of its neighbourhood stars indicates that the WD polarization is intrinsic. The other two WDs with reasonably high PD are WD1336+123 and WD1619+123 with PD values of 1.14% and 1.25%, respectively, and both are in binary systems. WD1336+123 is a DB WD with a dwarf M4 companion (Silvestri et al.,

[2] `http://robopol.org/`

[3] Hereafter we follow the IAU convention, where the position angle is measured from the North direction increasing counter-clockwise.

2005) and WD1619+123 is of DA type with a dG0 companion (Farihi et al., 2005). Below we discuss binary and multiple systems observed within our 2016 sample.

WD0119-004 (GR 516, LP 587-44): its companion is a subdwarf M5 (Silvestri et al., 2005) and is not a common proper motion binary.

WD1336+123 (PG 1336+124, LP 498-26): we were able to measure its companion (dwarf M4) separated by 87″(Oswalt et al., 1988). It has PD = 0.34% ± 0.33%, while PA = 82.°4 ± 25.°4. This compares with WD PD = 1.14% ± 0.15% and PA = 2.°3 ± 3.°9. The maximum PD caused by the ISM is ∼ 0.42%.

WD1419+576: it is a multiple system resolved only in the HST images and consists of a DB WD and two dwarfs of M2 types (Farihi et al., 2010). It cannot be resolved with RoboPol because the separation between components is less than 0.″7. Therefore, the measured PD is the net PD (0.44% ± 0.28%) of all three. The same is for PA, −37.°5 ± 16.°1. The position angle of secondary stars is 304.°04 ± 0.°12.

WD1619+123: this is a SLS with a dwarf G0 companion separated by 63″(Farihi et al., 2005). It can be resolved by RoboPol, but was unfortunately covered by the mask even in the pointing exposures. Holberg et al. (2013) give the position angle of the companion, where the orientation is measured from the WD to the companion, being 311.°39 (that corresponds to 131.°39) and it is aligned with the proper motion PA of 135.°8 found by Farihi et al. (2005).

WD2129+000: it is the second SLS in our sample. We were able to measure the polarization of its K2 star (Holberg et al., 2013) separated by 133.″1 (Oswalt et al., 1988) and obtained PD = 0.29% ± 0.05% and PA = -85.°9 ± 4.°9. The WD in this system has PD = 0.42% ± 0.28% and PA = −24.°6 ± 17.°4. The contribution from the ISM is estimated to be less than 0.44%. Holberg et al. (2013) give PA = 29.°04 of the companion measured from the WD.

For two CPMBs, WD1336+123 and WD2129+000, we were able to measure the PD of their companions. In both cases the measured PD of the companions (dwarf M4 in case of WD1336+123 and K2 in case of WD2129+000) is smaller than the expected maximum PD_{ISM}. Such measurements give an independent check on the contribution of the PD from the ISM, assuming that no intrinsic PD is expected from the companions – M4 and K2 type dwarfs.

We used the combined dataset from 2014 and 2016 to check the correlation between the interstellar polarization and the extinction. We found that for the E(B–V) range from 0.0 to 0.045 the maximum PD caused by the ISM is given by the relation $PD_{max,ISM}(\%) = 0.65\ E(B-V)^{0.12}$. We concluded that for three WDs with the highest PD their measured linear polarization is intrinsic.

The spatial distribution of our joined sample is in good agreement with the Berdyugin et al. (2014) measurements. There are regions in the Galaxy that show a higher PD, however, most of WDs from our sample are not located in these regions. Our statistical analysis shows that the isolated DB type WDs, similarly to isolated DA type WDs, have lower median PD values in comparison to isolated DC type WDs (0.3%, 0.36% and 0.66%, respectively). On the other

hand, the DB WDs in binary systems have much higher PD than the PD of all other binary systems in our sample (i.e. binary DA+dM and DDSs). However, the DB binaries sample size is small, therefore our result is not conclusive.

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References

Berdyugin, A., Piirola, V., & Teerikorpi, P. 2014, *Astron. Astrophys.*, **561**, A24

Blinov, D., Pavlidou, V., Papadakis, I., et al. 2016, *Mon. Not. R. Astron. Soc.*, **462**, 1775

Farihi, J., Becklin, E. E., & Zuckerman, B. 2005, *Astrophys. J., Suppl.*, **161**, 394

Farihi, J., Hoard, D. W., & Wachter, S. 2010, *Astrophys. J., Suppl.*, **190**, 275

Fosalba, P., Lazarian, A., Prunet, S., & Tauber, J. A. 2002, *Astrophys. J.*, **564**, 762

Fossati, L., Bagnulo, S., Mason, E., & Landi Degl'Innocenti, E. 2007, in ASP Conf. Ser., Vol. **364**, *The Future of Photometric, Spectrophotometric and Polarimetric Standardization*, ed. C. Sterken, 503

Holberg, J. B., Oswalt, T. D., Sion, E. M., Barstow, M. A., & Burleigh, M. R. 2013, *Mon. Not. R. Astron. Soc.*, **435**, 2077

King, O. G., Blinov, D., Ramaprakash, A. N., Myserlis, I., & et al., A. 2014, *Mon. Not. R. Astron. Soc.*, **442**, 1706

Oswalt, T. D., Hintzen, P. M., & Luyten, W. J. 1988, *Astrophys. J., Suppl.*, **66**, 391

R Core Team. 2013, R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria

Silvestri, N. M., Hawley, S. L., & Oswalt, T. D. 2005, *Astron. J.*, **129**, 2428

Słowikowska, A., Krzeszowski, K., Żejmo, M., Reig, P., & Steele, I. 2016, *Mon. Not. R. Astron. Soc.*, **458**, 759

Turnshek, D. A., Bohlin, R. C., Williamson, II, R. L., et al. 1990, *Astron. J.*, **99**, 1243

Vaillancourt, J. E. 2006, *Publ. Astron. Soc. Pac.*, **118**, 1340

Żejmo, M., Słowikowska, A., Krzeszowski, K., Reig, P., & Blinov, D. 2017, *Mon. Not. R. Astron. Soc.*, **464**, 1294