A&A 542, A64 (2012)
DOI: 10.1051/0004-6361/201219175

Astronomy & Astrophysics

Magnetic fields in central stars of planetary nebulae?*

S. Jordan[1], S. Bagnulo[2], K. Werner[3], and S. J. O'Toole[4]

[1] Astronomisches Rechen-Institut, Zentrum für Astronomie der Universität Heidelberg, Mönchhofstr. 12-14, 69120 Heidelberg, Germany
e-mail: jordan@ari.uni-heidelberg.de
[2] Armagh Observatory, College Hill, Armagh BT61 9DG, Northern Ireland, UK
e-mail: sba@arm.ac.uk
[3] Institute for Astronomy and Astrophysics, Kepler Center for Astro and Particle Physics, Eberhard Karls Universität Tübingen, Sand 1, Tübingen 72076, Germany
e-mail: werner@astro.uni-tuebingen.de
[4] Australian Astronomical Observatory, PO Box 296, Epping, NSW 1710, Australia
e-mail: otoole@aao.gov.au

Received 6 March 2012 / Accepted 16 April 2012

ABSTRACT

Context. Most planetary nebulae have bipolar or other non-spherically symmetric shapes. Magnetic fields in the central star may be responsible for this lack of symmetry, but observational studies published to date have reported contradictory results.

Aims. We search for correlations between a magnetic field and departures from the spherical geometry of the envelopes of planetary nebulae.

Methods. We determine the magnetic fields from spectropolarimetric observations of ten central stars of planetary nebulae. The results of the analysis of the observations of four stars were previously presented and discussed in the literature, while the observations of six stars, plus additional measurements of a star previously observed, are presented here for the first time.

Results. All our determinations of magnetic field in the central planetary nebulae are consistent with null results. Our field measurements have a typical error bar of 150–300 G. Previous spurious field detections using data acquired with FORS1 (FOcal Reducer and low dispersion Spectrograph) of the Unit Telescope 1 (UT1) of the Very Large Telescope (VLT) were probably due to the use of different wavelength calibration solutions for frames obtained at different position angles of the retarder waveplate.

Conclusions. There is currently no observational evidence of magnetic fields with a strength of the order of hundreds Gauss or higher in the central stars of planetary nebulae.

Key words. stars: magnetic field – stars: AGB and post-AGB

1. Introduction

There is still no conclusive theory capable of explaining why more than 80% of known planetary nebulae (PNe) have bipolar and non-spherically symmetric structures (Zuckerman & Aller 1986; Stanghellini et al. 1993; Corradi & Schwarz 1995). An overview of the mechanisms that may shape PNe is given by Balick & Frank (2002). Several of these processes suggest that it is magnetic fields which deflect the outflow of the matter along the magnetic field lines. Thirumalai & Heyl (2010) published model calculations for asymptotic giant branch (AGB) stars incorporating both magnetism and stellar winds with dust grains.

These magnetic fields could be either fossil remnants of previous stages of stellar evolution, or be generated by a dynamo at the interface between a rapidly rotating stellar core and a more slowly rotating envelope. Blackman et al. (2001) argue that some remnant field anchored in the core will survive even without a convection zone, although the convective envelope may not be removed completely.

The idea that magnetic fields are important ingredients shaping PNe has been supported by the detection of SiO, H_2O, and OH maser emission in circumstellar envelopes of AGB stars pointing at milliGauss fields in these nebula (Kemball & Diamond 1997; Szymczak & Cohen 1997; Miranda et al. 2001; Vlemmings et al. 2002, 2005, 2006; Herpin et al. 2006; Sabin et al. 2007; Kemball et al. 2009; Gómez et al. 2009; Vlemmings 2011). Moreover, using an idea of Pascoli (1985), Huggins & Manley (2005) connected the extreme filamentary structures seen in high-resolution optical images of certain PNe to magnetic fields consistent with those measured in the maser from the precursor circumstellar envelopes.

For the first time, and with the help of optical circular spectropolarimetry carried out with the FORS1 spectrograph of the UT1 ("Antu") telescope of the VLT of the European Southern Observatory (ESO), Jordan et al. (2005) reported on the detection of magnetic fields in the central stars of the PNe NGC 1360 and LSS 1362. For the central stars of EGB 5 and Abell 36 a magnetic field was found to be probable but with less certainty.

Pascoli & Lahoche (2008) pointed out that the magnetic fields at the surface of the central stars of PNe are not necessarily connected to the magnetic fields in the nebula itself; the latter may be a fossil component of the primary field embedded

* Based on observations collected at the European Organisation for Astronomical Research in the Southern Hemisphere, Chile, under programme ID 072.D-0089 (PI = Jordan) and 075.D-0289 (PI = Jordan).

in the AGB star. Nevertheless, the reported detection of magnetic fields in central stars of PNe has triggered several additional observational and theoretical studies on the shaping of PNe, e.g. by García-Díaz et al. (2008), Tsui (2008), and Pascoli & Lahoche (2010) taking magnetic fields into account. Soker (2006) casted strong doubts that magnetic fields could be the main agent shaping PNe. He argued that a single star cannot supply the energy and angular momentum if the magnetic fields have the large-scale structure required to shape the outflow from an AGB star.

Recently, the detection of magnetic fields in the central stars of planetary nebulae (CPNs) was called into question by Leone et al. (2011), who re-observed NGC 1360 and LSS 1362 with the FORS2 instrument, and concluded that their effective magnetic field is null within an uncertainty of ~100 G (NGC 1360), and ~290 G (LSS 1362). Furthermore, both Leone et al. (2011) and Bagnulo et al. (2012) reanalysed the observations previously obtained with FORS1 by Jordan et al. (2005), and were unable to the original detection by Jordan et al.

The conclusion based on the observations of four CPNs reached by two independent groups is that there is no observational evidence of magnetic fields in CPNs. We aim to enlarge the sample of CPNs for which searches for for magnetic fields have been performed in order to estimate the frequency of the magnetic fields in CPNs and, when a magnetic field is detected, whether its presence correlates with the asymmetry of their envelope. To achieve this goal, two of the teams that had presented (discordant) results on previous FORS measurements have combined their efforts to present here a more complete survey of magnetic fields of CPNs obtained during a three-night observing run with FORS1 carried out in 2005.

2. Observations, data reduction, and magnetic field determinations

All spectropolarimetric data reported in this paper were taken with the FORS1 instrument (Appenzeller et al. 1998) of the ESO Very Large Telescope. The polarimetric optics of FORS1, which has been moved to the twin instrument FORS2, are based on the principle described by Appenzeller (1967). FORS2 is one of the few optical spectropolarimeters available for the study of stellar magnetism. Owing to the large aperture of the telescope (8 m), FORS2 is best suited to the study of faint stars such as white dwarfs (Aznar Cuadrado et al. 2004; Jordan et al. 2007), subdwarfs (Jordan et al. 2005), and CPNs (Jordan et al. 2005).

The FORS1 dataset previously analysed by Jordan et al. (2005), Leone et al. (2011), and Bagnulo et al. (2012) consists of observations of NGC 1360 = CD–26 1340, EGB 5 = PN G211.9+22.6, LSS 1362 = PN G273.6+06.1, and Abell 36 = ESO 577-24. These observations were obtained by Jordan et al. (2005), in service mode between November 2, 2003, and January 27, 2004, using the grism 600B, and a 0.8″ slit width, at a spectral resolution of about 1000.

Three additional nights of telescope time were obtained in visitor mode between June 4, 2005 and June 6, 2005 at the UT2 ("Kueyen") of the ESO VLT. The instrument setup included again grism 600 B, but with a slit width of 0.7″, for a spectral resolution of about 1200.

The criterion for the selection of objects were the optimum visibility during the observation nights and the brightness of the stars in order to reach an optimum signal-to-noise ratio. Moreover, we made sure that at least two of the stars were at the centre of a nebula with almost spherical shape (LSE 125 and Hen 2-194) so that in the case of positive detections the magnetic field can be correlated with the topology of the nebulae.

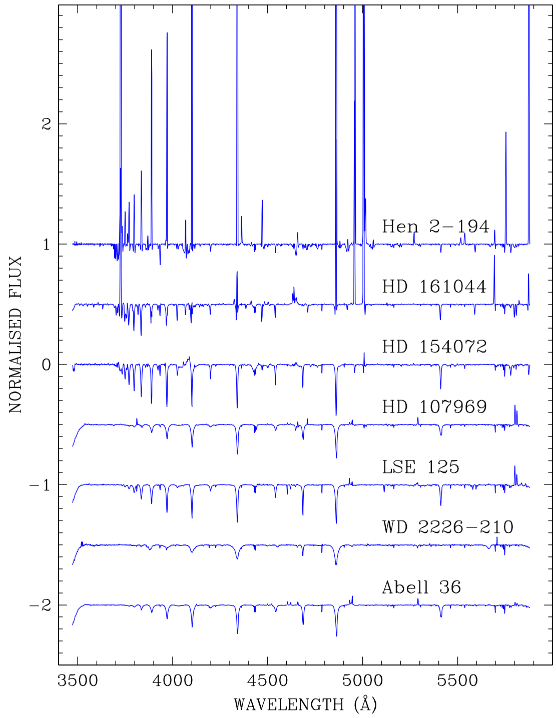

Fig. 1. Normalised spectra of CPNs observed in the 075.D-0289 campaign ordered by increasing effective temperature from top to the bottom. The 072.D-0089 spectra are shown in Fig. 1 of Jordan et al. (2005).

During the visitor run, six new CPNs were observed two or three times: HD 107969 = NGC 4361, LSE 125 = PN G335.5+12.4, Hen 2-194 = ESO 392-2, HD 154072 = IC 4637, HD 161044 = IC 1266, and WD 2226-210 = NGC 7293. The CPN Abell 36 = ESO 577-24, which had already been checked for a magnetic field in the previous service observing run, was re-observed three times. In addition, we took one spectropolarimetric dataset for HD 160917, a non-magnetic B9V comparison star.

Figure 1 shows the summed up high-quality spectra for all CPNs. Only Hen 2-194 and HD 161044 contained significant nebula emission.

We analysed all these old and new observational data by adopting a method described in detail by Bagnulo et al. (2012). Spectra were calibrated and extracted using the ESO FORS pipeline (Izzo et al. 2010), then combined using the difference method to obtain both the reduced Stokes V profiles (P_V) and the null profiles (N_V), as described by Bagnulo et al. (2012). The mean longitudinal magnetic field $\langle B_z \rangle$ was then calculated by using a least-squares technique based on the relationship

$$P_V(\lambda) = -g_{\rm eff}\, C_Z\, \lambda^2\, \frac{1}{I(\lambda)}\, \frac{{\rm d}I(\lambda)}{{\rm d}\lambda}\, \langle B_z \rangle, \quad (1)$$

where P_V is the reduced Stokes V profile, $I(\lambda)$ is the Stokes I profile of a spectral line, $g_{\rm eff}$ is the effective Landé factor, and

$$C_Z \simeq 4.67 \times 10^{-13}\ \text{Å}^{-1}\ \text{G}^{-1}. \quad (2)$$

For more details we refer to Bagnulo et al. (2012). As in Bagnulo et al. (2012) we implemented a sigma-clipping algorithm in the determination of the magnetic field from the correlation diagram of circular polarisation against a local flux derivative. We also calculated the null profiles N_V and compared their oscillation about zero with the P_V error bars, and also measured the null field $\langle N_z \rangle$, i.e., the magnetic field obtained by applying Eq. (1)

Table 1. Fundamental stellar parameters and FORS1 magnetic field measurements for ten CPNs and for a (presumably non-magnetic) B9 star observed for comparison.

CPN name/alias		$T_{\rm eff}$ /K	$\log g$	Exp. time /s	Peak signal-to-noise ratio /Å^{-1}	MJD	$\langle B_z \rangle$ ± /G	Remark
Programme 072.D-0089								
CD-26 1389	NGC 1360	97 000	5.3	1248	1440	52 946.291	207 ± 325	1, 5
				1248	1552	52 988.235	336 ± 283	1
				1248	1340	52 989.060	358 ± 361	1
				1248	1400	52 990.081	72 ± 320	1
EGB5	PN G211.9+22.6	34 060	5.85	1986	552	52 988.347	−155 ± 780	1, 6
LSS 1362	PN G273.6+06.1	114 000	5.7	1986	930	52 989.309	62 ± 406	1, 5
Abell 36	ESO 577-24	113 000	5.6	1500	1290	53 031.287	977 ± 445	1, 5
Programme 075.D-0289								
HD 107969	NGC 4361	82 000	5.5	6000	1308	53 525.093	−348 ± 400	8
				1199	1845	53 526.072	93 ± 295	
				8800	1600	53 527.053	507 ± 351	
Abell 36	ESO 577-24	113 000	5.6	7200	3040	53 525.004	−33 ± 158	5
				3600	1880	53 525.972	110 ± 214	
				3600	1880	53 526.973	115 ± 222	
LSE 125	PN G335.5+12.4	85 000	5.1	10 000	2950	53 525.236	−129 ± 116	9
				6000	1870	53 526.208	135 ± 152	
				3600	1260	53 527.266	449 ± 239	
Hen 2-194	PN H 2-1	33 000	3.35	3400	995	53 525.325	197 ± 523	2, 8
				6000	1250	53 527.202	−409 ± 544	2
HD 154072	IC 4637	50 000	4.05	7200	1485	53 526.295	79 ± 185	8
				4800	1110	53 527.323	−93 ± 216	
HD 161044	IC 1266	34 700	3.3	6600	2820	53 525.396	−74 ± 123	3, 10
				1200	1030	53 526.442	−309 ± 410	3
				1200	1045	53 527.425	345 ± 410	3
WD 2226-210	NGC 7293	105 000	7.0	6800	1065	53 526.387	1865 ± 1097	7
				4200	920	53 527.386	−1277 ± 1269	
HD 160917	CD-45 11850	–	–	300	3431	53 527.450	110 ± 68	4

Notes. 1. Observations already published by Jordan et al. (2005). 2. The field is estimated from absorption lines only. 3. Many spectral lines are in emssion, and the field is estimated from absorption lines only. 4. Non-magnetic B9V star observed for comparison. $T_{\rm eff}$ and $\log g$ from: 5.Traulsen et al. (2005). 6. Lisker et al. (2005). 7. Napiwotzki (1999). 8. Mendez et al. (1992). 9. Mendez et al. (1988). 10. Pottasch et al. (2011).

to the N_V profile instead of P_V. The statistical significance of the null field values is extensively discussed in Bagnulo et al. (2012). Here we report that all null field values were found to be consistent with zero within the error bars. We also note that the targets of this survey are relatively faint, and that most of the observations discussed here are not characterised by a ultra-high signal-to-noise ratio. The main contributors to the error bars are thus photon noise and background subtraction (since our targets are embedded in a circumstellar envelope).

The original data reduction of the observations obtained within programme ID 072.D-0089 by Jordan et al. (2005) was based on two distinct wavelength calibration solutions for the frames obtained at the two different position angles of the retarder plate adopted for the science observations: science frames obtained with the retarder waveplate at position angle −45° were calibrated with calibration frames obtained with the retarder waveplate at −45°, and science frames obtained with the retarder waveplate at +45° were calibrated with calibration frames obtained at +45°. However, Bagnulo et al. (2006) and Bagnulo et al. (2009) demonstrated that this method prevents wavelength calibration errors from being cancelled out, and may lead to spurious detections. While this problem did not occur in various tests (e.g. Bagnulo et al. 2002), in the case of for instance the 075.D-0289 data it would lead to spurious magnetic field measurements of the order of ~9 kG.

In their analysis of the data obtained in 072.D-0089, Jordan et al. (2005) compared the Stokes profiles obtained using a common wavelength calibration with those obtained using two distinct solutions, and concluded that both methods produced similar Stokes profiles. However, at that time they did not notice that, although the profiles looked similar, the field measurements were different: after the analysis of the profiles obtained using two wavelength calibration frames, a field was firmly detected, while using a unique wavelength calibration frame, field detections would have disappeared. For this reason we conclude that the relatively high magnetic fields reported by Jordan et al. (2005) are spurious.

A similar conclusion was drawn by Bagnulo et al. (2012) and Landstreet et al. (2012) for the measurements of magnetic fields in subdwarfs by O'Toole et al. (2005): the kG magnetic fields similarly disappear when a single wavelength calibration frame is used for the entire science dataset. We note instead that the detections of Aznar Cuadrado et al. (2004) of weak magnetic fields in white dwarfs were basically confirmed by Bagnulo et al. (2012).

3. Results

Table 1 lists our field determinations from all new FORS observations. We have also included new field determinations from

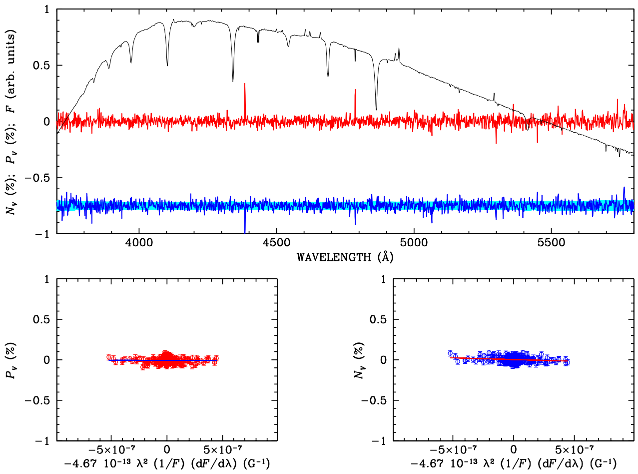

Fig. 2. The observations of Abell 36 were obtained with FORS1 on June 3, 2005. The *top panel* shows the observed flux F (black solid line, in arbitrary units, and uncorrected for the instrumental response), the $P_V = V/I$ profile (red solid line centred on about 0), and the null profile N_V (blue solid line, offset by −0.75% for display purposes). The null profile is expected to be centred on about zero and scattered according to a Gaussian of width σ given by the P_V error bars, which are represented by light blue bars centred on about −0.75%. The slope of the interpolating lines in the bottom panels gives the mean longitudinal field from both P_V (*left bottom panel*) and the null profile (*right bottom panel*) both calculated using the H Balmer and metal lines. The corresponding $\langle B_z \rangle$ and $\langle N_z \rangle$ values are -33 ± 158 G and -420 ± 161 G, respectively.

the observations carried out in service mode by Jordan et al. (2005). We note that the field estimates for the observations obtained in 072.D-0089 differ slightly from those published by Bagnulo et al. (2012) because of the implementation of the sigma-clipping algorithm, and also a slightly different choice of the spectral points considered for the field determination. Figure 2 shows an example of the reduced data.

4. Discussion

Our analysis of ten CPNs has failed to uncover significant evidence of longitudinal magnetic fields stronger than a few hundred Gauss. This contradicts the result of Jordan et al. (2005), who determined magnetic field strengths of several kG in their analysis of four CPNs. Our current results are, however, consistent with the investigation of the central star of NGC 1360 by Leone et al. (2011), who determined an upper limit to the magnetic field of 300 G (while Jordan et al. 2005, reported a longitudinal magnetic field of up to 3 kG). For the central star of LSS 1362, Leone et al. (2011) obtained an upper limit of 600 G. We conclude that a non-optimal wavelength calibration method led Jordan et al. (2005) to a spurious detection of magnetic fields.

Our re-reduction of the 072.D-0089 data, previously analysed by Jordan et al. (2005), has inferred a weighted mean magnetic field (see Table 1) for NGC 1360 of 244 ± 162 G, assuming that a possible (and weak) magnetic field appears constant with time.

For our sample of ten stars (Abell 36 has been observed in both observational campaigns), we conclude that there is no confirmed case of a magnetic field in the central star of a planetary nebuala at a kG level. Magnetic fields of the order to 100–300 G, however, cannot be discarded. Indirect evidence of mG fields in proto-planetary nebulae could still support an influence of magnetic fields on the shape of PNe. However, these fields need not be connected to a field of the central star (Pascoli & Lahoche 2008).

Acknowledgements. We thank the staff of the ESO VLT for carrying out the service observations of programme 072.D-0089 and supporting our visitor mode observations of programme 075.D-0289 (PI = S. Jordan for both programmes). We are greatful to Luca Fossati for helping us with the preparation of Fig. 1.

References

Appenzeller, I. 1967, PASP, 79, 136
Appenzeller, I., Fricke, K., Fürtig, W., et al. 1998, The Messenger, 94, 1
Aznar Cuadrado, R., Jordan, S., Napiwotzki, R., et al. 2004, A&A, 423, 1081
Bagnulo, S., Szeifert, T., Wade, G. A., Landstreet, J. D., & Mathys, G. 2002, A&A, 389, 191
Bagnulo, S., Landstreet, J. D., Mason, E., et al. 2006, A&A, 450, 777
Bagnulo, S., Landolfi, M., Landstreet, J. D., et al. 2009, PASP, 121, 993
Bagnulo, S., Landstreet, J. D., Fossati, L., & Kochukhov, O. 2012, A&A, 538, A129
Balick, B., & Frank, A. 2002, ARA&A, 40, 439
Blackman, E. G., Frank, A., Markiel, J. A., Thomas, J. H., & Van Horn, H. M. 2001, Nature, 409, 485
Corradi, R. L. M., & Schwarz, H. E. 1995, A&A, 293, 871
García-Díaz, M. T., López, J. A., García-Segura, G., Richer, M. G., & Steffen, W. 2008, ApJ, 676, 402
Gómez, Y., Tafoya, D., Anglada, G., et al. 2009, ApJ, 695, 930
Herpin, F., Baudry, A., Thum, C., Morris, D., & Wiesemeyer, H. 2006, A&A, 450, 667
Huggins, P. J., & Manley, S. P. 2005, PASP, 117, 665
Izzo, C., de Bilbao, L., Larsen, J., et al. 2010, in SPIE Conf. Ser., 7737
Jordan, S., Werner, K., & O'Toole, S. J. 2005, A&A, 432, 273
Jordan, S., Aznar Cuadrado, R., Napiwotzki, R., Schmid, H. M., & Solanki, S. K. 2007, A&A, 462, 1097
Kemball, A. J., & Diamond, P. J. 1997, ApJ, 481, L111
Kemball, A. J., Diamond, P. J., Gonidakis, I., et al. 2009, ApJ, 698, 1721
Landstreet, J. D., Bagnulo, S., Fossati, L., Jordan, S., & O'Toole, S. 2012, A&A, 541, A100
Leone, F., Martínez González, M. J., Corradi, R. L. M., Privitera, G., & Manso Sainz, R. 2011, ApJ, 731, L33
Lisker, T., Heber, U., Napiwotzki, R., et al. 2005, A&A, 430, 223
Mendez, R. H., Kudritzki, R. P., Groth, H. G., Husfeld, D., & Herrero, A. 1988, A&A, 197, L25
Mendez, R. H., Kudritzki, R. P., & Herrero, A. 1992, A&A, 260, 329
Miranda, L. F., Gómez, Y., Anglada, G., & Torrelles, J. M. 2001, Nature, 414, 284
Napiwotzki, R. 1999, A&A, 350, 101
O'Toole, S. J., Jordan, S., Friedrich, S., & Heber, U. 2005, A&A, 437, 227
Pascoli, G. 1985, A&A, 147, 257
Pascoli, G., & Lahoche, L. 2008, PASP, 120, 1267
Pascoli, G., & Lahoche, L. 2010, PASP, 122, 1334
Pottasch, S. R., Surendiranath, R., & Bernard-Salas, J. 2011, A&A, 531, A23
Sabin, L., Zijlstra, A. A., & Greaves, J. S. 2007, MNRAS, 376, 378
Soker, N. 2006, PASP, 118, 260
Stanghellini, L., Corradi, R. L. M., & Schwarz, H. E. 1993, A&A, 279, 521
Szymczak, M., & Cohen, R. J. 1997, MNRAS, 288, 945
Thirumalai, A., & Heyl, J. S. 2010, MNRAS, 409, 1669
Traulsen, I., Hoffmann, A. I. D., Rauch, T., et al. 2005, in 14th European Workshop on White Dwarfs, ed. D. Koester, & S. Moehler, ASP Conf. Ser., 334, 325
Tsui, K. H. 2008, A&A, 491, 671
Vlemmings, W. H. T. 2011, in Asymmetric Planetary Nebulae 5 Conference
Vlemmings, W. H. T., Diamond, P. J., & van Langevelde, H. J. 2002, A&A, 394, 589
Vlemmings, W. H. T., van Langevelde, H. J., & Diamond, P. J. 2005, A&A, 434, 1029
Vlemmings, W. H. T., Diamond, P. J., & Imai, H. 2006, Nature, 440, 58
Zuckerman, B., & Aller, L. H. 1986, ApJ, 301, 772