Astron. Astrophys. 327, 721–724 (1997)

ASTRONOMY AND ASTROPHYSICS

A search for planetary nebulae around hot white dwarfs*

K. Werner[1], **K. Bagschik**[2], **T. Rauch**[1], **and R. Napiwotzki**[3]

[1] Institut für Astronomie und Astrophysik der Universität, Waldhäuser Str. 64, D-72076 Tübingen, Germany
[2] Sternwarte Bonn, Auf dem Hügel 71, D-53121 Bonn, Germany
[3] Dr. Remeis–Sternwarte, Universität Erlangen-Nürnberg, Sternwartstr. 7, D-96049 Bamberg, Germany

Received 2 June 1997 / Accepted 10 July 1997

Abstract. We have performed a search for old planetary nebulae around hot white dwarfs by direct Hα narrow-band imaging. The 16 examined objects are white dwarfs representing different spectral subtypes, comprising DA and various non-DA stars, among them being PG 1159 stars and white dwarfs exhibiting spectral signatures of ongoing mass-loss by ultra-hot winds.

The search was entirely negative – with one possible exception: PG 0109+111, which is the most massive DO white dwarf known (M=0.74 $M_\odot$) and among the hottest DOs (T_{eff}=110 000 K). An asymmetric nebulosity extends about 5′ from the star to the south-west, and there are hints that it extends even further out. If our detection is in fact the first definite case of a PN around a DO white dwarf it needs to be investigated by detailed spectroscopic observations.

Key words: stars: evolution – stars: AGB and post-AGB – white dwarfs – planetary nebulae: general

1. Introduction

It is well known that stellar post-AGB ages derived from spectroscopic analyses in combination with theoretical evolutionary calculations are in many cases discrepant when compared with expansion ages of planetary nebulae. These discrepancies can be very large and occur in both extreme directions, i.e. highly evolved white dwarf central stars are observed in young PNe and on the other hand large, senile PNe can host young post-AGB stars. Two such extreme examples are the nebulae MWP 1 (PN G080.0-10.4) and Wray 17-31 (PN G277.7-03.5) and their central stars. MWP 1 is among the largest (6pc linear diameter) hence oldest (150 000 years) PNe but its H-deficient central star RX J2117.1+3412 is a hot ($T_{\rm eff}$=170 000 K), luminous and hence young post-AGB object whose age is about two orders of magnitudes smaller (Appleton et al. 1993, Werner et al. 1996). The other example, Wray 17-31, has a hot H-rich white dwarf (DAO, i.e. with traces of helium) central star whose post-AGB age is of the order 10^6 years whereas the PN is much younger, about 16 000 years, as derived from its expansion velocity (Peña et al. 1997). The reasons for these discrepancies are debated (see e.g. McCarthy et al. 1990 and Tweedy & Kwitter 1994) and obviously our understanding of post-AGB stellar evolution and PN formation is not sufficient to explain these facts.

Highly interesting are the H-deficient post-AGB stars such as PG 1159 stars and DO white dwarfs because we do not even understand how they evolve into their H-deficient state. Detection and analyses of PNe around these objects might give a clue to their evolutionary history. But also the hydrogen-rich DAO white dwarfs surrounded by a PN represent a mystery because it was suggested that the DAO stars did evolve directly from the extended horizontal branch bypassing AGB evolution (Bergeron et al. 1994). It is worthwhile to see if this phenomenon is more common than we know by now. Hence we have performed a systematic search for faint, extended nebulosity around hot white dwarfs, where the probability to make a positive detection can be expected to be highest. Similar searches were previously performed either by deep imaging or long-slit spectroscopy (e.g. Kwitter et al. 1989, Tweedy & Kwitter 1994, Méndez et al. 1988).

2. Observations

The observations were performed in 1995, Sept. 28 to Oct. 3 at the Calar Alto 1.23m telescope. The effective area of the primary mirror was reduced to approximately 0.9m by covering a segment with faulty coating. The PN search was conducted by direct Hα narrow-band imaging using a wide angle ($20' \times 20'$) CCD camera (WWFPP[1]), which was built at the Bonn observatory. The CCD is a Loral 2048^2 pixel chip with a pixel size of 15μ. The Hα filter has a half-width of 40Å. Single exposure times amount to 45 minutes and all objects were observed at least twice. The frames were reduced by suitable dome- and skyflats

Send offprint requests to: K. Werner

* Based on observations obtained at the German-Spanish Astronomical Center, Calar Alto, operated by the Max-Planck-Institut für Astronomie Heidelberg jointly with the Spanish National Commission for Astronomy

[1] Weitwinkel-Flächenphotometer/Polarimeter

Table 1. The observed targets and exposure times. Also given are available spectroscopic data with respective references

star	spectral type	t_{exp}/min	T_{eff}/K	log g	reference
HS 0615+6535	DA	90	110 000	7.5	Jordan priv. comm.
HS 2246+0640	DA	90	95 000	8.1	Jordan priv. comm.
PG 0231+051	DAO	135	≈100 000	≈7.0	Heber et al. 1996
HS 2033+0507	DAO	90	≈100 000	≈7.0	Heber et al. 1996
KPD 0005+5106	DO	135	120 000	7.0	Werner et al. 1994
PG 0038+199	DO	135	115 000	7.5	Dreizler & Werner 1996
PG 0109+111	DO	270	110 000	8.0	Dreizler & Werner 1996
PG 0046+078	DO	90	73 000	8.0	Dreizler & Werner 1996
PG 0108+101	DO	135	95 000	7.5	Dreizler & Werner 1996
PG 0237+116	DO	90	70 000	8.0	Dreizler & Werner 1996
HS 0158+2335	hot-wind DO	90	>80 000	≈7.0	Dreizler et al. 1995
HS 0713+3958	hot-wind DO	90	>80 000	≈7.0	Werner et al. 1995
HS 2027+0651	hot-wind DO	90	>80 000	≈7.0	Dreizler et al. 1995a
PG 0122+200	PG 1159	90	75 000	7.5	Dreizler et al. 1995b
HS 0444+0453	PG 1159	135	100 000	7.5	Dreizler et al. 1995b
HS 2324+3944	hybrid PG 1159	135	130 000	6.2	Dreizler et al. 1996

using standard IRAF[2] procedures. Table 1 lists the observed targets, exposure times, as well as available spectroscopic information (see also Fig. 1). We have selected very hot members from different white dwarf subtypes. Many of them are objects recently discovered in the Hamburg-Schmidt Survey (Hagen et al. 1995).

2.1. DA stars

HS 0615+6535 and HS 2246+0640 are two newly discovered DA white dwarfs found by the Hamburg-Schmidt Survey (Jordan priv. comm.). They are among the hottest DAs at all and only about a dozen objects with similar or higher temperature are known. They are in fact the hottest DAs which are not associated with a PN. The positive detection of extended nebulosity around two hot DAs (Ton 320 and RE 1738+665 with T_{eff}=69 000 K and 88 000 K, respectively; Bergeron et al. 1994, Barstow et al. 1994) by Tweedy & Kwitter (1994) prompted us to look for a PN around these two new hot DAs – without success.

2.2. DAO stars

PG 0231+051 and HS 2033+0507 are extremely hot DAO white dwarfs, concluded from spectroscopy performed by Heber et al. (1996), although detailed model atmosphere analyses are still lacking. The existence of evolved DAOs in planetary nebulae (e.g. Peña et al. 1997) promised a possible PN discovery here, but nothing was found in our investigation.

Our non-detection of PN around the two hottest DA white dwarfs and DAO stars is not surprising, considering the stellar evolutionary age which is long enough for a PN to disperse within that time. In light of this result the detection of PNe

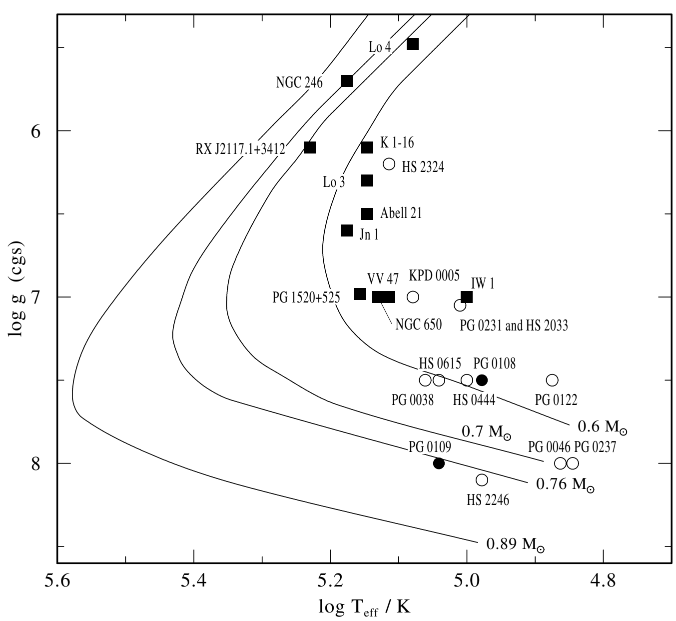

Fig. 1. Open circles: positions of the examined objects in the log g –log T_{eff} diagram (see also Table 1). The two filled circles represent the DO PN candidates discussed in the text. Filled squares denote all known PG 1159 stars with an associated PN (from Werner et al. 1997). Evolutionary tracks for He-burning post-AGB stars are from Wood & Faulkner (1986)

around cooler, hence more evolved DA and DAO stars as mentioned above becomes even more intriguing and seems to confirm the idea that binary evolution plays an important role in these cases.

2.3. DO stars

No DO white dwarf central stars were hitherto known, which appears strange because their position in the HRD overlaps with the known hot DA central stars. There is one possible exception,

[2] IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc. (AURA) under cooperative agreement with the National Science Foundation

which will be discussed in more detail below: Very faint and extended nebulosity around PG 0108+101 was detected with a Fabry-Perot spectrometer (Reynolds 1987). On our image centered on this star there is no indication for such nebulosity. In total we have observed six DO stars and they are among the hottest in this group. The hottest DO, KPD 0005+5106, was a promising target, as FUV spectroscopy with the Hopkins Ultraviolet Telescope showed strong molecular hydrogen lines, which were interpreted as possible relics of a PN around this star (Kruk & Werner 1996). But our search was negative, as well as in the other cases, except for PG 0109+111. An asymmetric nebulosity extends about 5′ from the star to the south-west, and there are hints that it extends even further out (Fig. 2, see discussion below).

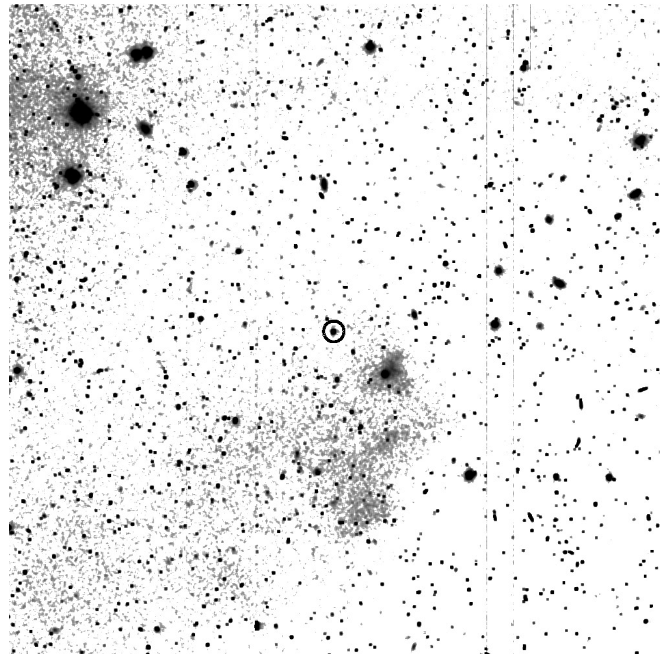

Fig. 2. Hα image of the field around the DO white dwarf PG 0109+111 (encircled). Nebulosity is visible to the south of the star, but also in the north-west corner of the field. The field size is approximately 11′ by 11′ and represents the overlapping area of six exposures with slightly different pointings. The total integration time amounts to 4.5 hours. Most cosmic ray hits have been removed and afterwards the image was smoothed with a five pixel boxcar. North is up and east to the right

2.4. DO stars with signatures of a hot wind

This is a new spectral subtype of hot DO white dwarfs discovered recently (Dreizler et al. 1995a, Werner et al. 1995). They show signatures of a very hot wind, displaying ultrahigh-ionisation absorption features e.g. from O VIII. No details are known about these stars (except that their effective temperatures must exceed about 80 000 K) because attempts of model atmosphere analyses failed. The high temperature and the signatures of on-going mass loss made these objects interesting targets for our PN search. However, no nebulosity was detected. The fact that we did not find nebulae around three of the six known stars of this spectral type suggests that we are in fact witnessing here mass loss events from hot, evolved white dwarfs.

2.5. PG 1159 stars

About every other of the presently known PG 1159 stars is associated with a PN (see e.g. Werner et al. 1997), with the clear tendency that these central stars are among the most luminous PG 1159 stars, as it could be expected. One of our targets, HS 2324+3944, belongs to these luminous stars so it is natural to look for a PN. The two other PG 1159 stars we looked at are relatively cool and compact and belong to the most evolved stars of this spectral class. The detection of a PN about these stars would be quite surprising. No PN was detected in all three cases. One of these, PG 0122+200, was also examined with long-slit spectroscopy by Kwitter et al. (1989).

The non-detection of a PN around the PG 1159 star HS 2324+3944 is difficult to understand. If there is a connection to the spectral peculiarities of this star, it can only be speculated. HS 2324+3944 is one of only four known hybrid PG 1159 stars (the other three have an associated PN), i.e. those objects which do have detectable amount of hydrogen in their photosphere, in contrast to the “usual” PG 1159 stars. A possible explanation could be that HS 2324+3944 has experienced a very late He-shell flash (which is thought to be responsible for the PG 1159 phenomenon), which may have occurred during the WD cooling phase long after the PN has dispersed. But on the other hand at least four “usual” PG 1159 stars are also located in this PN region in the HRD and lack a PN. Only in the case of PG 1520+525 a PN was found recently (Jacoby & Van de Steene 1995), whereas no PN was detected near PG 1144+005, PG 1151-029, and the prototype PG 1159-035 (Tweedy & Kwitter 1994). Hence we need to find an explanation for the fact that luminous (i.e. young) PG 1159 stars with similar parameters either i) have an old, extended PN (e.g. RX J2117.1+3412) or ii) a relatively young PN (e.g. Abell 43) or iii) are not associated with a PN at all (e.g. HS 2324+3944).

3. Concluding remarks

Only very few white dwarf central stars are known (see e.g. Napiwotzki & Schönberner 1995) and all of them are of spectral type DA (i.e. hydrogen-rich) or DAO (i.e. with small helium admixtures) or PG 1159 (carbon- and helium-rich). No WD central star of type DO (i.e. pure helium) was known, with one possible exception. A very faint and large (1.6°) emission nebula (Hα) around PG 0108+101 was detected by Reynolds (1987) with a Fabry-Perot spectrometer, but the question as to the nature of this nebula (extremely evolved PN or ionized ambient interstellar gas) remains unanswered. Our image centered on this star does not show any nebulosity, which can be understood because according to Reynolds (1987) the geocoronal Hα emission is much stronger than the nebular one. He also examined PG 0109+111 and – in contrast to our image – could not detect any emission. This is somewhat disturbing, but could be explained if the nebula has a high peculiar velocity or a high expansion velocity. In this case it would have escaped detection by the Fabry-Perot spectrometer. If our detection of an emission nebula around PG 0109+111 is in fact a PN around a DO white dwarf it needs to be confirmed by detailed spectroscopic studies.

Dreizler & Werner (1996) have recently analyzed almost all of the known DOs. They found that PG 0109+111 is the most massive of these (M=0.74 $M_\odot$) and that it is among the hottest DOs known ($T_{\rm eff}$=110 000 K, log g =8.0). Comparing the magnitude V=14.4 (Cheselka et al. 1993) with the model astrophysical flux ($F_\nu = 6.1 \cdot 10^{-3}$ erg/cm^2/sec/Hz) yields a distance of d=280 pc. If we assume that the nebulosity is an associated PN with an angular radius of $5'$ and an expansion velocity of 20 km/sec, then we arrive at a linear radius of 0.4 pc and an expansion age of ≈20 000 years. This contrasts with the post-AGB age of the white dwarf which exceeds 100 000 years according to evolutionary calculations by Blöcker (1995).

Acknowledgements. We gratefully acknowledge a travel grant (We 1312/14-1) from the Deutsche Forschungsgemeinschaft (DFG).

References

Appleton P.N., Kawaler S.D., Eitter J.J. 1993, AJ 106, 1973
Barstow M.A., Holberg J.B., Marsh M.C., et al. 1994, MNRAS 271, 175
Bergeron P., Wesemael F., Beauchamp A., et al. 1994, ApJ 432, 305
Blöcker T. 1995, A&A 299, 755
Cheselka M., Holberg J.B., Watkins R., Collins J., Tweedy R.W. 1993, AJ 106, 2365
Dreizler S., Werner K. 1996, A&A 314, 217
Dreizler S., Heber U., Napiwotzki R., Hagen H.-J. 1995a, A&A 303, L53
Dreizler S., Werner, K., Heber, U. 1995b, in: White Dwarfs, eds. D. Koester & K. Werner, Lecture Notes in Physics 443, Springer, Berlin, p. 186
Dreizler S., Werner K., Heber U., Engels D. 1996, A&A 309, 820
Hagen H.-J., Groote D., Engels D., Reimers D. 1995, A&AS 111, 195
Heber U., Dreizler S., Hagen H.-J. 1996, A&A 311, L17
Jacoby G.H., Van de Steene G. 1995, AJ 110, 1285
Kruk J.W., Werner K. 1996, in: Hydrogen-Deficient Stars, eds. U.Heber & C.S.Jeffery, The ASP Conference Series 96, 205
Kwitter K.B., Massey P., Congdon C.W., Pasachoff J.M. 1989, AJ 97, 1423
McCarthy J.K., Mould J.R., Méndez R.H., et al. 1990, ApJ 351, 230
Méndez R.H., Gathier R., Simon K.P., Kwitter K.B. 1988, A&A 198, 287
Napiwotzki R., Schönberner D. 1995, A&A 301, 545
Peña M., Ruiz M.T., Bergeron P., Torres-Peimbert S., Heathcote S. 1997, A&A 317, 911
Reynolds R.J. 1987, ApJ 315, 234
Tweedy R.W., Kwitter K.B. 1994, ApJL 433, 93
Werner K., Heber U., Fleming T.A. 1994, A&A 284, 907
Werner K., Dreizler S., Heber U., et al. 1995, A&A 293, L75
Werner K., Dreizler S., Heber U., et al. 1996, A&A 307, 860
Werner K., Dreizler S., Heber U., et al. 1997, in: Reviews in Modern Astronomy 10, ed. R.E. Schielicke, Astronomische Gesellschaft, p. 219
Wood P.R., Faulkner D.J. 1986, ApJ 307, 659

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.