X-ray emission from hot hydrogen-deficient white dwarfs

K. Werner

Lehrstuhl Astrophysik, Universität Potsdam, Am Neuen Palais 10, D-14469 Potsdam, Germany

Abstract. The ROSAT observatory has detected X-rays from a small number of hot hydrogen-deficient (pre-) white dwarfs. These PG 1159 stars and helium-rich white dwarfs are hot enough ($T_{\rm eff}$≥100 000 K) to emit thermal X-rays from their photospheres. We summarize the results of non-LTE model atmosphere analyses.

One remarkable result is the discovery of two previously unknown and peculiar PG 1159 stars. In a combined analysis with ultraviolet spectroscopic data obtained with the Hubble Space Telescope one of these objects turns out to be the hottest known PG 1159 star. Another surprising result is the first detection of a corona about a white dwarf.

1. Introduction

Within the last few years evidence was growing for the existence of a distinct post-AGB evolutionary sequence which comprises hydrogen-deficient stars all along the way from the Wolf-Rayet type central stars of planetary nebulae to the PG 1159 stars to the helium-rich white dwarfs. During the evolution through these stages the low mass stellar remnants ($M/M_\odot \lesssim 1.0$) reach surface temperatures well in excess of 100 000 K, making them potential X-ray sources detectable at earth provided that interstellar extinction is not too high.

Before the ROSAT mission the only known X-ray emitter among the PG 1159 stars was the famous H 1504+65 which was found to be extremely hot ($T_{\rm eff}$=170 000 K) and H- *and* He-deficient, thus representing a naked carbon/oxygen stellar core (Nousek et al. 1986, Werner 1991). Out of the He-rich white dwarfs, only one object was detected before in the X-ray band, namely PG 1034+001 (Paerels & Heise 1989) which later turned out to be one of the hottest known He-rich (i.e. DO) white dwarfs ($T_{\rm eff}$=100 000 K, Werner et al. 1995a). X-rays observed from another DO, HD 149499 B, most probably arise from the corona of its late-type companion.

2. PG 1159 stars

The 27 known members of this spectroscopic class spread over a wide range in the HR diagram ($T_{\rm eff}$=70 000–170 000 K, $\log L/L_\odot$=1.2–4.2) and their masses are low ($M/M_\odot$=0.5–0.9), hence they represent the hottest phase in post-AGB stellar evolution and are just about to enter the white dwarf cooling sequence. Most remarkable is their surface composition. Carbon and helium are the main atmospheric constituents along with a significant amount of oxygen. This abundance pattern is probably the result of a late thermal pulse which caused the removal and ablation of the H- and He-rich stellar layers, respectively (see reviews by Dreizler et al. 1995 and Werner & Dreizler 1996). Immediate progenitors of the PG 1159 stars are the Wolf-Rayet type central stars which have very similar compositions (Leuenhagen et al. 1993), as well as transition objects like Abell 78 (Werner & Koesterke 1992). In the all sky survey ROSAT has detected eight PG 1159 stars (cf. Fleming 1993), two of them were previously unknown and identified by optical follow-up spectroscopy (see Fig. 1).

The first new identification is RX J 2117+3412. In combination with optical spectra a detailed X-ray analysis was carried out by Motch et al. (1993). The high effective temperature determined was later slightly corrected to an even higher value ($T_{\rm eff}$=170 000 K) on hand of a more precise UV spectral analysis based on high resolution HST data (Werner et al. 1995b). Together with H 1504+65 this is the highest temperature known from a PG 1159 star. In addition RX J 2117+3412 was among the first PG 1159 stars for which a (strongly enriched) neon abundance could be determined, which corroborates the late He flash scenario as the origin of these stars (Werner & Rauch 1994).

The second new identification is RX J 0122−7521 (Cowley et al. 1995). A rough estimate from optical spectra reveals a lower temperature and luminosity as compared to RX J 2117+3412. Together with the fact that it is visually fainter by more than two magnitudes it is surprising that the X-ray luminosity is a factor of 2.4 higher. Clearly, a sophisticated analysis is desirable to explain these observations. This new PG 1159 star is also remarkable because it shows prominent signatures for the presence of nitrogen, which points at complicated mixing processes taking place during the late He flash. For a detailed discussion of this problem see Werner & Heber (1991) who analysed the only N-rich PG 1159 star known before (PG 1144+001).

3. Hot He-rich white dwarfs

At the hot end of the white dwarf cooling sequence we find the He-rich white dwarfs of spectral type DO (i.e.

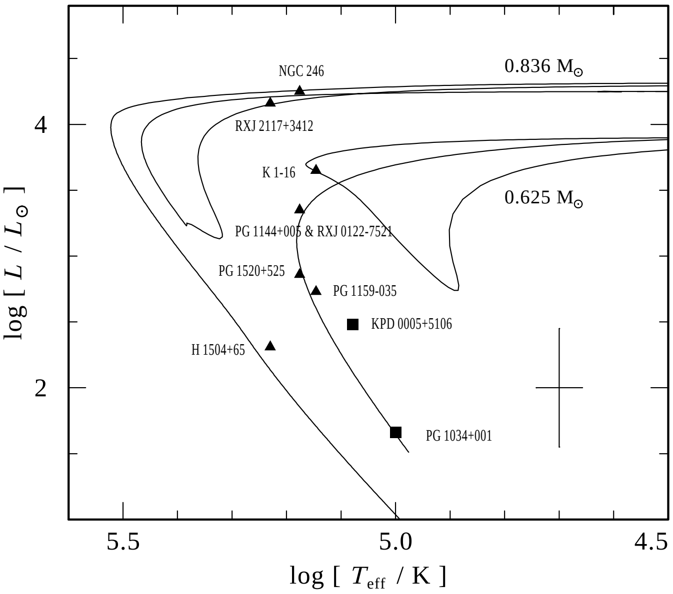

Fig. 1. Position of the PG 1159 stars (triangles) and DO white dwarfs (squares) with X-ray emission detected by the ROSAT X-ray telescope. Also shown are two post-AGB evolutionary tracks with different stellar masses (from Blöcker 1995). The stars suffer a late He flash at about log $L/L_\odot=3$ causing a loop back to the AGB before their final fading on the white dwarf cooling sequence. A typical error bar is displayed in the lower right corner

they are hot enough to exhibit spectral lines from ionized helium). The 22 known objects of this type are located in the $T_{\rm eff}$=50 000 K–120 000 K and log $L/L_\odot$=0–2 ranges in the HR diagram. They have typical white dwarf masses ($M/M_\odot$=0.5–0.8) and have helium atmospheres which are occasionally contaminated by trace metals (C, N, O, Si, Fe). They are probably descendants from the PG 1159 stars after gravitational settling has removed most C and O from the atmospheres, although many details remain still unexplained. For a detailed analysis and discussion of the DOs see Dreizler & Werner (1996). ROSAT has observed two DOs in the X-ray band (KPD 0005+5106 and PG 1034+001). In addition, the only DO detected in the EUV band of the Wide Field Camera is a new discovery (RE 0503−289, see Barstow et al. 1994).

KPD 0005+5106 is a relatively bright X-ray source and all sky survey plus optical and HST UV data have been analysed with NLTE model atmospheres by Fleming et al. (1993) and Werner et al. (1994). It is most remarkable that the X-ray spectrum cannot be explained by photospheric emission, although KPD 0005+5106 is the hottest DO known ($T_{\rm eff}$=120 000 K), but that it must stem from a hot plasma around the star. This means the first detection of a corona about a white dwarf.

For the other hot DO (PG 1034+001) a pointed ROSAT observation was carried out and analysed with complementary UV and optical spectra. A significant X-ray flux excess in the models was attributed to missing opacity sources, most probably underestimated bound-free photon cross sections of highly ionized iron group elements (Werner et al. 1995a).

4. Conclusions

The ROSAT mission has led to the discovery of two new PG 1159 stars and one DO white dwarf. All three objects have particular characteristics which make them outstanding representatives of the respective spectral classes. These objects as well as the other X-ray detected PG 1159 and DO stars are among the hottest members of these classes. The other members remain undetected primarily because they are too cool, but also because interstellar extinction absorbs X-rays from potential X-ray emitters. No PG 1159 star cooler than $T_{\rm eff}$=140 000 K was detected by ROSAT and no DO below 80 000 K. The higher limit for the PG 1159 stars is a consequence of strong C and O continuous opacities which are not present in the He-dominated DO white dwarfs.

Last but not least, ROSAT has uncovered the first corona about a white dwarf.

Acknowledgements. This research was supported by the DARA (grant 50 OR 9409 1) and the DFG (grant We 1312/6-1).

References

Barstow M.A., Holberg J.B., Werner K., Buckley D.S., Stobie R. 1994, MNRAS 267, 653
Blöcker T. 1995, A&A 299, 755
Cowley A.P., Schmidtke P.C., Hutchings J.B., Crampton D. 1995, ApJ, in press
Dreizler S., Werner K. 1996, A&A, submitted
Dreizler S., Werner K., Heber U. 1995 in White Dwarfs, eds. D.Koester and K.Werner, Lecture Notes in Physics 443, Springer, Berlin, p. 160
Fleming T.A. 1993, Adv. Space Res., Vol. 13, No. 12, p. 7
Fleming T.A., Werner K., Barstow M.A. 1993, ApJL 416, 79
Leuenhagen U., Koesterke L., Hamann W.-R. 1993, Acta Astronomica 43, 329
Motch C., Werner K., Pakull M. 1993, A&A 268, 561
Nousek J.A., Shipman, H.L., Holberg, J.B., et al. 1986, ApJ 309, 230
Paerels F.B.S., Heise J. 1989, ApJ 339, 1000
Werner K. 1991, A&A 251, 147
Werner K., Heber U. 1991, A&A 247, 476
Werner K., Koesterke L. 1992, in Atmospheres of Early-Type Stars, eds. U.Heber and C.S.Jeffery, Lecture Notes in Physics 401, Springer, Berlin, p. 288
Werner K., Rauch T. 1994, A&A 284, L5
Werner K., Dreizler S. 1996, in Hydrogen-deficient stars, eds. U.Heber and C.S.Jeffery, The ASP Conference Series, in press
Werner K., Heber U., Fleming T.A. 1994, A&A 284, 907
Werner K., Dreizler S., Wolff B. 1995a, A&A 298, 567
Werner K., Dreizler S., Heber U., et al. 1995b, A&A 298, 567