Astron. Astrophys. 268, 561–569 (1993)

ASTRONOMY AND ASTROPHYSICS

A new PG 1159 star discovered in the ROSAT XRT all sky survey: NLTE analysis of X-ray and optical spectra*

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Received July 4, accepted September 19, 1992

Abstract. We report in this paper on the discovery of a new PG 1159 star in the ROSAT XRT all sky survey. The X-ray source RX J2117.1+3412 is relatively faint (≈0.33 cnt s^{-1}) and was selected for optical identification on the basis of its extreme X-ray softness. With V ≈ 13.2, the counterpart of the X-ray source is in the optical the second brightest member of this class. CCD [O III] imagery reveals that the star is surrounded by an old highly excited planetary nebula of faint surface brightness. Optical line strengths of He II, C IV, and O VI and the overall optical and ROSAT PSPC (0.1-2.4 keV) energy distributions are compared to predictions of NLTE model atmospheres. We find an excellent agreement between the atmospheric parameters derived from optical and soft X-ray data. The effective temperature is close to 150,000 K. Abundances of He, C and O are found to be consistent with those derived in other PG 1159 stars using the same NLTE analysis whereas the surface gravity is significantly smaller in RX J2117.1+3412.

Key words: stars: PG 1159 – stars: atmospheres – stars: white dwarf – stars: evolution – X-ray sources

1. Introduction

From 1990 July 22 till 1991 January 23 the ROSAT satellite has performed the first X-ray (XRT+PSPC) and EUV (WFC) all sky survey made with imaging instruments (Trümper et al. 1983). The median XRT sensitivity is 2-4 10^{-13} erg cm^{-2} s^{-1} in the energy range 0.1-2.4 keV. XRT survey positions are typically better than 30 arcsec (90% confidence radius).

Optical identifications of XRT survey sources proceed in two parallel approaches. The first program aims at a complete identification of all sources contained in small areas for statistical studies, while the second program concentrates on sources selected for their peculiar X-ray or combined X-ray and optical characteristics suggesting the possible identification with a rare (and interesting) kind of emitter.

We report here on a ROSAT source which we have identified with a new PG 1159 star in the framework of the ROSAT Galactic Plane Survey (Motch et al. 1991). The source was selected for optical identification on the basis of its very soft X-ray spectrum.

The PG 1159 stars are hydrogen-deficient pre-white dwarfs representing the hottest stage of post-AGB stellar evolution. These objects are believed to be on the evolutionary path from the Wolf-Rayet central stars of planetary nebulae PNe (spectral type [WC]) and the hottest He-rich white dwarfs (spectral type DO). Because the evolution time is short (some 10^5 yrs in total; e.g. Wood & Faulkner 1986) these stars are rare and their mean distance is significantly larger (1.3 kpc; Werner 1992) than that of known white dwarfs.

Six stars of the 19 currently known objects were subject to quantitative NLTE model atmosphere analyses (Werner, Heber & Hunger 1991, henceforth WHH; Werner & Heber 1991a; Werner 1991) with the result that the effective temperatures range between 100,000 K and 170,000 K. The surface gravities are high (log g =6.5–8) indicating that the PG 1159 stars are about to enter the hot end of the white dwarf cooling sequence. The surface abundances are remarkable: Four of the six analysed stars including the prototype of the PG 1159 class (PG 1159-035) have carbon-helium-dominated atmospheres with a high admixture of oxygen (He/C/O mass ratios = 33/50/17). In another case (PG 1144+005), the oxygen content is substantially lower (1.5%) whereas nitrogen – not detectable in optical spectra of any other PG 1159 star – is exceptionally enriched (1.5%). The most extreme object among the whole PG 1159 sample, however, is the hottest star sofar analysed by model atmosphere techniques: H 1504+65 ($T_{\rm eff}$ =170,000 K). Its atmosphere is vir-

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* Partly based on observations obtained at the Observatoire de Haute-Provence, CNRS, France

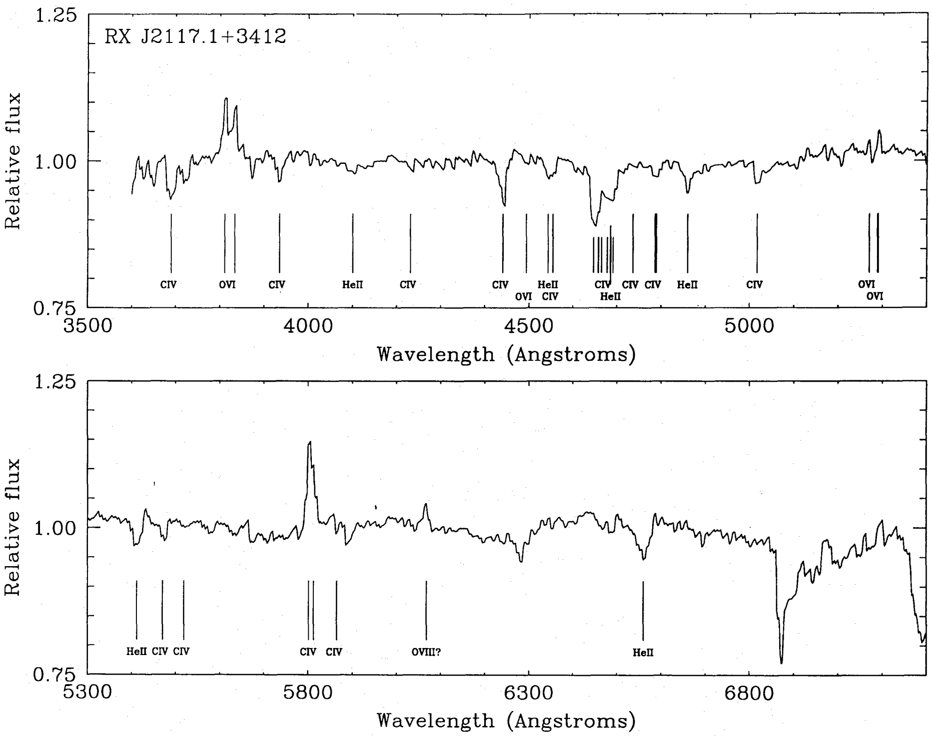

Fig. 1. The low resolution rectified spectrum obtained at OHP on 1991 August 14. A strong C IV λ5801 Å/5812 Å doublet in emission (unresolved with our instrumental setting) and pronounced C IV and He II absorption trough between λ4646 and 4688 Å clearly identify the counterpart of the ROSAT source as a new PG 1159 star

tually free of hydrogen and helium and is composed of equal parts carbon and oxygen.

The optical counterpart of the ROSAT source has become the second brightest member of the PG1159 group just after the central star of the planetary nebula NGC246. Its position close to the galactic plane (b=-10.5°) in a rather dense stellar field and the absence of a conspicuous associated nebula has probably precluded its discovery by the usual optical means. Because of its brightness at optical and X-ray wavelengths, this object is a target of choice for detailed investigations and particularly for testing the consistency of atmospheric models in the X-ray and optical domains and the accuracy of the inferred atmospheric parameters.

In this paper, we report on the optical and X-ray characteristics of this new PG 1159 star and present the first NLTE analysis of a member of this class based on the *combined* modelling of X-ray and optical energy distributions and line profiles.

2. ROSAT survey data

The X-ray source was seen during 32 satellite orbits for a total of 855 sec spread over a time interval of ≈64 hours. About 210 photons were detected, corresponding to an on axis count rate of 0.33 cnt s^{-1} (0.08-0.55 keV). Source mean coordinates computed by the Standard Analysis Software System (SASS; Voges et al. 1992) are α = 21^{h}17^{m}07.6^s, δ = +34°12'22.0" (eq. 2000.0) with a formal 90 % confidence radius of 18 arcsec and without evidence for source extent. X-ray photons collected inside a 15 arcmin radius circle centered on the source position were extracted from the all sky survey. Using the EXSAS system developed at MPE, source photons were accumulated within a circle of 3.2 arcmin radius and the background was estimated from the rest of the extracted area. Count spectra were then corrected for satellite attitude and effects caused by the varying point spread function as the source crosses the detector in survey mode. On the average, the background represents less than 6% of the source intensity. Hardly any photons are detected at energies larger than 500 eV and the count distribution peaks near 200 eV. Accordingly, the first SASS hardness ratio defined as H1 = [(0.4-2.4)-(0.1-0.4)]/(0.1-2.4) with (a-b) being the count rate in the a - b keV band is very negative (soft) H1 = -0.84 ± 0.15. Because of the comparatively low count rate only little information is available on time variability. The 99% confidence upper limit on the semi-amplitude of a modulation at any period larger than 200s is 50%. Therefore, any photospheric X-ray pulsations such as observed in PG 1159-035 (Barstow et al. 1986) would have been undetectable in our data set.

3. Optical observations

From the comparison of the Palomar Observatory Sky Survey O and E plates it was clear that a blue excess object was lying less than 10 arcsec away from the X-ray position. A first low resolution long slit spectrum (FWHM ≈ 10 Å) of this candidate was obtained at the Observatoire de Haute-Provence (France) on 1991 June 8.986 UT using the CARELEC spectrograph (Lemaitre et al. 1990) and the RCA1 SID501 CCD at the 1.93 m telescope.

The hallmarks of PG1159 stars, i.e. a strong C IV λ5801 Å/5812 Å doublet in emission (unresolved with our instrumental setting) and a pronounced C IV and He II absorption trough between λ4646 Å and λ4688 Å were readily detected.

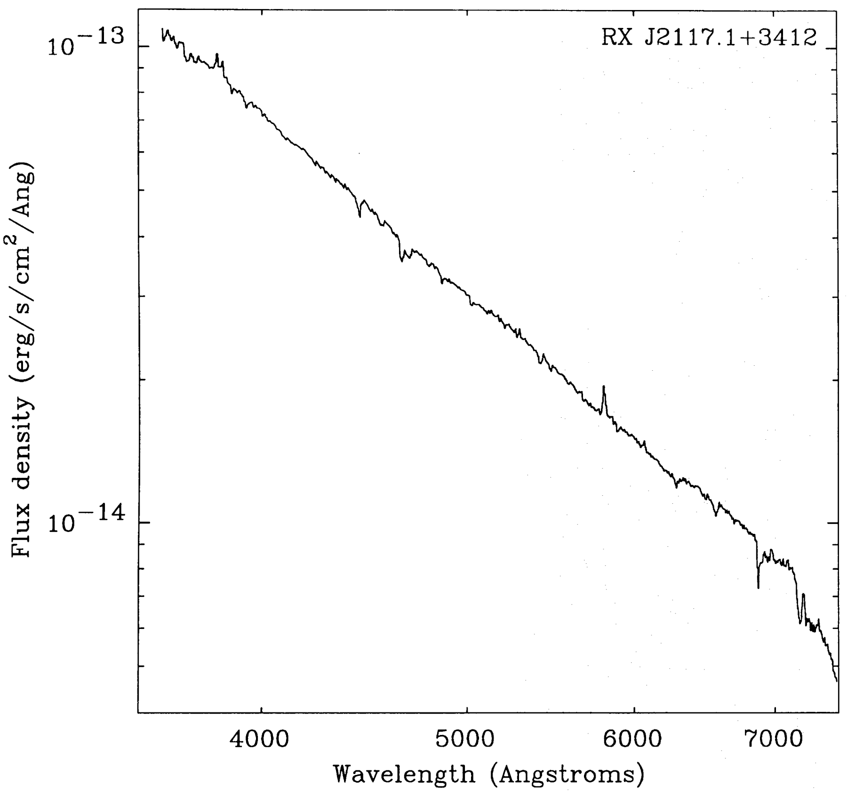

Fig. 2. Same spectrum as in Fig. 1 but flux calibrated using the standard star BD +28 4211 and plotted in $log(flux), log(\lambda)$ units. At optical wavelengths, the energy distribution closely matches that of a Rayleigh-Jeans tail undergoing very little interstellar absorption (E(B-V)=0.05±0.01)

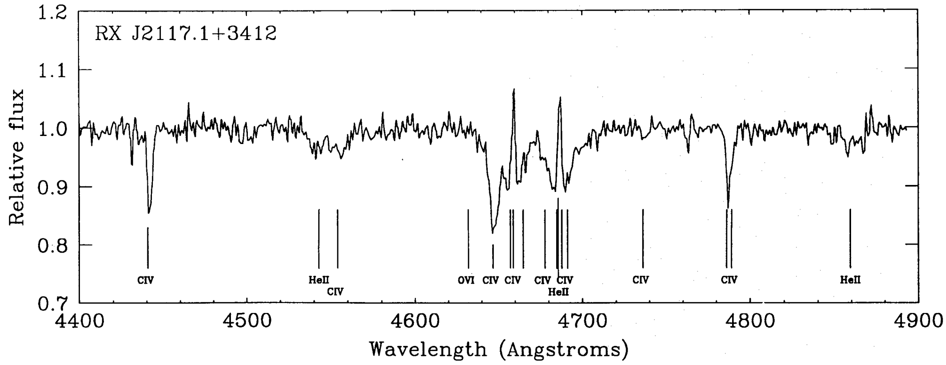

Fig. 3. A medium resolution spectrum obtained at OHP on 1991 November 25. The presence of narrow core emissions from C IV and He II lines in the absorption trough indicates a high effective temperature

On 1991 August 14.023 UT, a second flux calibrated spectrum of higher signal to noise ratio was obtained with the same instrumental setting as in June. The rectified spectrum, shown in Fig. 1 exhibits many lines of He II, C IV and O VI species. Some evidence for the presence of the high excitation O VIII emission line at λ6068 Å may exist. This would be the second detection of O VIII lines in a pre-WD spectrum, besides the hot DO KPD0005+5106 (Werner & Heber 1992). Like in the latter object, the origin of an O VIII line in RX J2117.1+3412 is unclear. Since it is formed by O IX recombination, the extremely high ionization energy of O VIII (871 eV) points at a non-photospheric origin.

Figure 3 shows the flux spectrum calibrated using the standard star BD +28 4211. Since the counterpart of the X-ray source was observed just before the flux standard, at a similar low airmass (1.05) and during a photometric night, we believe that the absolute calibration is probably accurate to a few percents. At optical wavelengths, the energy distribution is compatible with that of a Rayleigh-Jeans tail undergoing a small interstellar reddening of E(B-V)=0.05 $\pm$ 0.01. The corresponding V magnitude is 13.16^m.

Finally, a medium resolution spectrum (FWHM $\approx$ 1.5 Å, $\lambda\lambda$4400-4900 Å) with an exposure time of one hour was obtained on 1991 November 25.833 UT using the same instrumentation as in June and August. Narrow core emissions from C IV and He II lines are clearly visible in the absorption trough (Fig. 3).

RX J2117.1+3412 exhibits several spectral features found in model atmospheres of low surface gravity PG 1159 stars. In particular, the O VI λ5291 Å over C IV λ5801/5812 Å equivalent width ratio is rather small and the C IV and He II absorptions trough wings appear relatively narrow. Since the low gravity old planetary nebula central star K 1-16 displays a very similar optical spectrum (Werner 1992), we searched for a possi-

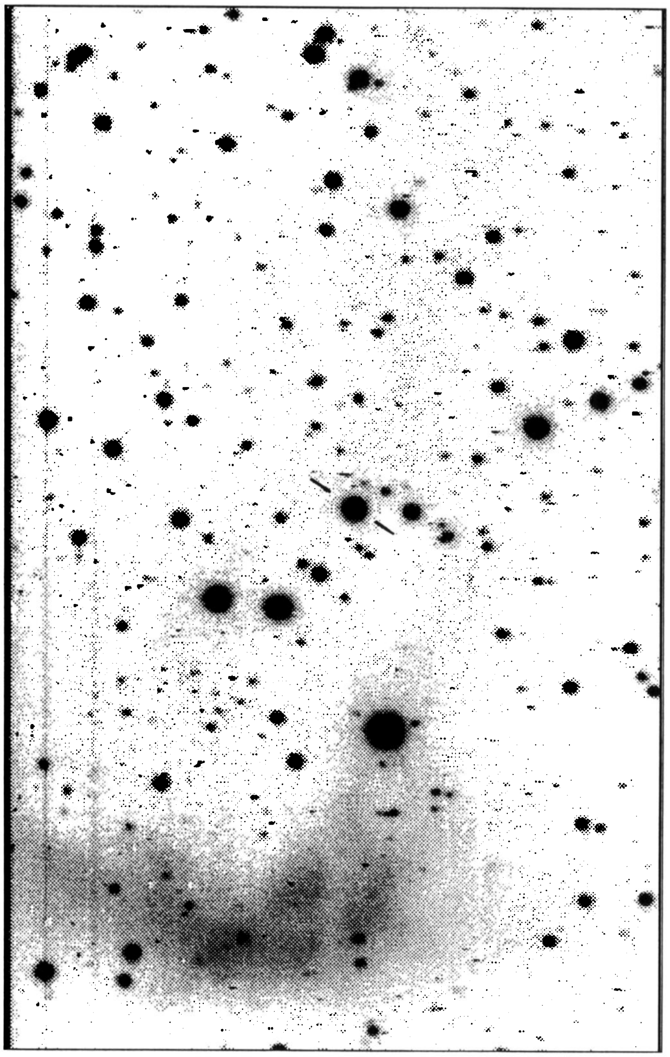

Fig. 4. A 30 minute long exposure obtained with a [O III] λ5007 Å interference filter, centered on the marked optical counterpart of RX J2117.1+3412. North is at the top and East is left. The field of view is 7.1x4.6 arcmin. Diffuse nebular emission is clearly detected southwards from the new PG 1159 star. Long slit spectroscopy reveals the presence of other emission lines such as H α, H β and He II λ4686 in the field of the new PG 1159 star

ble weak nebular emission in the vicinity of the new PG1159 star. On 1991 November 10.766 UT, two CCD images were obtained at the Observatoire de Haute-Provence: a 30 min long exposure taken in the [O III] λ5007 Å line followed by a comparison V band image of exposure time 5min. The 1.2 m telescope equipped with the RCA3 SID 501EX CCD chip has a pixel size of 0.83 arcsec and a full field of view of 7.1 × 4.6 arcmin. As suspected, weak λ5007 Å emission is clearly detected in the vicinity of RX J2117.1+3412. The morphology is that of an arc-shaped nebula southward of the star (see Fig. 4). Moreover, our low resolution spectra (taken with the slit orientated in the E-W direction) reveal in addition to the [O III] lines, nebular H α, H β and He II λ4686 Å emission all along the 5 arcmin covered by the slit. The λ4686 Å/ H β ratio is larger than unity suggesting that the ionizing star is extremely hot and that the nebula is optically thin to the stellar EUV continuum in most directions (Stasinska & Tylenda 1986).

4. Model atmosphere and line formation calculations

For the analysis of optical spectra and ROSAT data a grid of line blanketed NLTE model atmospheres composed of H, He, C, and O was computed. It is an extension of a previously constructed grid for the analysis of PG 1159 stars and it covers the ranges $T_{\rm eff}$ =120,000 K – 160,000 K, log g =5.5 – 6.5 and various element mixtures. The models are plane-parallel and in radiative and hydrostatic equilibrium. Details of the model construction (atomic data, model atoms, line broadening) may be found in WHH.

The NLTE model code is based on the so-called Accelerated Lambda Iteration (ALI) technique (Werner 1988). The latest improvements concerning efficiency and capacity of the numerical method are described by Dreizler & Werner (1991, 1992).

The continuum flux of the models is used for the calculation of theoretical ROSAT count rates. Despite the complexity of the employed model atom which is required to properly model the EUV continua (Werner & Heber 1991b) the atomic population numbers still need further improvement for the calculation of realistic line profiles. This is done by subsequent line formation computations (i.e. pressure and temperature stratifications are kept fixed) with even more detailed carbon and oxygen model atoms.

5. Fit procedure and results

The analysis of RX J2117.1+3412 was performed assuming a He/C = 2 abundance ratio (by number), a typical value that was found for five PG 1159 stars. Results of the final fits justify this assumption in retrospect. We chose He/H = 47.5 which is a value that is in concordance with the fact that hydrogen is not detected in the spectra. Due to the high effective temperatures this low hydrogen abundance causes no effects on the emergent model fluxes, i.e., hydrogen is virtually absent. Then we started to compute models with different $T_{\rm eff}$, log g and O/He abundance ratios in order to fit the observed ROSAT energy distribution. This procedure was guided by the comparison of theoretical line profiles with optical observations, which helps to prevent "exotic" solutions from the X-ray data alone and which helps to reduce the number of model computations.

5.1. Fitting the ROSAT energy distribution

Spectral fitting was carried out using the EXSAS system. Raw count spectra were rebinned in order to yield an energy resolution consistent with the instrument's capability. The PSPC detector response matrix used here is the latest available and is also the most accurate at low energies. The X-ray normalization of each test model atmosphere was fixed in the fit and computed from the mean optical flux between $\lambda\lambda$4000 and 6500 Å

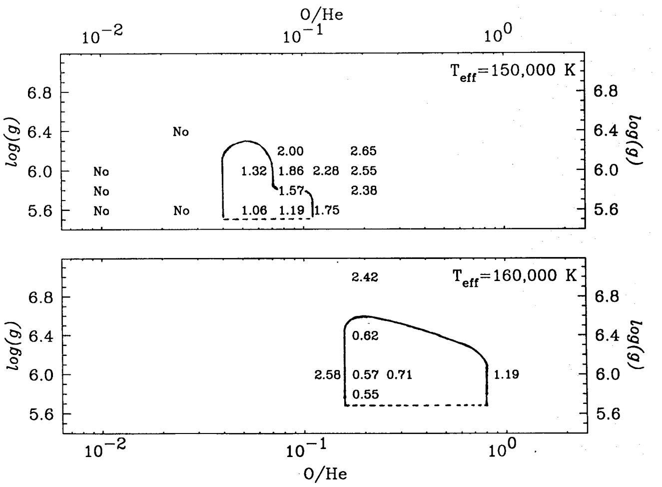

Fig. 5. Best fit values of $\chi^2_9/9$ obtained for the different atmospheric models tested. For each trial, the normalization of the X-ray spectrum was fixed by the optical flux density as measured from Fig. 3 and the interstellar absorption was the only free parameter. Atmospheres with effective temperatures lower than 140,000 K do not yield good fits while effective temperatures in excess of 160,000 K request O/He abundances larger than acceptable from optical line profiles. 'No' means that no reasonable fit could be obtained for the parameter values. For each $T_{\rm eff}$ considered, the contour sketched encloses the $\log g$ - O/He region acceptable at the 90% confidence level. The lower limit on $\log g$ is set by the Eddington limit. X-ray data provide a lower limit on O/He of $\approx$0.04 for $T_{\rm eff}$ =150,000 K and constrain $\log g$ to be less than $\approx$6.6.

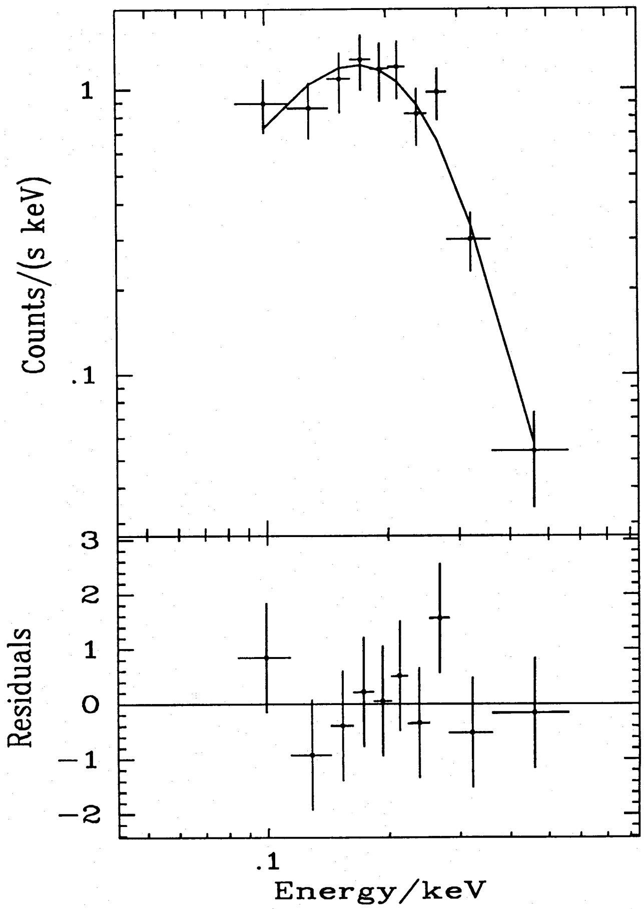

Fig. 6. One of the best fit model atmosphere to the ROSAT data. The non-LTE model shown here folded through the PSPC detector response has $T_{\rm eff}$ =160,000 K, $\log g$ =5.8 and O/He=0.20. Best fit Nh is 3.2 10^{20} H atom cm^{-2}.

as observed on 1991 August 14. In a first step, the normalization was computed assuming negligible interstellar absorption in the optical. Each model was then matched to the observed X-ray energy distribution by fitting the interstellar absorption. In a second step, the optical flux was corrected for the absorption found in X-rays and a new fit was done using the improved normalization. In all cases, the correction applied in the second step yielded only negligible changes in the best fit parameters.

In the ROSAT PSPC energy range, the most prominent spectral feature is the sharp O VI edge at 126 eV which determines almost completely the soft X-ray energy distribution. In terms of detected photons, the strong drop in flux over the edge is compensated to some extent by the steep increase of the PSPC effective area toward higher energies and by the effects of interstellar absorption. As expected, the height of the O VI edge strongly depends on the assumed oxygen abundance and increases significantly with surface gravity. In the range explored here (140,000-160,000 K), increasing the effective temperature does not significantly change the relative amplitude of the photon flux drop at 126 eV but raises the overall X-ray continuum. This last effect can be in part compensated by a simultaneous increase of the interstellar absorption (essentially efficient in decreasing the X-ray flux before the O VI edge) and of the oxygen abundance which dims the X-ray flux at higher energies.

With the spectral normalization determined from optical data, none of the models with effective temperatures $T_{\rm eff} \leq$ 140,000 K gives an acceptable fit to the PSPC data. However, we cannot rule out the possibility that for $T_{\rm eff}$ = 140,000 K some good fit is obtained for a narrow range of $\log g$ and O/He parameters. We show in Fig. 5 the reduced χ^2 values in the $\log g$ versus O/He diagram for $T_{\rm eff}$ = 150,000 K and $T_{\rm eff}$ = 160,000 K. As the effective temperature increases, the best fit oxygen abundance moves toward larger values while the allowed $\log g$ range widens. The lower limit on $\log g$ is set by the Eddington limit whereas the upper limit is $\log g$ $\approx$6.6 for T=160,000 K. No strong lower limit on the oxygen abundance can be clearly set from our X-ray analysis since we did not investigate with enough detail models with effective temperature between 140,000 and 150,000 K. Figure 6 shows one of the best fit models to ROSAT X-ray data.

We estimate that the combined errors on the optical spectrophotometry and on the absolute flux calibration of ROSAT data are less than 15 %. Changing the assumed normalization by this amount has virtually no effect on the best fit χ^2 values and parameters.

The best fit Nh varies in a narrow range from 2.6 to 3.2 10^{20} H atoms cm^{-2} which corresponds to E(B-V)=0.03-0.06 (Ryter et al. 1975). Although this could be a chance coinci-

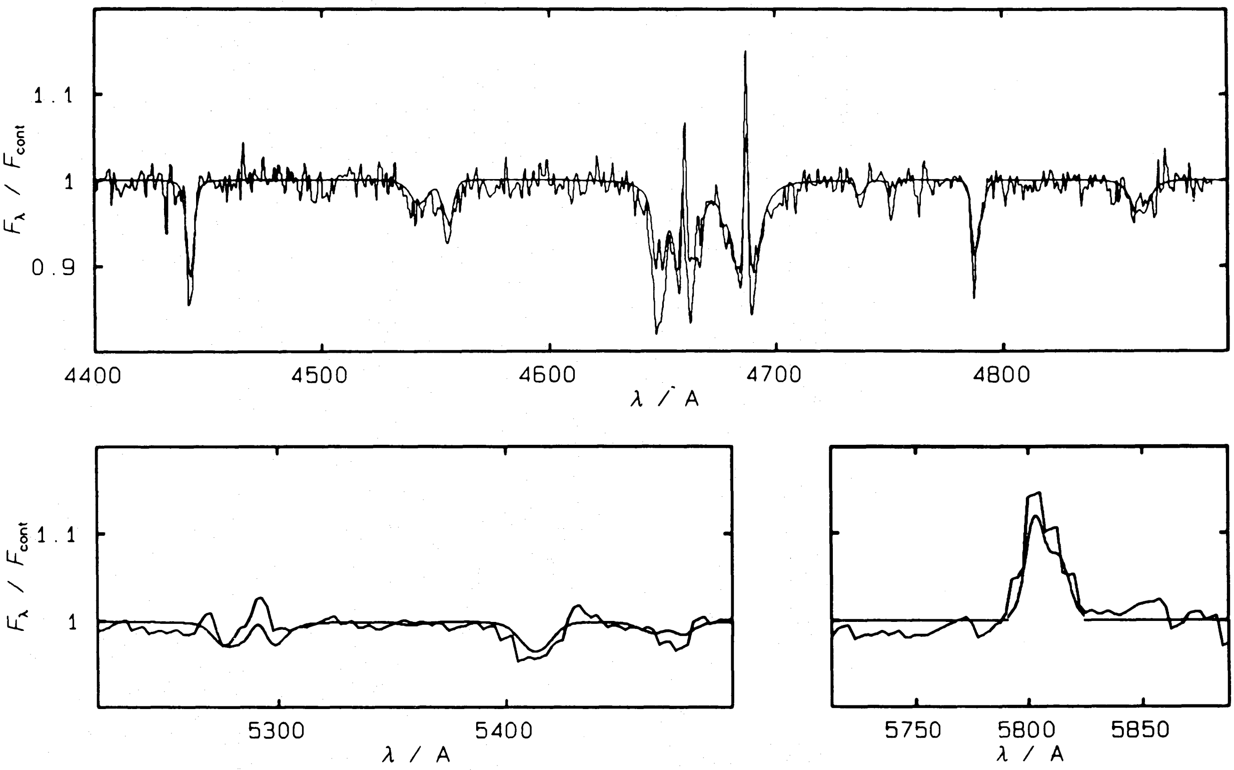

Fig. 7. Non-LTE line profile fits to the spectrum of the new PG 1159 star. a) top: the characteristic absorption trough region, b) bottom left: the O VI complex near 5291 Å and the He II 5411 Å and C IV 5471 Å lines, c) bottom right: the C IV 5801 Å/5812 Å emission doublet (unresolved). The model parameters are those of Fig. 6: $T_{\rm eff}$ =160,000 K, log g =5.8, He/C/O=5/2.5/1 (abundance ratios by number). The computed profiles are folded with a Gaussian to match the resolution of the spectra: FWHM = 1.5 Å (top) and 10 Å (bottom panels)

dence, considering the likely unnoticed presence of systematic effects in the absolute optical spectrophotometry, the colour excess computed from the slope of the optical energy distribution (E(B-V)=0.05 $\pm$ 0.01) is in close agreement with that derived from X-ray data.

5.2. Fitting the optical line profiles

Figure 7a shows the spectrum of RX J2117.1+3412 in the absorption trough region together with a synthetic spectrum of the model that fits the ROSAT data best ($T_{\rm eff}$ =160,000 K, log g =5.8, O/He=0.2 by number). The general quality of the fit is good. The strongest absorption features are satisfactorily reproduced as well as the two prominent central emission reversals of C IV 4659 Å and He II 4686 Å. Small discrepancies detectable in the line cores are not removed by other model parameters. In particular, the mismatch of the absolute peak heights of the emissions as well as the too shallow line core of C IV 4647 Å may be suspected to be due to inaccurate electron collisional data used (see discussion in WHH). Additionally, RX J2117.1+3412 is close to the Eddington limit so that the line cores might be affected by wind-effects which, of course, are beyond the scope of our static models.

All but one of the strong features in the low resolution optical spectra are also matched by the synthetic line profiles, but the observations are of limited use for a further constraint of the model parameters. Especially the O VI 5291 Å transition (Fig. 7b) is a good oxygen abundance indicator, but the present data does not allow us to resolve the shallow absorption wings and the central emission. However, there is a tendency for the computed profile to have too strong wings and a too weak emission, indicating that the oxygen abundance is probably smaller. Therefore we consider the O/He=0.2 ratio as an upper limit and fix the ratio as O/He = 0.05 $^{+0.15}_{-0.03}$. The accepted lower oxygen abundance does not affect the determination of other model parameters within the error limits.

It has been shown by WHH that the C IV 5801 Å/5812 Å doublet, appearing in emission if $T_{\rm eff}$ exceeds 120,000 K, is very sensitive to temperature and gravity variations. The model fit to this doublet, whose components are unresolved in our spectra, is very good (Fig. 7c). The O VI 3811 Å/3834 Å doublet, is the only line that cannot be reproduced by our models. While it is observed in emission, the model predicts a weak absorption line. This qualitative drawback cannot be removed, unless the effective temperature of the model is unrealistically high. We are convinced that the emission feature is due to wind effects.

It is worth mentioning that the N V 4604 Å/4620 Å doublet is not detected in our spectra. Werner & Heber (1991a, their Fig. 6) have published extensive nitrogen line formation calculations from which we can deduce an upper limit of the nitrogen abundance. Given the high $T_{\rm eff}$ and the low gravity of

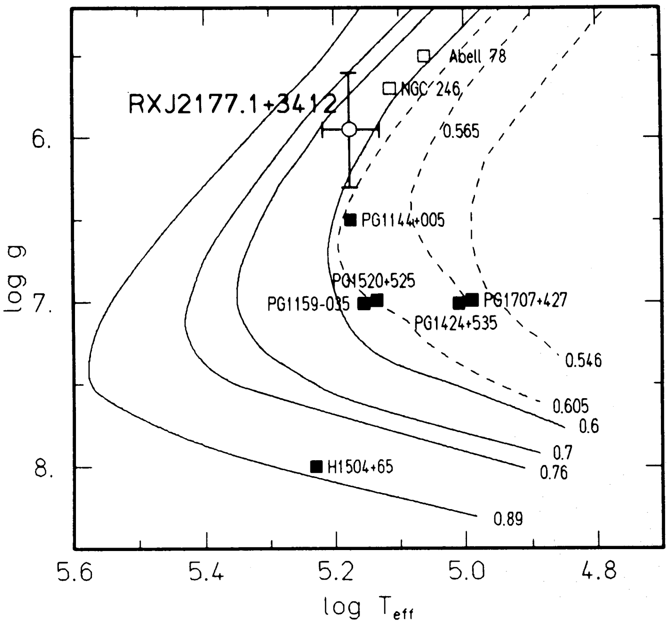

Fig. 8. Position of RX J2117.1+3412 in the $\log g$ versus $\log T_{\rm eff}$ diagram. Also given are the positions of six previously analysed PG 1159 stars (filled squares, no associated PN), another PG 1159-type central star (NGC 246) and the [WC]-PG 1159 transition object Abell 78 (open squares, associated PN). Evolutionary tracks are labelled with the respective stellar masses (in $M_\odot$). Dashed: H burners, solid: He burners.

RX J2117.1+3412, the N v doublet would certainly be detectable if the abundance exceeds N/He = 10^{-3} (by number).

5.3. Combined X-ray and optical analysis

Effective temperatures in excess of $\approx$160,000 K, although acceptable by the X-ray data alone, would imply an oxygen abundance larger than the upper limit of O/He = 0.20 set from the optical line fits. The best fit optical O/He value is identical to the best fit X-ray value for $T_{\rm eff}$ = 150,000 K. Finally, the $\log g$ range independently determined at optical and X-ray energies are fully consistent. To summarize, we find a complete agreement between the atmospheric parameters determined at optical wavelength and in the ROSAT PSPC energy range and we adopt the following for RX J2117.1+3412:

$$T_{\rm eff} = 150{,}000\,{\rm K} \pm 15{,}000\ {\rm K}$$
$$\log g = 5.6 - 6.3$$
$${\rm C/He} = 0.5\,^{+1.1}_{-0.34}$$
$${\rm O/He} = 0.05\,^{+0.15}_{-0.03}$$
$${\rm N/He} < 10^{-3}$$

The error estimates for $T_{\rm eff}$, $\log g$, and the C/He abundance ratio are similar to those of previously performed analyses. The oxygen abundance has a large uncertainty for reasons discussed above. Higher resolved optical spectra would reduce the possible error and in turn the errors in $\log g$ and $T_{\rm eff}$ derived from X-ray data. As has been stressed in previous analyses of PG 1159 stars, we reiterate that the presence of traces of hydrogen cannot be excluded due to the high effective temperatures. Assuming the absence of hydrogen, we obtain for the abundance fractions He/C/O = 37/56/7 (in % by mass), or He/C/O = 65/32/3 (in % by number).

5.4. Mass, luminosity, distance

Figure 8 shows the position of RX J2117.1+3412 in the $\log g$ - $\log T_{\rm eff}$ diagram together with evolutionary tracks for He burning post-AGB stars (Wood & Faulkner 1986) and for H burners (Schönberner 1983; Blöcker & Schönberner 1990). Comparison with the Wood & Faulkner tracks yields the following mass and luminosity:

$$M/M_\odot = 0.65\,^{+0.2}_{-0.1}$$
$$\log L/L_\odot = 3.95 \pm 0.5$$

We note that the stellar evolutionary models assume an outer envelope of almost pure helium. Obviously, this is in conflict with the derived photospheric abundances, which are typical for deep intershell matter (see discussion below) and one might suspect a systematic error in our mass determination. However, the evolution of a single post-AGB remnant ($M=0.84M_\odot$) has been computed (Schönberner & Blöcker 1992) which experienced mass-loss until the C/O core became exposed. The track is essentially the same as in the case of a pure helium envelope, only the evolutionary time scale is somewhat different. From this study we may conclude that no systematic error in the mass determination occurs.

The distance of RX J2117.1+3412 is determined from its gravity and angular diameter. The latter is derived by comparison of the measured visual flux (V=13.2) to the model flux (parameters: $T_{\rm eff}$ =160,000 K, $\log g$ =6, H/C/O=5/2.5/1 number ratios): H_ν[5400 Å]=2.75 $\cdot$ 10^{-3} erg cm^{-2} s^{-1} Hz^{-1}:

$$d\,[{\rm kpc}] = 1.4\,^{+0.7}_{-0.5},$$

corresponding to a height of 250^{+120}_{-80} pc below the galactic plane. Interstellar reddening is low (see above) and negligible here. Spectral and photometric data extracted from the Simbad data base indicate that the mean reddening of the 4 B-type stars located in the direction of RX J2117.1+3412 (HR 8146, HD 203921, HR 8215 and HR 8338) is E(B-V)=0.07 $\pm$ 0.05 up to $\approx$ 600 pc. Therefore, the spectroscopic distance is probably compatible with the interstellar column density derived from optical and X-ray data.

6. Discussion and conclusions

The excellent agreement of the optical and X-ray fits of non-LTE theoretical atmospheres strongly suggests that these models correctly describe the energy distribution of PG 1159 stars. ROSAT offers for the first time enough energy resolution and sensitivity to efficiently constrain the stellar atmospheres of these very hot stars. This is of particular importance when studying for instance, the ionizing radiation field which excites the surrounding planetary nebulae.

Abundances found here for RX J2117.1+3412 are consistent with those derived by WHH from an optically based NLTE analysis of four PG 1159 stars. The only remarkable difference is the significantly lower surface gravity of RX J2117.1+3412 compared to log g=7 found by WHH. In order to explain the surface abundances, WHH proposed that the PG 1159 stars are successors of the so-called "born-again AGB stars" which, according to a scenario developed by Iben et al. (1983), have suffered a late He-shell flash on their way from the AGB to the white dwarf configuration. As a consequence, the stars climb back onto the AGB and retrace their post-AGB evolution for a second time. By the onset of a second superwind phase on the AGB and additional mass-loss during the repeated descent from the AGB, the H-rich and most (or all, in the case of H 1504+65) of the He-rich envelope is removed and deep intershell layers rich in He and C become visible at the surface. An evolutionary link between the Wolf-Rayet [WC] central stars of planetary nebulae, the PG 1159 stars and the DO white dwarfs is now evident, in fact, nine PG 1159 stars have an associated PN.

So far, all low gravity PG 1159 stars (K 1-16, NGC 246 [see spectra in Werner 1992], Longmore 4 [Werner et al. 1992], RX J2117.1+3412, as well as the [WC]–PG 1159 transition object Abell 78 [Werner & Koesterke 1992]) have an associated PN, whereas the four PG 1159 stars with higher gravity have no detectable nebulae. Two other analysed PG 1159 stars with a higher gravity than RX J2117.1+3412 also lack a PN (PG 1144+005 and H 1504+65 having log g=6.5 and 8, respectively, see Fig. 8). This finding is in qualitative agreement with the idea that the high gravity PG 1159 stars are more evolved and that their PNe have dispersed. As an example, the post-AGB age (starting with the 2nd descent from the AGB) of RX J2117.1+3412 is $\leq$ 3000 years compared to the age of PG 1159-035 which is about 20,000 years (cf. Wood & Faulkner 1986, their Fig. 1d), or compared to H 1504+65 whose age is more than 30,000 years (Schönberner & Blöcker 1992). However, the picture is not so simple, because "old" high gravity PG 1159 stars with an associated PN have also been discovered (IW 1 and Jn 1, Schönberner & Napiwotzki 1990). Apparently, by some unknown reasons (e.g. moment when He flash starts, i.e., duration of first descent from the AGB) there is an overlap in the HR diagram between the PG 1159 central stars and those objects that lack a PN.

The PG 1159 stars define a new instability strip in the HR diagram. Seven out of 15 investigated objects are low-amplitude non-radial g-mode pulsators. The photospheric abundances support the hypothesis that the pulsations are driven by cyclic ionization of C and O close to the surface layers (Starrfield et al. 1984). Many details about the pulsation strip are still poorly known and more spectroscopic analyses are needed to improve our understanding. In this respect, planned photometric observations of RX J2117.1+3412 and comparison with its spectroscopic twin K 1-16 using non-LTE atmospheric model fitting might shed some light onto the limits of the PG 1159 instability strip and may help to put the pulsational analyses onto firmer grounds.

RX J2117.1+3412 is after H1504+65 (Nousek et al. 1986) the second PG 1159 star discovered on account of its X-ray emission. The lack of a conspicuous nebula on optical survey photographic plates and stellar crowding which renders difficult optical search for UV excess objects may explain why this star was not known before ROSAT in spite of its relative optical brightness. Assuming a scale height of 190 to 250 pc for Planetary Nebulae (Zijlstra & Pottasch 1991) and a detection threshold in the ROSAT survey of 0.03 cnt s^{-1}, i.e. 3 times farther than RX J2117.1+3412 for the same Nh, we expect that several such new stars may be discovered in the ROSAT Galactic Plane Survey.

Acknowledgements. The ROSAT project is supported by the Bundesministerium für Forschung und Technologie (BMFT). C.M. acknowledges support from a CNRS-MPG cooperation contract and thanks Prof. J. Trümper and the ROSAT group for their hospitality. K.W. is supported by BMFT under grant 50 OR 9007 3. M.W.P. acknowledges support by BMFT. This research has made use of the Simbad database operated at CDS, Strasbourg, France.

References

Barstow, M.A., Holberg, J.B., Grauer, A.D., Winget, D.E., 1986, ApJ 306, L25.
Blöcker, T., Schönberner, D., A&A 240, L11.
Dreizler, S., Werner, K., 1991, in Stellar Atmospheres: Beyond Classical Models, eds. L.Crivellari, I.Hubeny and D.G.Hummer, NATO ASI Series C, Vol. 341, p. 155
Dreizler, S., Werner, K., 1992, in Atmospheres of Early-Type Stars, eds. U.Heber and C.S.Jeffery, Lecture Notes in Physics, Vol. 401, Springer, Berlin, p. 436
Iben, I., Jr., Kaler, J.B., Truran, J.W., Renzini, A., 1983, ApJ 264, 605.
Lemaitre, G. Kohler, D., Lacroix, D., Meunier, J.P., Vin, A., 1990, A&A 228, 546.
Motch, C., Belloni, T., Buckley, D., Gottwald, M., Hasinger, G., Pakull, M.W., Pietsch, W., Reinsch, K., Remillard, R.A., Schmitt, J.H.M.M., Trümper, J., Zimmermann, H.-U., 1991, A&A 246, L24.
Nousek, J.A., Shipman, H.L., Holberg, J.B., Liebert, J., Pravdo, S.H., White, N.E., Giommi, P., 1986, ApJ 309, 230.
Ryter, C., Cesarsky, C.J., Audouze, J., 1975, ApJ 198, 103.
Schönberner, D., 1983, ApJ 272, 708.
Schönberner, D., Napiwotzki, R., 1990, A&A 231, L33.
Schönberner, D., Blöcker, T., 1992, in Atmospheres of Early-Type Stars, eds. U.Heber and C.S.Jeffery, Lecture Notes in Physics, Vol. 401, Springer, Berlin, p. 305
Starrfield S., Cox A.N., Kidman R.B., Pesnell W.D., 1984, ApJ 281, 800.
Stasinska, G., Tylenda, R., 1986, A&A 155, 137.
Trümper, J., 1983, *Adv. Space. Res.*, **2**, 241
Voges, W., Gruber, R., Paul, J., Bickert, K., Bohnet, A., Bursik, J., Dennerl, K., Englhauser, J., Hartner, G., Jennert, W., Köhler, H., Rosso, C., 1992, in proceedings of the European ISY meeting: "Space Science with particular emphasis on High Energy Astrophysics", Munich, April 1992.
Werner, K., 1988, A&A 204, 159.
Werner, K., 1991, A&A 244, 437.
Werner, K., 1992, in Atmospheres of Early-Type Stars, eds. U.Heber and C.S.Jeffery, Lecture Notes in Physics, Vol. 401, Springer, Berlin, p. 273
Werner, K., Heber, U., 1991a, A&A 247, 476.
Werner, K., Heber, U., 1991b, in Stellar Atmospheres: Beyond Classical Models, eds. L.Crivellari, I.Hubeny and D.G.Hummer, NATO ASI Series C, Vol. 341, p. 341

Werner, K., Heber, U., 1992, in Atmospheres of Early-Type Stars, eds. U.Heber and C.S.Jeffery, Lecture Notes in Physics, Vol. 401, Springer, Berlin, p. 273

Werner, K., Koesterke, L., 1992, in Atmospheres of Early-Type Stars, eds. U.Heber and C.S.Jeffery, Lecture Notes in Physics, Vol. 401, Springer, Berlin, p. 288

Werner, K., Heber, U., Hunger, K., 1991, A&A 244, 437. (WHH)

Werner, K., Hamann, W.-R., Heber, U., Napiwotzki, R., Rauch, T., Wessolowski, U., 1992, A&A in press

Wood, P.R., Faulkner, D.J., 1986, ApJ 307, 659.

Zijlstra, A.A., Pottasch, S.R., 1991, A&A 243, 478.

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