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LETTER

Letter to the Editor

Weak emission line [WELS] central stars of planetary nebulae are [WC]-PG1159 stars*

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Abstract. The characteristics of the spectra of weak emission line stars (WELS) are found to be very similar to that of [WC]-PG1159 and PG1159 objects. On the basis of the spectra we find 31 WELS central stars of planetary nebulae to be in fact [WC]-PG1159 stars. These stars mark the transition from the [WC] central stars of planetary nebulae to the PG1159 (pre-)white dwarfs. The evolutionary sequence appears to be [WC late] - [WC early] - WELS = [WC]-PG1159 - PG1159. The presence of nebulae and dust shells around these stars and also the significant percentage of [WC]-PG1159 stars among the [WC] central stars of PN indicates that late He-flash scenario may not be the principal mechanism for their post-AGB evolution towards the non-DA white dwarf stage.

We found 4 hybrid central stars. They display a HeII/CIV 4650 - 4686Å trough very similar to that of PG1159 stars. However, their spectra show stellar Balmer lines indicating that they are relatively hydrogen-rich in contrast to the PG1159 stars.

Key words: stars: post-AGB – stars: carbon – stars: evolution – ISM: planetary nebulae – stars: emission-line

1. Introduction

About 7 percent of the known central stars of planetary nebulae (CSPN) show Wolf-Rayet (WR) spectrum falling all in the [WC] class (Acker et al 1992). It is not yet understood why some CSPN show emission lines spectrum. Acker et al (1996) and Pottasch (1996) noted that PN with [WC] central stars are similar in almost all ways to all other PN in their spatial distribution, radial velocities, temperature distribution, nebular abundances, surface gravities at comparable temperatures, and luminosity distribution. There is no evidence that [WC] central stars have on an average, higher core mass than other central stars, nor higher luminosities, nor do they evolve relatively more faster. The nebular abundances of PN with [WC] central stars are very similar to that of all other PN even though the central stars are helium and carbon rich. All central stars with WR spectrum fall in the subclass [WC]. There are no well established cases of WN central stars.

The distribution of the spectral types of [WC] stars shows that most of them are either early type [WC2 -4] and late type [WC9 - 11]. The reasons for the paucity of [WC5-7] types is not clear. Acker, Górny and Cuisinier (1996) classified the central star of M1-25 to be [WC6]. It is the only [WC6] star known so far. The temperatures range from 20,000 K for few of the [WC11] stars to as much as 150,000 K for the [WC2] and [WC3] stars. The [WC2] includes the O VI central stars. Heap (1982) precedes the O VI type with a WC type and a numerical subclass. Méndez (1991) find that most of the WC CSPN are helium-rich and hydrogen poor. He grouped the helium -rich CSPN into O(He), O(C), Of(C), Of-WR(C). The O(He) and O(C) stars show predominantly an absorption line spectrum dominated by helium and carbon. The Of(C) and Of-WR(C) central stars are defined by the He II-line as the criteria and the spectrum is dominated by strong C emissions. The Of-WR(C) central stars show mass-loss features but otherwise resembles the very hot PG 1159 stars composed mainly of carbon, oxygen and helium. Only a handful of [WC]-PG1159 stars is known so far (Schönberner & Napiwotzki, 1990).

Tylenda, Acker and Stenholm (1993) determined the [WC] subclasses for a large number of CSPN. They found several "weak emission line central stars" (WELS) which have the C IV 5805Å line systematically weaker and narrower than early [WC] CSPN and also the CIII 5695Å line is very weak or undetectable. The spectra used by Tylenda et al (1993) were of low resolution (8Å at 5000Å) and often the signal-to-noise ratio was about 10.

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* Based on observations obtained at the European Southern Observatory (ESO), La Silla, Chile

A spectroscopic study (with better resolution and signal-to-noise ratio) of [WC] CSPN and their nebulae was initiated at the Strasbourg Observatory in order to further understand their evolution and relation to other hot CSPN.

In this paper we report that the spectral characteristics of WELS CSPN are very similar to those of [WC]-PG 1159 stars. On the basis of the spectral features of the central stars at 4650 - 4686Å and 5806Å we detected 31 new [WC]-PG 1159 stars.

2. Observations

The [WC] type CSPN were selected from the catalogue of Acker et al (1992). Spectra of about 90 CSPN were obtained in 1994, March and July, and 1995, July, with the Boller and Chivens Spectrograph with CCD detector on the 152 cm telescope at ESO. The spectra cover the wavelength range 3700Å to 7500Å, with a spectral resolution of 1500. In order to observe the central star continuum and stellar emission lines with a high signal - to-noise ratio, we adopt an exposure times of 40 minutes.

The stellar emission lines used for the classification of [WC] stars are: O VI 3811Å and 3834Å, CIV 4651Å - 4658Å, He II 4686Å, O VI 5290Å, OV 5471 and 5595Å, O VII 5670Å, CIII 5696Å, and C IV 5806Å. We have detected the stellar carbon features in 63 CSPN. About 30 CSPN are classified as weak emission line stars (WELS). The results of [WC] stars will be published in a separate paper. In this paper we discuss the spectra of WELS.

3. Analysis of weak emission line stars

In the spectra of about 30 CSPN we find relatively weak and narrow emission lines of C IV 5806Å and 4650 - 4686Å CIV - HeII (Fig. 1). In most of these stars the O V and O VI emission lines are very weak or absent. The presence of the C IV 5806Å and 4650 - 4686Å features and the absence of the CIII 5696Å line indicates that these stars belong to the [WC2] and [WC3] type. However here the C IV 5806Å line is relatively weak and narrow, and the 4650 - 4686Å feature appears as a broad absorption due to C IV and He II, often accompanied by central emission reversals and /or absorption lines due to He II and C IV. In several of the WELS stars we find the He II 5412Å line in absorption (Fig. 1). In NGC 6629 and NGC 6891 the He II 4541 line appears also in absorption. In M1-46 we find He II 5412Å and C IV 5806Å absorption lines. Also at 5590Å we find an absorption line probably due to O V in the spectra of some of these stars (for example: M1-46, Cn3-1). Now, on the basis of the 4650 - 4686Å and the 5806Å CIV features, we compare the spectra of WELS to that of PG 1159 stars.

Schönberner and Napiwotzki (1990) showed that several CSPN are spectroscopically indistinguishable from PG 1159 pre white dwarfs. The PG 1159 objects have a broad He II and C IV absorption near 4650 -4686Å and the O VI emission is very weak or absent. The 4650 - 4686Å feature and the 5806Å feature in the WELS CSPN is similar to that observed in the spectra of central stars of Abell 30, Abell 78, NGC 6567, NGC 6578 and Longmore 4 at outburst, which are considered as [WC]-PG 1159 type stars (Hamann 1996).

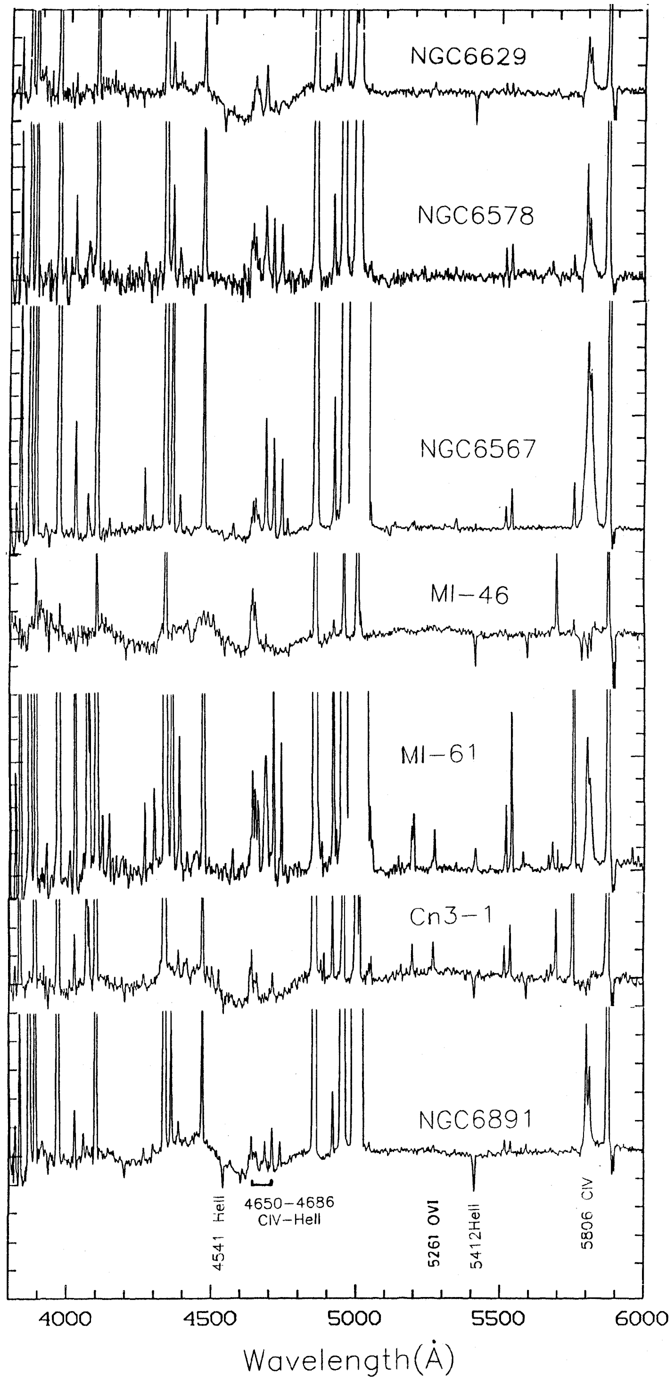

Fig. 1. Spectra of several new [WC]-PG1159 stars = WELS.

The first detection of a new hot non-DA pulsating white dwarf: PG 1159 -035 (Mc Graw et al, 1979) revealed a broad absorption around 4650-4686Å due to C IV and He II accompanied by central emission reversals. The broad HeII/C IV absorption complex some times with NLTE emission cores is the spectroscopic hallmark in the optical to identify PG 1159 stars (Werner,1992, Napiwotzki, 1992, Dreizler et al, 1995).

Based on the 4650-4686Å absorption, the PG 1159 stars are divided into three groups. Group 1 = A (absorption) shows pure absorption in the trough. Group 2 = E (emission) exhibits emission cores in He II 4686Å, C IV 4659Å, and 4647Å (for example: PG 1520 + 525, PG 1159-035, PG 1144 + 005). Group 3 = lg E (low gravity emission) represented by K1 - 16 and NGC 246. The Group 3 objects comprise relatively low gravity central stars (no such object without a PN has been found). Like the stars in Group E they exhibit two strong central emissions but C IV 4647Å is in absorption. The C IV 5801/ 5812Å doublet is a weak and narrow emission feature in Group E and also in low gravity PG 1159 stars, and appears in absorption in some cases (example PG 0122 + 200).

We compared the spectra of WELS CSPN with the spectra of PG1159-035, Jn1, A30, A78 and also with the spectra of several PG1159 and related stars displayed in the papers by Napiwotzki and Schönberner (1995) and Werner (1992). We find that most of the WELS can be assigned to Group 2 = E(emission) class of PG1159 stars. The central stars of M1-46 and Cn3-1 show the CIV 5806Å feature in absorption, which is similar to that found in the Group 1 = A(absorption) class of PG 1159 stars. However the 4650 - 4686Å feature is similar to that seen in Group 2 objects. We have not found a Group 1 = A(absorption) (pure absorption in the trough) object in the WELS CSPN. Because of the moderate resolution of our spectra it may not be possible to distinguish Group 2 and Group 3 objects. On the basis of the spectral chracteristics of WELS we conclude that these stars mark the transition from the [WC] central stars of planetary nebulae to the PG1159 (pre-)white dwarfs ([WC]-PG1159). In Table 1 we give a list of 31 [WC] - PG 1159 stars discovered from our present analysis. The spectra of some these stars are shown in Fig. 1.

The definitive classification of a few CSPN (M1-62, NGC 6818, NGC 6803, SP4-1, IC 5217, Cn2-1), classified as WELS by Tylenda et al (1993), needs spectra with better resolution and signal to noise ratio. We have also studied the spectra of normal [WC] stars of early and late type. We have not found the [WC]-PG1159 spectral characteristics in the late type [WC9-11] stars. Tylenda et al. (1993) classified SwSt1 as WELS. The spectra used by Tylenda et al. were of low resolution and low signal to noise ratio. We have compared our spectrum of SwSt1 with the spectra of several [WC9-11] stars. On the basis of the ratios of the strengths of stellar CII, CIII, and OV lines we find that SwSt1 is a [WC10] star. The 5806Å feature in its spectrum is peculiar.

There seems to be clear separation of the [WC]-PG1159 stars from the normal [WC] stars. Four stars listed in Table 1 were earlier classified as either Of(H) (NGC 6629, NGC 6891) or Of(H)-WR(H) (NGC 6572, NGC 6543) (Méndez 1991). The presence of hydrogen lines in these stars is shown in Méndez et al. (1988,1990). However we find that the spectra of the central stars of NGC 6629 and NGC 6891 to show the 4650-4686Å absorption trough, absorption lines of helium and the 5806Å CIV emission feature (Fig. 1) indicating the [WC]-PG1159 characteristics. Due to moderate resolution of our spectra and contamination by the nebular lines we could not detect the stellar hydrogen lines. The similarity of the spectra of the central stars of NGC 6629 and NGC 6891 with that of PG1159 stars and the presence of stellar hydrogen lines (Méndez et al. 1988,1990) suggests that they may be hybrid central stars (Napiwotzki and Schönberner 1991, 1995., Napiwotzki 1992). The hybrid central stars display a HeII/CIV 4650-4686Å trough very similar to that of PG1159 stars and also show stellar Balmer lines.

Table 1. New [WC] - PG 1159 stars = Weak Emission Lines Stars

004.2-04.3	H1-60	058.3-10.9	IC 4997
006.0-03.6	M2-31	096.4+29.9	NGC6543
006.4+02.0	M1-31	194.2+02.5	J 900
007.0-06.8	Vy2-1	253.9+05.7	M3-6
009.4-05.0	NGC 6629	258.1-00.3	He2-9
010.8-01.8	NGC 6578	274.6+02.1	He2-35
011.7-00.6	NGC 6567	285.4+01.5	Pe1-1
012.5-09.8	M1-62	292.4+04.1	PB 8
016.4-01.9	M1-46	300.7-02.0	He2-86
019.7-04.5	M1-60	315.1-13.0	He2-131
034.6+11.8	NGC 6572	316.1+08.4	He2-108
038.2+12.0	Cn3-1	331.3+16.8	NGC 5873
051.9-03.8	M1-73	351.1+04.8	M1-19
054.1-12.1	NGC 6891	355.2-02.5	H1-29
055.5-00.5	M1-71	356.7-04.8	H1-41
057.2-08.9	NGC 6879	357.1+03.6	M3-7
058.3-10.9	IC 4997	359.9-04.5	M2-27

Napiwotzki and Schönberner (1995) suggest that the hybrid central stars are the missing link between the hydrogen-rich and hydrogen-poor helium-and carbon-rich evolutionary sequences. The hybrid stars do not fit into the scheme of hydrogen-rich and hydrogen-poor. Napiwotzki and Schönberner (1995) proposed to classify the hybrid central stars as O(H,C) or hgO(H,C) to notify their relationship with the PG1159 stars in view of their carbon-richness. In the classification system of Méndez (1991) they are classified as O(H) or hgO(H). The central stars of NGC 6629, NGC 6891, NGC 6572 and NGC 6543 may be classified as hybrid type.

In the list of new [WC]-PG1159 stars given in Table 1 we may find few more hybrid stars if observed at higher resolution. In the spectra of some of the CSPN the broad absorption trough at 4650-4686Å is contaminated by the nebular lines (4711Å [ArIV], 4713Å HeI, 4725Å [NeIV] and 4740Å [ArIV]). We find that the broad absorption trough is real. However in a few cases it may be slightly influenced by the normalization and fixing the local continuum.

4. Discussion and conclusions

We propose a possible evolutionary sequence of the [WC] stars: [WC late] - [WC early] - WELS = [WC]-PG1159 -PG1159. Detailed spectroscopic analysis of these central stars in order to determine their effective temperatures, surface gravities, carbon, oxygen and helium abundances, will provide important clues to the question, to what extent the existence of two separate white dwarf sequences (hydrogen-rich and helium-rich) is determined by the previous post-AGB evolution.

[WC] stars and WELS show the same galactic distribution and kinematics as all the remaining CSPN which implies that they are not formed from a more massive subgroup of progenitors (Górny and Stasińka 1995, Acker et al, 1996). Acker et al (1996) find that in the IRAS color-color diagram the [WC] stars and WELS are separated. The WELS have 12 to 25 micron flux ratio about 0.5 dex smaller than that of [WC] stars. Further work is needed to confirm and understand the significance of this result. Another aspect will be to search for pulsational variability of WELS = [WC]-PG1159 stars, since PG1159 stars have shorter pulsation periods than the pulsating planetary nebulae nuclei (PNNs) (Ciardullo and Bond 1996).

Sion et al. (1985) detected strong O VI absorption/emission lines in several PG 1159 stars and also in the spectrum of the central star of K1-16 which is a lgE type PG1159 star. They also suggested an evolutionary link to O VI planeatry nebula nuclei. It is most likely that the CSPN classified as Of(C), Of-WR(C) and O(C) are infact [WC]-PG1159 stars and a few may turn out to be hybrid PG1159 type stars. The presence of hybrid PG1159 stars indicates a wide range of carbon abundances and hydrogen abundances among the CSPN. For example the central stars of NGC 7094, Abell 43 and S 68 (Napiwotzki and Schönberner 1991, Napiwotzki 1992) which are similar to the central star of K1-16 but show stellar Balmer lines. In the central star of NGC 7094 Werner (1992) finds He/H =1 and C/H $\geq$ 0.1 (by number). Therefore, in order to further understand the [WC]-PG1159 stars listed in Table 1 and the hybrid PG 1159 stars we need to derive their H, He, C, O abundances and surface gravities.

PG 1159 stars appear to have lost their H-rich layer and most of the He-rich envelope. This phenomenon is considered to be due to late He shell flash (born-again AGB scenario, Iben et al 1983). The spectra of three [WC]-PG1159 stars Abell 30, Abell 78, Longmore 4 were found to yield a surface gravity of log g = 5.5 and C/He = 1 by mass which are similar to those of low gravity emission (lgE type) PG 1159 stars (Hamann 1996). The detection of several [WC]-PG1159 stars (Table 1) with planetary nebulae and dust shells indicates that late He-flash scenario may not be the mechanism. We should not yet rule out the possibility of producing a H-poor, C-rich post-AGB star already at the time of the first departure from the AGB.

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