UV spectral analysis of very hot H-deficient [WCE] CSPNe: NGC 6905, Pb 6, NGC 5189, NGC 2867 and Sand 3

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Abstract

[WCE] Central stars of planetary nebulae (CSPNe) are the hottest among [WC]-type stars, with temperatures above ~90kK, and are probably the direct predecessors of [WC]-PG1159 and PG1159 stars, which are, in turn, believed to evolve into DO WDs. The spectra of [WCE] stars are characterized by lack of photospheric absorption lines, the presence of strong wide emission lines, UV P-Cygni profiles and a paucity of lines in the optical region, in which none of the few strong lines they present have P-Cygni profiles, a circumstance that severely limits our knowledge of their wind structure. UV and Far-UV spectral regions show important diagnostic lines of highly ionized iron, argon and neon and, in the case of very hot [WCE] CSPNe, the few available lines of multiple ionization stages of a given element. Their analysis can help to establish constraints for the different post-AGB evolutionary scenarios and to tackle questions concerning possible evolutionary links among different CSPN sub-types, the wind driving mechanism and the properties of the surrounding nebulae. We derived stellar parameters for a [WCE] CSPNe sample (the central stars of NGC 6905, NGC 5189, Pb 6, NGC 2867 and Sand 3) from HST/STIS, FUSE and IUE UV and Far-UV observations, making use of our grids of synthetic spectra calculated with the CMFGEN non-LTE stellar atmosphere code (Hillier & Miller 1998), which accounts for spherically symmetric stationary expanding atmospheres, line blanketing and wind clumping. The models calculated by us include many ionic species previously neglected.

2. UV Spectral Analysis

Our uniform model set enables systematic analysis of observed spectra to constrain stellar parameters. We used the grid models to analyze UV and far-UV spectra obtained with FUSE, IUE and HST/STIS spectrographs of the hot [WCE] central stars of **NGC 6905**, **NGC 5189**, **NGC 2867**, **Pb 6** and **Sand 3** and constrain their main stellar parameters.

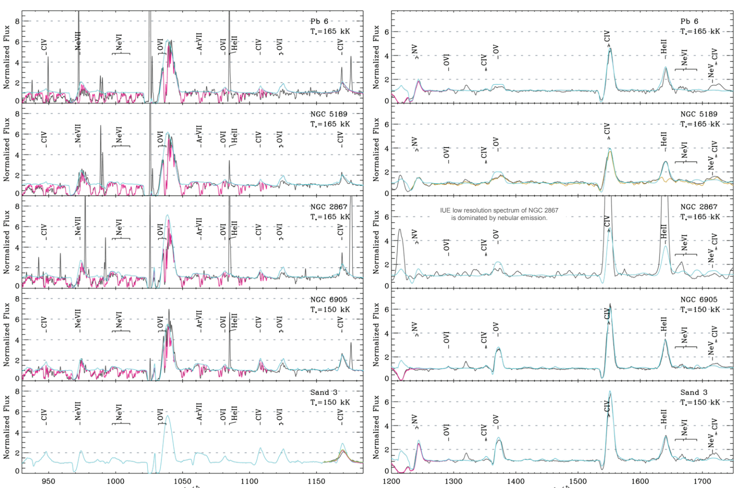


Figure 4. **Left panel**: FUSE spectra (black line) shown together with our best-fitting models, with (pink) and without (blue) the effects of interstellar absorption due to molecular and atomic hydrogen. The observed and synthetic spectra were degraded to a 0.5 Å resolution for clarity. No FUSE spectrum is available for Sand 3. **Right panel**: observed spectra of the sample objects (black) in the region between 1200 and 1750 Å shown with our best-fitting models, with (pink) and without (blue) ISM absorption, degraded to match the resolution of the observations. The observed spectra of CSPNe Pb 6, NGC 6905 and Sand 3 were obtained with HST/STIS G140L. For CSPNe NGC 5189 and NGC 2867 we show low resolution IUE spectra.

Our best-fitting models include many ionic species that were omitted in the grid models because of computation limitations. Their inclusion was found to affect the predicted strength of O V lines, as shown on Keller et al. 2011.

Ion superlevels and levels of the best-fitting final models.

Element	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
He	40,45	22,30	1								
C				49,64	1						
N					13,21	1					
O				29,48[a]	58,163	41,47	1				
Ne				45,355[a]	37,166	36,202	38,182	24,47	1		
Na						52,452	37,251	72,214	27,71	1	
Mg					43,311	46,444	54,476	1			
Si				22,33	33,71[a]	33,98[a]	1[a]				
P					16,62	1					
S						28,58	1				
Ar						30,205	33,174	57,72	1		
Ca						47,108[a]	55,514[a]	54,445[a]	35,367[a]	31,79[a]	1[a]
Fe						44,433[a]	41,252	53,324	52,490	43,210	1
Co							45,1000	50,1217	24,355	1	
Ni							37,308	113,1000	75,1217	1	

[a]These ionic species are not present in the best-fitting final models for the central stars of NGC 5189, Pb 6 and NGC 2867.

Parameters of our best-fitting models

Object	T_*[kK]	$R_t[R_\odot]$	v_∞[km/s]	X_{He}	X_C	X_N	X_O	X_{Ne}
NGC 6905	150	10.7	2000	0.44	0.45	1.1×10^{-4}	0.08	0.02
NGC 5189	165	9.9	2500	0.58	0.25	0.01	0.12	0.04
Sand 3	150	9.3	2000	0.28	0.55	0.07	0.08	0.02*
Pb 6	165	9.9	2500	0.49	0.35	0.03	0.12	0.01
NGC 2867	165	8.6	2000	0.60	0.25	0.01*	0.10	0.04

* Not constrained in this object.

The transformed radius (R_t) dictates the strength of the wind lines.

$$R_t = R_* \left[\frac{v_\infty / 2500\ km\ s^{-1}}{\dot{M}/10^{-4}\ M_\odot yr^{-1}} \right]^{2/3}$$

1. Grids of Synthetic Spectra

The stellar parameters adopted for the grid models are within typical literature values for **H-poor CSPNe** and approximately follow the evolutionary calculations of Miller Bertolami & Althaus (2006).

The ionic species included in the models can vary, since they were limited to keep the models within a workable size. All models have the following species: He I, He II, He III, C IV, C V, N V, N VI, O V, O VI, OVII, Ne V, Ne VI, Ne VII, Ne VIII, Ne IX, Si IV, Si V, P V, P VI, S VI, S VII, Fe VII, Fe VIII, Fe IX, Fe X, Fe XI. The other ionic species, which include C II, C III, N II, N III, N IV, O II, O III, O IV, Ne II, Ne III, Ne IV, Al III, Al IV, Al V, Si III, Si VI, P IV, S III, S IV, S V, Fe IV, Fe V, Fe VI, were added as needed

The grids are available at http://dolomiti.pha.jhu.edu/planetarynebulae.html.

Grid Models' Abundances

Element	Mass Fraction
He	0.43
C	0.45
N	0.01
O	0.08
Ne	0.02
Al	solar
Si	solar
P	solar
S	solar
Fe	1.36×10^{-5}

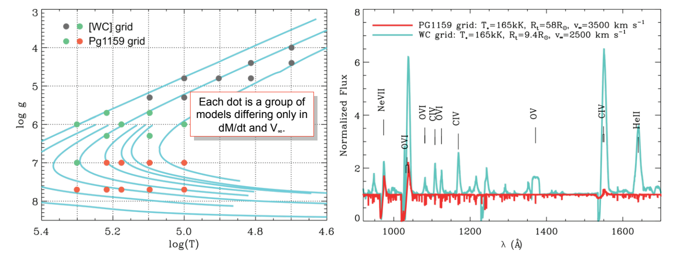


Figure 1. Left panel: the [WC] (gray and green dots) and PG1159 (green and orange dots) grids of synthetic spectra are shown on the log(*T*) X log(*g*) diagram, along with evolutionary calculations from Miller Bertolami & Althaus (2006), in blue. Right panel: comparison between similar temperature synthetic spectra from the PG1159 and the [WC] grids. The PG1159 models have fainter winds that reach higher terminal velocities than the ones from the [WC] grid models.

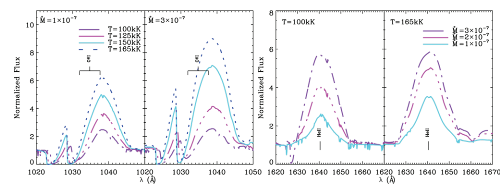


Figure 2. Synthetic line profiles from the [WC] grid models of different mass-loss rates and temperatures. The left and right panels illustrate the behavior of the far-UV O VI λλ 1031.9, 1037.6 Å doublet and the He II λ 1640.4 Å line with changing stellar parameters, respectively.

The grids can be used to plan the observations, determining the necessary instrument specifications, particularly if the shapes of the LSFs (not just their FWHM) fit the requirements of the desired measurement.

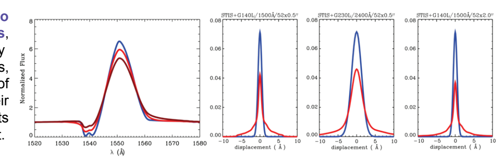
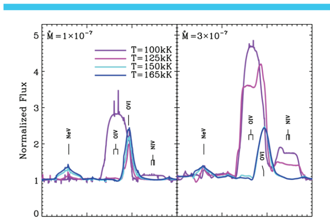
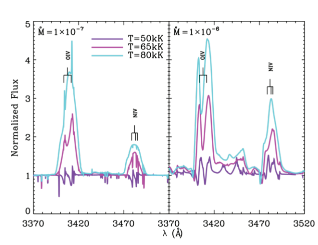


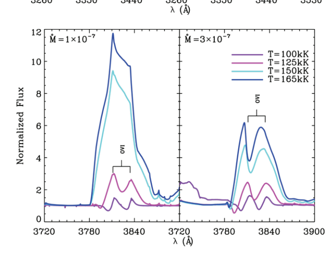
Figure 3. **Left panel**: C IV λλ 1548.2, 1550.8 Å synthetic line profile from a grid model convolved with: a Gaussian of FWHM equal to the nominal resolution of the G140L difraction grating from the STIS spectrograph (blue line), with the G140L instrumental LSF for the 52x0.5" apperture (red line), and for the 52x2.0" apperture (dark red line). **Other panels**: the HST STIS LSFs (red lines) are compared to Gaussians (blue lines) with FWHM equal to the nominal spectral resolution of the configuration.

3. H-poor CSPNe in the CUBES Region

Between 3000 and 4000 Å, our grid models predict O III, O IV, O VI, N III, N IV, He I, He II, Ne V and C IV lines, which can help constrain temperature, mass loss and elemental abundances in [WCE] and [WCL] stars. The figures show some of the most important line diagnostics of temperature and mass loss available for these stars and which lie within the wavelength region that would be covered by CUBES.







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The data presented here were obtained from MAST.

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