CSPN wind diagnostic lines in the Far-UV

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Abstract. As they transition toward the white dwarf cooling sequence, Central Stars of Planetary Nebulae (CSPNe) are characterized by very high temperatures ($T_{\rm eff} > 100$ kK) and fading winds. Determination of wind parameters of these stars is challenging because these tenuous winds offer few if any optical spectral diagnostics. Fortunately, the FUSE wavelength range has revealed new useful wind diagnostics such as high-ionization Argon and Neon lines. We show examples of results from our ongoing analysis of hot Galactic CSPN.

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INTRODUCTION

As they migrate from the constant-luminosity post-AGB / central-star of planetary nebulae phase onto the white dwarf (WD) cooling sequence, low/intermediate-mass stars reach the highest effective temperatures of their lifetimes, which can range from 80 to 200 kK. During this transition, their winds (which typically have mass-loss rates of $\dot{M} \simeq 10^{-8}$ M$_\odot$ yr^{-1}and $V_\infty \simeq 2000$ km s^{-1}) are fading, and because of the extreme temperatures, wind spectral features may be non-existent at optical wavelengths and scarce at other wavelengths. Lines which may serve as abundance diagnostics are particularly valuable, as these abundances can be compared with those predicted by evolutionary models. As part of our ongoing analysis of some of the hottest H-deficient CSPN, we've calculated models using the CMFGEN code [1, 2] including ionization stages up to Ar VIII and Ne VIII, which have revealed new wind diagnostics for each of these elements in the FUSE wavelength range (907–1187 Å), discussed below.

ARGON

Werner et al. [3] first identified an Ar VII photospheric absorption line at 1063.55 Å in different types of CSPN (PG 1159, DA and DAO white dwarfs, O(H)) and used it to determine the argon abundance in these objects. For the H-deficient PG 1159 stars of their sample, they found the argon abundances to be roughly solar, in line with evolutionary nucleosynthesis models for AGB stars. We have identified this same line appearing as a wind feature in the FUSE spectra of some of the hottest [WR]-type CSPN ([WO2]). In these stars, the line appears as a P-Cygni profile with a weak absorption component and a broad emission component (which is eaten into by interstellar molecular hydrogen (H_2) absorption lines). Our initial results indicate that the feature is absent or weak

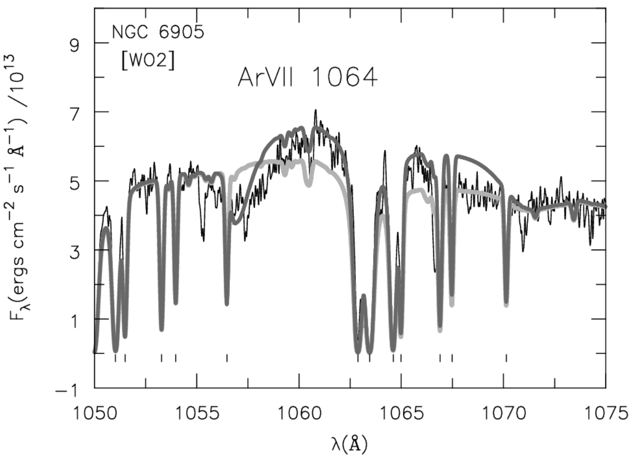

FIGURE 1. The effects of varying the argon abundance X_{Ar} (mass fraction) of our NGC 6905 ([WO2]) model with $T_{\rm eff} = 140$ kK ($T_{\rm eff}$ constrained primarily by O V/O VI ionization balance). The observations are shown (black) along with models with $X_{Ar} = 1X_\odot$ (thick light gray), $X_{Ar} = 5X_\odot$ (thick dark gray). A super-solar argon abundance is needed to match the observations. A $T_{\rm eff} = 150$ kK model require higher argon abundances to match, while $T_{\rm eff} = 135$ kK still requires $X_{Ar} = 5X_\odot$. Lower temperatures do not reproduce the other diagnostic lines. Absorption features caused by molecular hydrogen are marked by ticks. The spectra are convolved with a 0.15 Å Gaussian for clarity.

using a solar argon abundance, and that an abundance of a few times the solar amount is required to fit the observed feature (an example is given in Fig.1).

NEON

In the spectra of CSPN, the Ne VII λ973.33 line can appear in absorption in stars without winds [4], and as a strong wind feature in PG 1159 stars, [WR]-PG 1159 stars [5] and the hottest [WR] stars (such as NGC 6905). In the latter cases it is typically saturated and thus not a very sensitive diagnostic. But in some PG 1159 where it appears unsaturated it can be a useful diagnostic of the mass-loss rate and the neon abundance [5], as shown in Fig. 2. This is important because evolutionary theories of these hydrogen deficient objects predict a neon enhancement of up to 20 times its solar value (*i.e.,* the "born-again" scenario of 6, 7). Our work on the PG 1159 star K1-16 indicates this object does indeed have a super-solar neon abundance, in line with these evolutionary calculations. Fig. 3 displays the FUSE spectra for the PG 1159 star K 1-16, along with our computed models from Herald et al. [5], which have a neon abundance 10 times the solar value.

SUMMARY

The inclusion of stages of ionic data of high ionizion stages in model atmosphere calculations has revealed new Argon and Neon wind diagnostics in the FUSE wavelength range. We've used these new diagnostics to derive chemical abundances in H-deficient

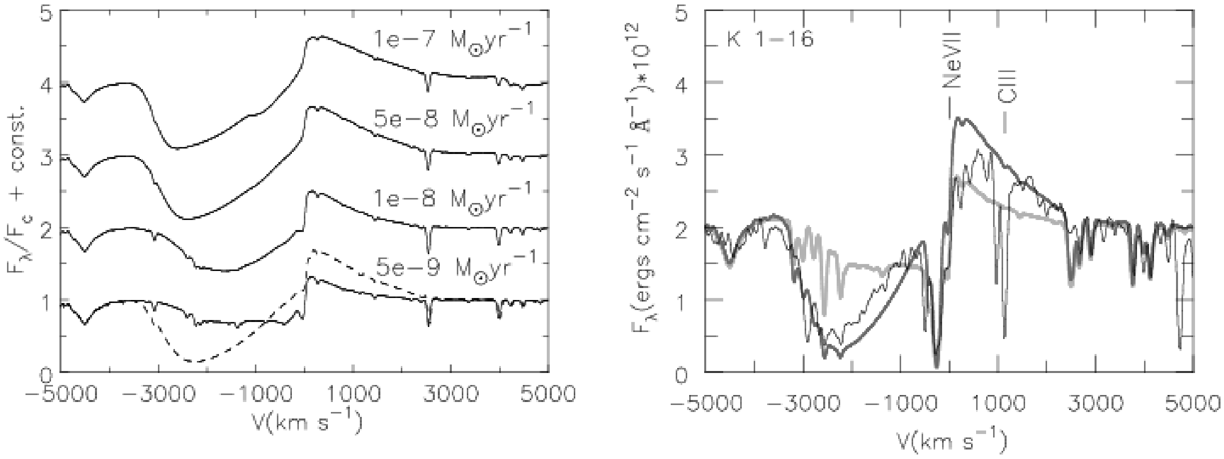

FIGURE 2. (left): The effects of varying $\dot{M}$ and X_{Ne} in our K 1-16 model ($T_{\rm eff} = 135$ kK) on Ne VII λ973. The solid and dashed lines represent models with neon abundances of $1X_\odot$ (solar) and $10X_\odot$, respectively. The feature is very sensitive to $\dot{M}$ when not saturated (*e.g.*, the $\dot{M} = 5 \times 10^{-9}$ $M_\odot$ yr^{-1} model). The spectra are normalized, and convolved with a 0.2 Å Gaussian for clarity. (right): The Ne VII λ973 profile (in velocity space) of K 1-16 (black, FUSE spectrum) along with two model spectra, one with $X_{Ne} = 1X_\odot$ (solar), and one with $X_{Ne} = 10X_\odot$ (thick light and dark gray, respectively). Effects of interstellar hydrogen absorption have been applied to the model spectra. The unsaturated profile is very sensitive to the neon abundance, and indicates a super-solar abundance in this object, in line with predictions of the born-again scenario. (From 8).

CSPN. In the PG 1159 star K 1-16, we derive a super-solar neon abundance in line with current evolutionary predictions. For the [WO] star NGC 6905, we find a super-solar argon abundance, which is unexpected as the argon abundance is not thought to change according to evolutionary models.

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