ON THE ORIGIN OF THE ABSORPTION AND EMISSION LINE COMPONENTS IN THE SPECTRA OF PHL 293B

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ABSTRACT

From the structure of PHL 293B and the physical properties of its ionizing cluster and based on results of hydrodynamic models, we point at the various events required to explain in detail the emission and absorption components seen in its optical spectrum. We ascribe the narrow and well centered emission lines, showing the low metallicity of the galaxy, to an H ii region that spans through the main body of the galaxy. The broad emission line components are due to two off-centered supernova remnants evolving within the ionizing cluster volume and the absorption line profiles are due to a stationary cluster wind that is able to recombine at a close distance from the cluster surface, as originally suggested by Silich et al. Our numerical models and analytical estimates confirm the ionized and neutral column density values and the inferred X-ray emission derived from the observations.

Key words: galaxies: star clusters: general – hydrodynamics – ISM: kinematics and dynamics

1. INTRODUCTION

PHL 293B is an extreme emission line blue compact dwarf or H ii galaxy first listed in the “Palomar-Haro-Luyten” survey of faint blue objects. It ranks among the lowest luminosity and metallicity and smallest size galaxies. The metal abundances are less than one-tenth of the solar value (French 1980; Izotov et al. 2007; Asplund et al. 2009), which situates it in the borderline of what is considered to be an extremely metal-deficient galaxy (e.g., Kunth & Östlin 2000). It is very compact with an effective radius of 0.4 kpc (Cairós et al. 2001; Geha et al. 2006) and its absolute magnitude according to the Sloan Digital Sky Survey (SDSS) is $M_V = -14.8$.

The optical spectrum of PHL 293B is that of a typical H ii galaxy with strong narrow emission lines resembling an H ii region. In addition, the spectrum shows some intriguing features: low intensity broad wings in the Balmer series plus weak narrow absorptions in the hydrogen recombination lines and Fe ii multiplet 42, all of which are blueshifted by about 800 km s$^{-1}$ with respect to the galaxy reference frame provided by the stellar IR Ca ii triplet.

While the observed broad wings in the Balmer lines may have originated in a very old supernova (SN) remnant (the SN rate of PHL 293B is about $3 \times 10^{-4}$ yr$^{-1}$), in order to generate relatively narrow absorption profiles such as the ones detected in PHL 293B, it was argued that the absorbing material must cover a substantial fraction of the continuum source, which, in this case, is a young stellar cluster several parsecs in size (Terlevich et al. 2014).

From the observed Balmer line luminosity and using the equivalent width of the Balmer emission lines as an age indicator, the resulting upper limit for the ionizing star cluster mass is $M_{SC} \approx (2-4) \times 10^5 M_\odot$ and the upper limit for the age is about $(5-7) \times 10^6$ yr.

Terlevich et al. (2014) analyzed extensive published and their own photometric and spectroscopic data and found that at the $3\sigma$ level, any long-term variability, i.e., over a few years, cannot be larger than 0.02 mag and that any medium term variability, i.e., over a few months, should be less than 0.04 mag. Furthermore, there is no variability at the level of a few tenths of magnitude over a period of 25 yr. This lack of variability suggests that the spectrum of PHL 293B is not due to transient phenomena like a luminous blue variable (LBV) or a type IIn SN.

From the ACIS-Chandra X-ray image of PHL 293B, Terlevich et al. (2014) estimated a luminosity upper limit in the 0.4 to 6 keV energy range of about $2 \times 10^{38}$ erg s$^{-1}$. Analysis of the detected narrow absorption lines of Fe i allows us to estimate that the column densities of ionized hydrogen ($N$(H ii)) are around $10^{20}$ cm$^{-2}$ if Fe/H is similar to that of the interstellar medium (ISM) in PHL 293B or substantially lower if Fe/H is that of the cluster wind. Assuming that the cluster wind has solar abundance, the estimated ($N$(H ii)) column density is $10^{19}$ cm$^{-2}$. From the equivalent width of the Balmer lines, Terlevich et al. (2014) also estimated that the column density of neutral hydrogen is $10^{13}$ cm$^{-2} < N$(H i) < $10^{14}$ cm$^{-2}$. The true column density of neutral hydrogen, however, may be higher because only Balmer absorption was used in this estimate. Measurements on Hubble Space Telescope images indicate that the diameter of the brightest cluster is less than 5 pc.

As discussed by Terlevich et al. (2014), while the presence of broad Balmer lines and blueshifted absorptions may be explained by either an extremely LBV or an old SN type IIn, the lack of variability over at least a quarter of a century strongly argues against these scenarios. Thus, the understanding of this object constitutes a challenge. Here we present a new scenario supported by detailed hydrodynamic calculations of a strongly radiative stationary cluster wind and a comparison of the theoretical predictions with the observed parameters.

Based on the structure of PHL 293B and on the physical properties of its ionizing cluster, we point at the various events required to explain in detail the emission and absorption components seen in its spectrum. In Section 2, we ascribe the narrow and centered emission lines to an H ii region that spans through the main body of the galaxy and propose an explanation for the observed broad emission line components and the P-Cygni absorption line profiles. Section 3 deals with our conclusions and further predictions from the model.

2. NEGATIVE STAR FORMATION

FEEDBACK IN PHL 293B

Knowledge of the cluster mass and age allow one to estimate its mechanical luminosity and the production of UV photons.
These are well-known negative star formation feedback agents that structure the galaxy ISM in a wide variety of ways. These parameters, together with the cluster size, have been shown to define whether the mass reinserted by massive stars ends up, after thermalization, streaming all supersonically as a stationary cluster wind or if instead strong thermal instabilities may deplete the pressure of the reinserted matter, particularly within the densest central volume, inhibiting its exit as part of the cluster wind. In the latter case, the reinserted matter is forced to accumulate there until its mass surpasses the Jeans limit, leading to a new stellar generation. As shown before, the more massive a young cluster is, the more of the reinserted matter is to accumulate and the smallest the resultant fraction of its mass radius, versus size diagram by a critical line, the position of which strongly depends on the radiative cooling law applied to the flow (see Tenorio-Tagle et al. 2007, 2013). This, however, as first pointed out by Silich et al. (2004), is not the end of the story. As one considers more massive clusters of a given size and approaches the critical line, the stationary cluster wind becomes strongly radiative, letting its temperature drop to \( \sim 10^4 \text{ K} \), closer to the cluster surface. Consequently, such cluster winds would not present an extended X-ray-free wind region but instead a recombining and, given the ample supply of UV photons, a re-ionized region, rapidly expanding close to the cluster surface.

Figure 1 displays the emission and absorption line components required to match the H II spectra of PHL 293B (see Figure 2 of Terlevich et al. 2014 or Figure 3 of Izotov et al. 2011), together with an illustration showing the structure of the galaxy and of its ionizing cluster, as well as the observer’s location. Various regions in the galaxy sketch and in the composed spectra are labeled (H II and B–D) to indicate their proposed correspondence. In this way, the narrow emission line component, centered at the redshift of the galaxy and showing its low metal abundance, results from the general ionization of the galaxy ISM (region H II). The narrow absorption line components are due to a fast (\( \sim 800 \text{ km s}^{-1} \)) strongly radiative cluster wind (region B) and the broadest components arise from rapidly evolving remnants cause by the off-centered explosion of the most recent type II SNe (regions C and D).

2.1. The Cluster Wind

In order to reproduce the absorption and emission line components in the spectra of PHL 293B, we have performed several hydrodynamic calculations and made analytical estimates of the feedback generated within the central star cluster. In all cases it was assumed that massive stars follow a generalized Schuster stellar density distribution (Palouš et al. 2013); in particular, with the form \( \rho_* \propto \left[ 1 + (r/R_c)^2 \right]^{-b} \) with \( b = 1.5 \), where \( r \) is the distance from the center and \( R_c \) is the core radius of the stellar distribution. This special case of the Schuster distribution appears as an asymptotic case to King’s surface formula (King 1962) when projected onto the sky (Ninković 1998). We assume the stationary presence of dust grains within the matter reinserted by massive stars as being due to its continuous deposition by core-collapse SNe and use the hydrodynamic treatment described by Tenorio-Tagle et al. (2013). We employed the equilibrium cooling function for an optically thin plasma obtained by Raymond et al. (1976) for solar metallicity and the contribution to the cooling due to gas-dust grain collisions for which we follow the prescription given by Dwek & Werner (1981). The latter is the dominant source of cooling for a gas with temperatures \( T \geq 10^6 \text{ K} \) (about two orders of magnitude larger than the gas cooling for a gas in collisional ionization equilibrium, as originally calculated by Ostriker & Silk 1973).

For the calculations, we consider clusters close to the critical line in the mechanical luminosity (or cluster mass) versus size and that lead, as mentioned in Section 2, to strongly radiative winds and thus to recombination of the stationary flow close to the cluster surface. In all cases we fixed the cluster half-mass radius, \( R_{1/2} \), and the cluster core radius, \( R_c \), and then calculate the corresponding cut-off radius, \( R_{SC} \). Other input parameters are the star cluster mechanical luminosity, \( L_{SC} \), and the adiabatic terminal speed, \( V_{\text{Ad}} \). The mass deposition rate
Figure 2. Distribution of the hydrodynamical variables and number of absorbed photons s$^{-1}$ in the free-wind region. Panels (a), (b), (c), and (d) present the wind velocity, temperature, density as a function of distance to the star cluster center, and the number of ionizing photons absorbed per unit time inside a volume of radius $r$, respectively. The dotted, dashed, dashed-dotted, and solid lines display the results of the calculations for models A, B, C and D, respectively.

Table 1

| Models | $R_{\text{HM}}$ (pc) | $R_c$ (pc) | $L_{\text{SC}}$ (erg s$^{-1}$) | $V_{\text{A\infty}}$ (km s$^{-1}$) | $Z_d$ |
|--------|----------------------|------------|-----------------------------|-----------------------------|-------|
| A      | 1                    | 1          | 1.46 $\times 10^{40}$      | 1000                        | $10^{-3}$ |
| B      | 1                    | 1          | 1.46 $\times 10^{40}$      | 1150                        | $10^{-3}$ |
| C      | 2                    | 2          | 2.62 $\times 10^{40}$      | 1000                        | $10^{-3}$ |
| D      | 2                    | 2          | 2.62 $\times 10^{40}$      | 1000                        | 0     |

$\dot{M}$ is then $\dot{M} = 2L_{\text{SC}}/V_{\text{A\infty}}^2$. The mechanical luminosity is assumed to scale with the total mass of the star cluster $M_{\text{SC}}$ as $L_{\text{SC}} = 3 \times 10^{40}(M_{\text{SC}}/10^6 M_\odot)$ erg s$^{-1}$ (Leitherer et al. 1999). Following the cluster mass estimates given in Terlevich et al. (2014), we considered star clusters with typical mechanical luminosity $L_{\text{SC}} = (1–2) \times 10^{40}$ erg s$^{-1}$. Table 1 summarizes the input parameters for our models A, B, C, and D. Models A and B have the same radii and a factor of two different mechanical luminosity. Models C and D have larger radii and the same mechanical luminosity as Model B. Models A–C are applicable once SNe begin to take place within the cluster volume ($\sim$ 3 Myr of evolution) and a continuous presence of dust within the reinserted matter is established (see Tenorio-Tagle et al. 2013). In models A–C, the dust to gas mass ratio, $Z_d$, was set to $10^{-3}$, dust grains were assumed to be spherical, and with a radius of 0.1 $\mu$m. We also explored, for the sake of comparison, a model (D) with the same input parameters as model C, but without dust radiative cooling.

Figure 2 shows the results from the hydrodynamical calculations for models A–D. The dusty models, A–C, were selected, among many models, because their stationary wind terminal velocity, $u_{\infty}$, is able to reach a value $\sim 800$ km s$^{-1}$ and further because strong radiative cooling is able to bring the wind temperature down to the range $T \sim 10^5$–$10^4$ K, which allows for H recombination at a short distance from the star cluster surface. The selected models are all for compact star clusters, with a central wind density value $\sim 10^3$ cm$^{-3}$ and a temperature $\sim 10^7$ K (see Figure 2). In all cases, once outside the cluster, the density drops as $r^{-2}$, it reaches values of a few (cm$^{-3}$) when the wind temperature is $\sim 10^5$ K (at $r = R_5$) between 10 pc and 15 pc, and then values $\sim 1$ cm$^{-3}$ when the cluster wind temperature reaches $10^4$ K, at a distance ($r = R_4$) between 15 and 22 pc. It is within this temperature range that hydrogen recombination takes place.

We then used the distributions of density, temperature, and velocity presented in Figure 2 to calculate the outward flux of ionizing photons (cm$^{-2}$ s$^{-1}$) $J = N_{\text{UV}}(r)/4\pi r^2$ and the degree of ionization $x = n_i/(n_i + n_n)$, where $n_i$ and $n_n$ are the ionized and neutral gas number densities in the free wind region. The transport of ionizing radiation and the ionization balance equations (Goldsworthy 1958) are then reduced to

$$\frac{dJ}{dr} = -\frac{2J}{r} - (1 - x)J \frac{\sigma_a \rho}{\mu},$$

$$\frac{dx}{dr} = (1 - x) \frac{\sigma_a J}{u} - \frac{\beta \rho \mu \nu^2}{\mu},$$

where $\sigma_a = 6 \times 10^{-18}$ cm$^2$ and $\beta = 3 \times 10^{-10} T^{-3/4}$ cm$^{-3}$ s$^{-1}$ are the H absorption cross section for ionizing radiation and the recombination coefficient to all but the ground level, respectively, and $\mu$ is the mean mass per particle. We solve these equations numerically assuming that the ionizing radiation is not depleted
in the hot wind region until the temperature drops to $10^5$ K (at $R_5$) and thus that the degree of ionization and the total ionizing photon flux are kept $x = 1$ and $N_{UV} = 2.71 \times 10^{51}$ s$^{-1}$ up to this radius.

In all our models the degree of ionization $x$ is close but not equal to unity. Note also that the number of ionizing photons is large and the wind density has a moderate value when the wind temperature reaches about $10^5$ K and recombination is large and the wind density has a moderate value when the distance from the star cluster center ($R_5 \approx 37$ pc). By then the wind density has fallen sufficiently as to inhibit recombination; therefore, this case is not presented on the last panel of Figure 2.

One can also calculate the photoionized ($N(H\text{II})$) and neutral ($N(H\text{I})$) hydrogen column densities taking into account that the degree of ionization $x$ is close to unity in the whole free wind region: $N(H\text{II}) = \int_{R_5}^{\infty} n_5 R_5^2 dr \approx n_5 R_5$ and $N(H\text{I}) = \int_{R_5}^{\infty} n_5 (1-x) R_5^2 dr$, where $n_5$ is the wind number density at the radius $R_5$. In all models with dust cooling the calculated values of $N(H\text{II})$ fall in the range $6.6 \times 10^{19}$ cm$^{-2} < N(H\text{II}) < 9.5 \times 10^{19}$ cm$^{-2}$, in good agreement with the observational estimate $(1-2) \times 10^{20}$ cm$^{-2}$ by Terlevich et al. (2014). The value of $(1-x)$ changes from 0 at $r = R_5$ to the asymptotic value of $2.3 \times 10^{-7}$ (model A), $3.2 \times 10^{-7}$ (model B) and $4.7 \times 10^{-7}$ (model C) at a distance $R_4$ from the star cluster center. The upper limit to the neutral hydrogen column density is then $N(H\text{I}) = (1-x) \int_{R_5}^{\infty} n_5 R_5^2 dr = (1-x) n_5 N(H\text{II})$, where $(1-x)$ is the asymptotic value of the $(1-x)$ factor. This leads to neutral hydrogen column densities within the range $1.5 \times 10^{13}$ cm$^{-2} < N(H\text{I}) < 4.5 \times 10^{13}$ cm$^{-2}$, which is also in good agreement with the observational estimates (see Section 1 and Terlevich et al. 2014). One can now compare these results with the dustless model D, which exhibits a quasi-adiabatic behavior, to note that despite the similar density and velocity distributions, model D does not present the drastic temperature fall at a short distance from the star cluster center and therefore it would not lead to the high velocity blue-shifted absorption features predicted for models A–C.

Finally, we have used the calculated model profiles to estimate the expected diffuse X-ray emission:

$$L_X = 4\pi \int_{0}^{R_{\text{out}}} r^2 n_e n_i A_X(T, Z) dr,$$

(3)

where $n_e(r)$ and $n_i(r)$ are the electron and ion number densities, $A_X(T, Z)$ is the X-ray emissivity used by Strickland & Stevens (2000), $Z$ is the metallicity of the X-ray plasma in solar units, and $R_{\text{out}}$ marks the X-ray cut-off radius (the radius where the temperature in the wind drops below $T_{\text{cut}} \approx 5 \times 10^5$ K). For $Z = 1$ we found that in cases A and D the 0.3 keV–2.0 keV diffuse luminosity ($L_X = 4.5 \times 10^{38}$ erg s$^{-1}$ and $4.0 \times 10^{38}$ erg s$^{-1}$, respectively) are in reasonable agreement with the observed upper limit of $\sim 2.2 \times 10^{38}$ erg s$^{-1}$ (Terlevich et al. 2014), whereas models B and C predict a somewhat larger X-ray emission: $L_X = 8.8 \times 10^{38}$ erg s$^{-1}$ and $1.2 \times 10^{39}$ erg s$^{-1}$, respectively. $L_X$ scales almost linearly with $Z$ and brings it into better agreement with the observational limits if the metallicity of the hot gas is subsolar. For example, in model A it falls to $L_X \approx 1.5 \times 10^{38}$ erg s$^{-1}$ when $Z = 0.3$.

A hot dusty plasma radiates mainly in the X-ray and IR regimes. Thus, one can obtain the upper limit for the IR luminosity expected in cases A, B, and C if one compares the star cluster mechanical luminosity $L_{\text{SC}}$ with the energy flux through a sphere of radius $r = R_{\text{out}}$ at which the X-ray emission vanishes and assume that all energy lost within this volume is radiated away either in the IR or in the X-ray regime:

$$L_{\text{IR}} \approx L_{\text{SC}} - L_X - 4\pi \rho u R_{\text{out}}^2 \left(\frac{u^2}{2} + \frac{\rho}{\gamma - 1} \frac{p}{\rho}\right),$$

(4)

where $\gamma = 5/3$ is the ratio of specific heats and all hydrodynamical variables (the density $\rho$, velocity $u$, and the value of thermal pressure $p$) are calculated at $r = R_{\text{out}}$. This leads to IR luminosities $L_{\text{IR}} = 3.6 \times 10^{39}$ erg s$^{-1}$, $8.9 \times 10^{39}$ erg s$^{-1}$, and $7.9 \times 10^{39}$ erg s$^{-1}$ in cases A, B, and C, respectively. The dusty wind models thus lead to IR luminosities that exceed the wind diffuse X-ray emission by about an order of magnitude ($L_{\text{IR}}/L_X = 8.0, 10.1, and 6.8$ in models A, B, and C, respectively).

In the dustless case D, the hot wind cools only through X-ray radiation. $L_X$ presents $\sim 87\%$ of the total radiated energy in this case.

### 2.2. The Broad Emission Lines

The broad emission components in the spectra of PHL293B, depicted, for example, in Figure 2 of Terlevich et al. (2014), are here ascribed to two rapidly evolving SN remnants resultant from the most recent type II SN explosions that had taken place within the ionizing cluster volume (see Figure 1). Furthermore, both explosions have occurred on the far side of the cluster to account for the intrinsic redshifted emission of the evolving remnants that should expand with slower velocities into regions of higher density (toward us and the cluster center) and faster into lower density regions (toward the cluster edge). One can estimate the size of such remnants as well as their cooling time, which mark the time when photoionization will lead to their strong emission at optical wavelengths. The size $R_5$ of such SN-driven shells from the energy conservation relation is

$$R_5^3 = \frac{3\alpha E_{\text{SN}}}{2\pi \rho V_{\text{exp}}^2},$$

(5)

where $E_{\text{SN}} = 10^{51}$ erg is the energy of the explosion, $\alpha$ is the fraction of the explosion energy that is transformed into kinetic energy of the swept-up gas ($\alpha \approx 0.3$ during the Sedov phase), and $M = 4\pi \rho R_5^3/3$, $V_{\text{exp}}$, and $R_5$ are the mass, expansion velocity, and radius of the swept-up gas, respectively. Taking $V_{\text{exp}} = 1/2$ FWHM $= 2 \times 10^4$ km s$^{-1}$ and the average gas density within the star cluster volume as $\rho \sim 10^{-21}$ g cm$^{-3}$ (see Figure 2) results into a remnant size $R_5 \sim 0.5$ pc, which warrants a strong SN remnant evolution within the cluster volume.
From the jump conditions across a strong shock, one can derive the temperature of the swept-up gas: $T_S = 1.3 \times 10^7 \left( \frac{V_{\text{exp}}}{10^3 \text{ km s}^{-1}} \right)^2$, required to estimate the cooling rate, and the shocked gas density, $n_S$ (cm$^{-3}$), equal to four times the background density. The above relations yield a shocked gas temperature $T_S = 5.2 \times 10^7$ K and a shocked gas density $n_S \sim 2 \times 10^3$ cm$^{-3}$. These, together with the value of the cooling rate, $\Lambda \sim 10^{-20}$ erg cm$^{-3}$ s$^{-1}$ (see Figure 2 of Tenorio-Tagle et al. 2013) lead to the cooling time:

$$t_\Lambda = \frac{3kT_S}{n_\Lambda \Lambda} \approx \text{a few } 100 \text{ yr.} \quad (6)$$

Thus, the SN remnants expanding within the cluster environment experience a strong evolution and after cooling become exposed to the cluster ionizing radiation which makes them shine at optical wavelengths. The number of ionizing photons absorbed by such a remnant is

$$N_{\text{abs}} = 4\pi F R_0^2 = 4\pi q_{\text{UV}} R_{SC} R_0^2 = 3X N_{\text{UV}}(R_s/R_{SC})^2. \quad (7)$$

where $F$ is the flux of ionizing photons per unit area of the SNe remnant, $q_{\text{UV}} = 3N_{\text{UV}}/4\pi R_{SC}^2$, and the factor $X$ is $1/4 < X < 1/3$ (see Palouš et al. 2014). If $X = 1/3$, the ratio of broad to narrow emission lines components is

$$L_{\text{broad}}/L_{\text{narrow}} = (R_s/R_{SC})^2/[1 - (R_s/R_{SC})^2]. \quad (8)$$

This ratio varies with the SN remnant size. For $R_s = 0.5$ pc and $R_{SC} = 1.46$ pc, it is about 13%. Given the fact that the remnant is expected to be elongated, as it expands into gas with different densities inside the cluster volume, it may easily reach the 20% value measured by Terlevich et al. (2014).

### 2.3. The Narrow Emission Line Components

As depicted in Figure 1, the narrow emission line components in the spectra of PHL 293B arise from the extended H II region that surrounds the central cluster. At first glance, the narrowness of the emission lines and the low metallicity derived from the various line intensity ratios imply that such an extended H II region is still unaffected by the mechanical energy of the central cluster. Note, however, that the interaction of the cluster motions in the ISM, what makes the supershell spectroscopically H II region is still unaffected by the mechanical energy of the central cluster. The dusty cluster wind models, with strong radiative cooling, predict an ionized and neutral gas column density as well as a diffuse X-ray emission in very good agreement with the observed values. We thus claim that the absorption features PHL 293B present the first observational evidence for a strongly radiative stationary cluster wind, as originally discussed in Silich et al. (2004).

We have also shown that the impact of the cluster wind on the galactic environment leads to an expanding supershell which, after 5 Myr of evolution, presents a velocity similar to the sound speed of the photoionized gas and has become spectroscopically undetectable.

The remnants of two recent type II SN explosions, which burst on the far side of the stellar cluster environment, have been claimed in our model as responsible for the broad redshifted emission components in the H spectra of PHL 293B. We have shown that even the fastest of these remnants undergoes a rapid evolution, reaching its cooling time while evolving well within the cluster volume. After such a time, the remnants become a target of the stellar ionizing radiation that allows us to trace them as the fastest structures in the galaxy.

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3. CONCLUSIONS

A thorough study of different observational data sets of PHL 293B that span over the last two decades (Terlevich et al. 2014) has shown a lack of variability, which rules out the possibility of a LBV star or a type IIn SN as the primary source of the spectra detected in this galaxy. The idea of an expanding ($V_{\text{exp}} \sim 800$ km s$^{-1}$) supershell causing the absorption components can also be discarded as its dynamical time will place it way out of the dwarf galaxy. On the other hand, we have shown here that a powerful, strongly radiative, stationary cluster wind is able to produce a stationary high-velocity recombinating layer that causes blueshifted absorption features similar to those observed in the spectra of PHL 293B. We have taken into consideration the mass, mechanical luminosity, age, and flux of ionizing photons from the central cluster of PHL 293B to built a grid of possible models of the stationary cluster wind. From these we have selected as favorites some of those that lead to a terminal velocity around 800 km s$^{-1}$ and that cause a rapidly recombinating stationary layer close to the cluster surface. The dusty cluster wind models, with strong radiative cooling, predict an ionized and neutral gas column density as well as a diffuse X-ray emission in very good agreement with the observed values. We thus claim that the absorption features PHL 293B present the first observational evidence for a strongly radiative stationary cluster wind, as originally discussed in Silich et al. (2004).

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