RevMexAA (Serie de Conferencias), **40**, 167–168 (2011)

NGC 6826: A UNIFIED STUDY OF THE PLANETARY NEBULA AND ITS CENTRAL STARS

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RESUMEN

Presentamos una metodología de trabajo para obtener un modelo estelar-nebular autoconsistente. Determinamos la distancia usando las trazas evolutivas teóricas de estrellas centrales de nebulosas planetarias. Se aplicó esta metodología a la nebulosa planetaria galáctica NGC 6826. El modelo unificado requiere más trabajo pero disminuye las incertidumbres debido al mayor número de restricciones observacionales.

ABSTRACT

We present a methodology to obtain a stellar-nebular self-consistent model. Distance is determined using theoretical evolutive tracks of central stars of planetary nebulae. This methodology is applied to study of the galactic planetary nebula NGC 6826. A unified model requieres more work, but its uncertainties are smaller due to their larger number of observational constraints.

Key Words: ISM: abundances — planetary nebulae: individual (NGC 6826) — stars: abundances — stars: atmospheres — stars: rotation — stars: winds, outflows

1. INTRODUCTION

Planetary nebulae (PNe) are the final stage of low and intermediate mass stars (0.8 to 8.0 $M_\odot$). They are shells of gas surrounding the nucleus of the progenitor star, the stellar remnant is hot enough to emit photons able to ionize the surrounding gas. Many detailed models of either PNe or central stars of planetary nebulae (CSPN) have been developed separately; however, there are few works that combine the study of the nebula with its central star. We present a methodology to obtain a self-consistent model of the planetary nebula and its central star.

2. NEED OF A UNIFIED MODEL

From the data published in the literature we note that, in the case of central stars (CSPN) of galactic planetary nebulae, more than one model can reproduce the observations of the same star. The biggest problem is the high uncertainty in the distance to these objects. Table 1 shows two examples of the stellar models from the literature with different parameters.

On the other hand, the ionization sources generally used in photoionization models are black bodies (BB) or atmosphere models. The criterion to fix the temperature of a BB is only the number of ionizing photons necessary to reproduce the state of ionization in the nebular gas. When an atmosphere model is used, some parameters are adopted from other sources, while $T_{\rm eff}$ and luminosity are changed to reproduce the state of ionization in the nebula. Stellar wind is not considered in these studies. The degeneration distance-luminosity allows several nebular models to reproduce the observations in the nebular spectrum. Table 1 shows two examples of nebular models from the literature with different parameters.

There are few studies that simultaneously fit the CS and PN parameters (Morisset & Georgiev 2009). One way to link the two objects (CS and PN) is to use the atmosphere model as input to the photoionization model. The CS model should reproduce the stellar spectrum, including P-Cygni profiles associated with the wind. The nebular model responds to changes in $T_{\rm eff}$ and luminosity of the star changing its ionization degree. A stellar-nebular model requires additional work over producing a stellar or nebular model separately; but the additional observational constraints imposed, reduce the number of possible models and the uncertainties in the parameters.

3. LUMINOSITY-DISTANCE DEGENERATION

The distances to the Galactic PNe are poorly known, making the determination of the absolute luminosity a difficult problem. The luminosity-distance degeneration produces degenerations in many others parameters; because of this problem,

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TABLE 1

PARAMETERS OF NGC 6826

Reference	$T_{\rm eff}$ (kK)	$\log g$	$\dot{M}$ (10^{-8} $M_\odot$ yr^{-1})	v_∞ (km s^{-1})	$L/L_\odot$	Distance (kpc)
Pauldrach et al. 2004 (stellar model)	44.0	3.90	18.0	1200	15848	3.18
Kudritzki et al. 2006 (stellar model)	46.0	3.80	7.94	1200	12882	2.60
Kwitter & Henry 1998 (nebular model)	50.0	···	···	···	186200	···
Surendiranath & Pottasch 2008 (nebular model)	47.5	3.75	···	···	1640	1.40
This work (stellar-nebular model)	45.0±2.5	3.65±0.2	1.50±1	1100±100	6000±500	0.80±0.2

several models with different combinations in the values of L, R, and M can reproduce the observations.

On the other hand, a change in the distance directly affects the size ($R_{\rm in}$, $R_{\rm out}$) assumed for the nebula, as well as the volume of emitting gas. Photoionization models with different combinations of distance, luminosity, and temperature of the ionizing source can reproduce the observations.

4. BREAKING THE DEGENERACY

To solve the degeneracy in the parameters of the star and the nebula the critical parameter is the distance. In order to reduce uncertainty in the distance we used the evolutive tracks of Vassilidis & Wood (1994) in conjunction with the dynamic age of the nebula.

The $T_{\rm eff}$ of the CS can be constrained using a line ratio of the same element in two subsequent stages of ionization (e.g., C IV λ1169/C III λ1176 ratio).

Distances reported in the literature help to set a distance range. The dynamic age is known from the expansion velocity in observations, for a given distance. We obtained an upper limit to the dynamic age of 30150 yr by assuming $d_{\rm max} = 3.18$ kpc and $v_{\rm (exp)}{}_{\rm min} = 10$ km s^{-1}. The lower limit to the dynamic age was fixed in 3700 yr assuming $d_{\rm min} = 0.7$ kpc and $v_{\rm (exp)}{}_{\rm max} = 18$ km s^{-1}.

Knowing the dynamic age and temperature of CS is possible to locate it in the evolutive tracks. We use the evolutive tracks of Vassiliadis & Wood (1994). Possible solutions are in the region delimited by $T_{\rm eff}$ and dynamic age range. Every point within this region represent a combination of luminosity, $T_{\rm eff}$, and dynamic age. Assuming as expansion velocity the average of the available data we obtain a distance for each studied model.

Several possible solutions were explored within the area delimited on the evolutive tracks. Several models were obtained for CS, selecting those that best reproduce the observed spectra. These models were used as input to photoionization models in order to reproduce the state of ionization of the nebula. This yields a stellar-nebular self-consistent model.

TABLE 2

ADDITIONAL PARAMETERS FOR NGC 6826

Rotational $v \times \sin\ i$	70 ± 15 km s^{-1}		
Age	5000 ± 1000 yr		
$R_{\rm neb}$	0.07 ± 0.01 pc		
	Stellar	Nebular	Solar
He	11.04±0.15	11.03±0.15	10.93
C	8.00±0.30	8.80±0.30	8.30
N	8.18±0.30	7.95±0.30	7.78
O	8.60±0.30	8.50±0.30	8.60

5. RESULTS

Table 1 presents some parameters obtained from a preliminary model of NGC 6826 compared with others works. Table 2 shows additional parameters obtained in this work. With the exception of carbon, the stellar and nebular abundances agree within the errors. The solar value presented was taken from Asplund et al. (2005).

This work was partially supported by the grant PAPIIT IN123309 from DGAPA (UNAM, Mexico).

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