
B[e] phenomenon in bipolar planetary nebulae. Is the central star's wind symmetric?

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Summary. In this article we classify M1-92 and M3-60 CSPN as objects with B[e] phenomenon and suggest CRL618 as a possible candidate. A parallel between the supergiant B[e] stars and the CSPN are made on model simulations based on their spectra and line profiles similarities. We conclude, that similar spectra should point to similar physical conditions, therefore the cPNB[e] objects should contain fast rotators with a slowly expanding equatorial disks. The conservation of momentum of these disks, at least in the objects where the binarity is not confirmed, favours the magnetic field + rotation scenario for the collimation of the nebula.

1 Introduction

Stellar wind is a widely spread phenomenon in both young and evolved objects with high and low mass. The central stars of planetary nebulae are the counterparts of the massive O and Wolf-Rayet stars. The spectra of these objects, although of very different mass, can be interpreted with the same theory of radiative driven winds and only a scaling of luminosity, stellar radius and mass loss rate makes the difference between a WR star of 50 solar masses and a $0.5 M_{\odot}$ central star of a planetary nebula.

Similar links between massive and low mass stars exist for lower temperatures. There are several stars with strong Balmer lines in emission, presence of forbidden and permitted lines of low ionized metals, and IR excess. These stars are classified as B[e] phenomenon [5]. The group is heterogeneous and contains supergiants, pre-main sequence stars, symbiotic stars and some CSPN.

In this article we explore the possibility that the physics of the low mass members of the B[e] group is similar to that in supergiants, in the same way as the physics of the winds of the hotter stars is similar.

2 Observational data

We have a sample of high resolution spectra of proto planetary nebulae obtained with the echelle spectrograph at the Observatorio Astronomico Nacional at San Pedro Martir [1]. The inspection of the spectra revealed at least 4 objects which satisfy the classification criteria for cPNB[e] (Fig. 2). One of them, M2-9, is an already known cPNB[e] [5]; while M1-92 and M3-69 both show permitted and forbidden Fe II lines together with very strong $H\alpha$ in emission. In addition, we observed CRL 618, which is very similar to M2-9, but of a lower degree of ionization. It does not show Fe II lines, but it shows [O I] and Na D in emission which makes it a candidate for cPNB[e], although further analysis is necessary.

All four objects mentioned above show strong $H\alpha$ in emission with characteristic asymmetry toward the blue wing (Fig. 1, top). This feature appears more clearly in M2-9. The feature mimics an absorption component that splits the emission line in two. This line profile is similar to $H\alpha$ in the sgB[e] star R126 (Fig. 1, middle). Based on that similarity, we suggest, that the formation of the lines in the sgB[e] and cPNB[e] is similar.

The difference between a common CSPN and a B[e] object is the simultaneous presence of permitted and forbidden lines, which require very different densities for their formation. Fig. 2 shows the Fe II lines observed in M1-92 and M3-60 which classify then as cPNB[e].

3 Toward a quantitative model for objects with B[e] phenomenon

We have been developing a new radiative transfer code called ASTAROTH which can model 2D flows in nonLTE [4], [8]. We have completed few models for sgB[e] stars [9]. Here we present preliminary results for models with parameters appropriate for cPNB[e]. The code assumes a stellar luminosity and chemical composition. In addition, the mass loss rate and the velocity field are given as a function of radius and polar distance. The code solves simultaneously the equations of radiative transport, statistical equilibrium and thermal equilibrium. The populations of different levels of several ions are calculated together with the temperature distribution. These data are used to calculate the emitted flux in a range of wavelength and viewing angles.

The model we used here is the same as for the sgB[e] ([9]) but the luminosity and the mass loss rate were scaled down by a factor of 100. Similar to the sgB[e] model, the equator is cooler ($T \sim 12$ kK) and the pole is hotter ($T \sim 28$ kK). Although the luminosity was reduced, the hydrogen in the disk is ionized, which makes its blocking effect on the stellar light less efficient. We expect that the inclusion of rotation and meridional motion will help to reduce the degree of ionization. The predicted line profile at pole-on view resembles the observed profile (Fig. 1, bottom). The nebulae are seen mostly from the equator, but Arrieta et al. [2] showed that at least for M1-92, the disk blocks the direct light from the star and the observed spectrum is formed mainly by the flux from the pole, dust scattered toward the observer. A similar assumption is valid for the rest of the objects. We still need to explore the parameter space before modeling a particular object, but we can conclude that lines formed in a slowly expanding disk are similar to those observed in both sgB[e] and

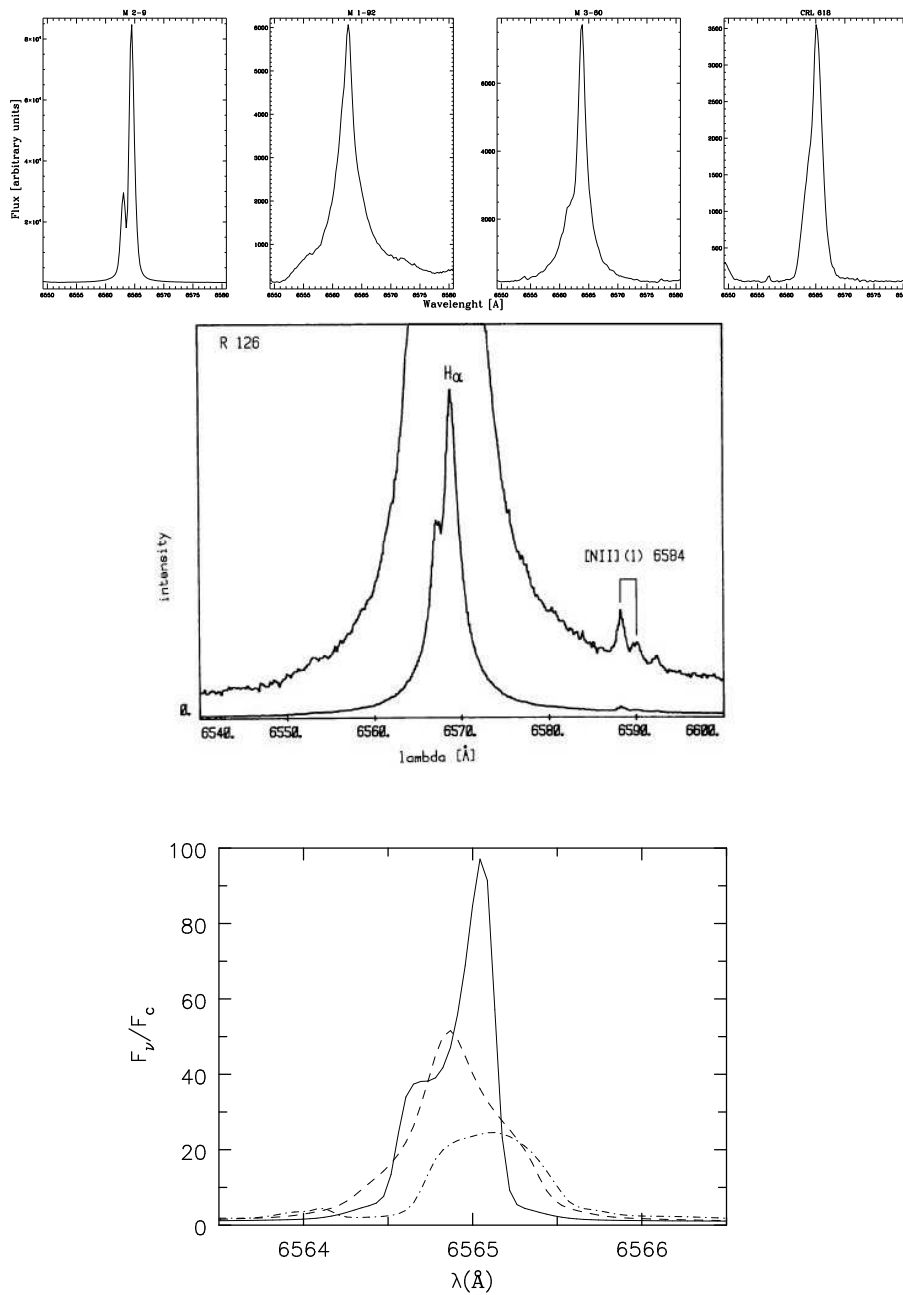


Fig. 1. Top: H α profiles in the four objects classified as cPNB[e]. All four objects show an asymmetric profile with extended blue wing and the presence of an absorption feature. Middle: H α profile in R126. The profile is similar to H α shown on the top panel (figure taken from [7]). Bottom: Synthetic H α profile calculated at three viewing angles; solid line - $i=0^\circ$; dashed line - $i=45^\circ$ and dash dotted line - $i=90^\circ$.

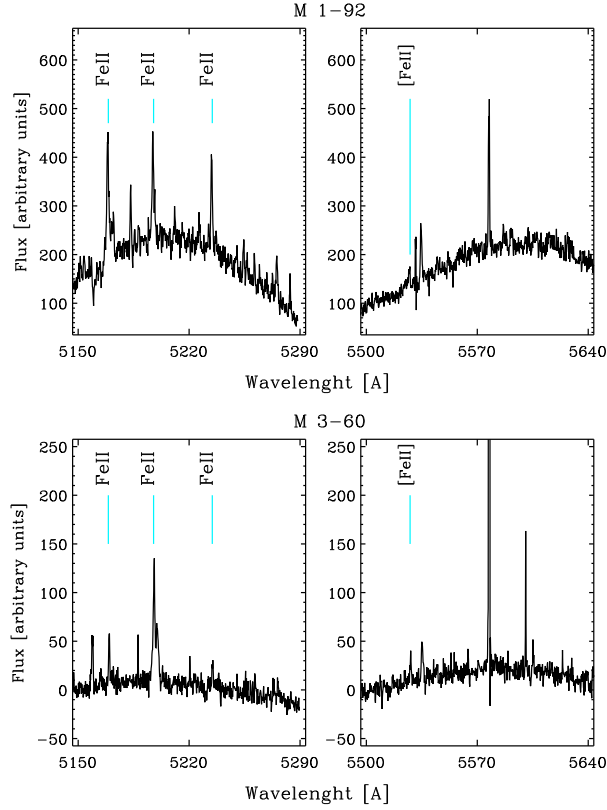


Fig. 2. Permitted and forbidden iron lines in M1-92 and M3-60. The presence of these lines is one of the classification criteria for B[e] phenomenon.

cPNB[e] and therefore it can be assumed that the physics of line forming regions of these objects is independent of their mass.

4 The formation of the disk and the stellar rotation velocity

The most popular mechanism for disk formation is the bi-stability of the stellar wind [6]. The opacity changes rapidly when temperature drops below ~ 20 kK and the velocity and the mass loss rate change accordingly. If the wind bi-stability mechanism is correct, then one needs an important rotational velocity to induce the bi-stability. There are several possible theories, but all of them require a rotational velocity above $0.7 V_{break}$. Where

$$V_{break} = \frac{V_{esc}}{\sqrt{2}} = 437 \text{ km s}^{-1} \sqrt{\frac{M/M_{\odot}}{R/R_{\odot}}}. \quad (1)$$

For a pessimistic estimate, we can reduce the rotational velocity to $0.5 V_{break}$, assume the mass of the CSPN to be $0.5 M_{\odot}$ and a large radius of $5 R_{\odot}$. Even in these extreme conditions, V_{rot} is of order of 100 km s^{-1} .

The remaining question is: how can the rotational momentum survive the formation of the nebula? Again, following the scenarios suggested for the massive B[e] and LBV stars, one can propose 3 possible explanations for the star to maintain its high momentum during the thermal pulses and the ejection of the nebula.

1. Magnetic field
2. Binarity
3. Ejection of nebula due to merging of two stars

The third scenario cannot be applied to bipolar PNe. The ejected material should stay mainly on the orbital plane. There is no direct evidence that the stars classified here as cPNB[e] are binary systems, so we focus on the case where the star appears single. In that case, the support of the high rotational speed requires a strong magnetic field [6]. It was shown [3] that similar conditions lead to a high degree of collimation. Therefore one can conclude, that the presence of B[e] phenomenon among the bipolar PNe, favours the rotation + magnetic field scenario for their formation.

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