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M2-9: an attempt to understand its central core

Silvia Torres-Peimbert,[1] Anabel Arrieta[2] & Leonid Georgiev[1]

[1]Instituto de Astronomía, Universidad Nacional Autónoma de México,
Apdo. Postal 70-264, México, 04510 D. F., México
email: silviaastroscu.unam.mx

[2]Universidad Iberoamericana, Prolongación Paseo de la Reforma 880,
Lomas de Santa Fe, México 01210, D. F., México

Abstract. We have studied the emission from the core of the Butterfly Nebula. We have tried to interpret the Balmer line profiles, double lines in emission. These profiles are not only observed in M2-9, but are also present in other objects of similar morphology.

Keywords. line: profiles, radiative transfer, planetary nebulae: individual (M2-9)

M 2-9 is a bright nebula of extreme bipolar morphology with a total extent of 115” that has been extensively studied (Allen 1972; Calvet 1978; Balick 1989; Hora 1994; Schwarz 1997; Solf 2000; Doyle 2000). The central source of M2-9 shows an exceptionally intense Hα emission line. The Balmer lines are double with a stronger red component; this behavior decreases towards higher lines in the Balmer series. M2-9 is not the only object that shows this behavior of Hα and Hβ profiles. Some examples of other young PNe and symbiotic stars with similar profiles are M1-91, IC 4997, Z And, and EG And, probably indicators of a transient wind present in some protoplanetary nebulae and symbiotic stars.

Echelle spectroscopic observations were carried out at the Observatorio Astronómico Nacional in San Pedro Mártir, Baja California with the 2.1-m telescope and the REOSC echelle spectrograph (R $\sim$ 18,000 at 5,000 Å) and a 1024×1024 Tektronix detector that yields a spectral resolution of 10.6 kms^{-1} and a spatial resolution of 0.9” per pixel.

The core of Hα shows a very pronounced double profile. This feature is also present, although with a somewhat different shape, in the rest of the Balmer lines. In Figure 1 the complex profiles of Hα/Hβ/Hγ are shown; these have been normalized to maximum intensity. The Hα line exhibits at least two strong components with peaks separated by $\sim 70\,\mathrm{km\ s^{-1}}$. The unreddened Hα/Hβ ratio at different velocity shows two maxima, at about -40 and $+60$ km s^{-1} and a minimum about -10 km s^{-1}. The minimum value is consistent with Case B recombination. On the other hand, the higher value (red shifted peak) is about 6 times the value predicted by recombination theory.

The excess in Hα line intensity relative to the one predicted for Case B is due to a high optical depth of the n = 2 transitions. Therefore it is proposed that the different observed components in these lines are the result of self-absorption.

Torres-Peimbert, Arrieta, Georgiev & Bautista (2005) computed a toy model to fit the profile of the core of the Balmer lines and derived line profiles by assuming simple geometry, density and velocity laws. From the code of Georgiev & Koenigsberger (2004) they obtained the source function from the Sobolev approximation and solved the 3D radiative transfer. It was possible to obtain the general shape of the line (double peaked with a blue shifted minimum) for models of a disk viewed in profile, for an expanding wind with velocity increasing with distance. In this model the critical condition is the

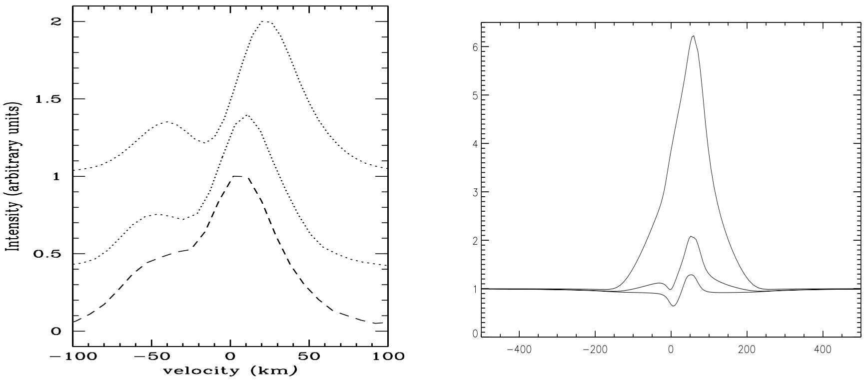

Figure 1. (Left) Observed Hα/Hβ/Hγlines, normalized to unity, and vertically displaced to display profiles. (Right) Unsuccessful modelling attempt, with the spherically symmetric complete radiation transfer code, to fit the Balmer line profiles. With reasonable parameters of R, L, $v(r)$, $\dot{M}$ we are unable to obtain profiles similar to the observed ones.

existence of a wind with a slow velocity gradient; this velocity law does not correspond to a standard radiation driven wind. The proposed expanding wind model is compatible with: (a) the asymmetry of the Balmer line profiles, (b) the difference between the profiles of the Balmer series, (c) the blue/red velocity difference between components, and (d) the Hα/Hβ/Hγ intensity ratios.

In this work, we have attempted to model the line profiles for a spherical symmetric wind with the complete radiative transfer code CSMGEN (Hillier & Miller 1998). We have only included H, He and C. At present, we have already studied a set of different plausible solutions, and our computed profiles of the Balmer lines do not resemble at all the observed profile behavior. (See Fig. 1).

Our preliminary conclusion is that it is not possible to model the line profile behavior with a spherically symmetrical configuration. Nevertheless we will continue to explore the parameter space (radius, luminosity, velocity distribution, and mass loss rate) to decide if indeed we can rule out a spherically symmetric configuration.

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