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EXPANSION VELOCITIES OF PLANETARY NEBULAE WITH [WC] CENTRAL STARS

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RESUMEN

A partir de datos espectro-fotométricos de alta resolución, hemos obtenido velocidades de expansión de una muestra amplia de nebulosas planetarias con estrella central de tipo [WC]. Los resultados se comparan con velocidades de expansión de nebulosas planetarias con estrella no [WC]. Todos los datos fueron obtenidos de manera consistente. Encontramos que las WRPNe muestran mayores velocidades de expansión y mayor turbulencia, lo que indica que la energía mecánica del viento estelar masivo ha afectado de manera importante el comportamiento cinemático de la nebulosa. También hemos encontrado que las WRPNe con estrellas de alta temperatura (por lo tanto más evolucionadas) se expanden más rápido. Esto podría utilizarse para comprobar la secuencia evolutiva que se ha propuesto para estrellas [WC].

ABSTRACT

High resolution spectra have been used to determine the expansion velocities of a large sample of planetary nebulae around [WC] central stars. The results are compared with expansion velocities of non-WR planetary nebulae. All the data were obtained in a consistent way. We find that WRPNe have larger expansion velocities and larger turbulence than non-WRPNE, demonstrating that the mechanical energy of the massive [WC] stellar wind strongly affects the kinematical behavior of nebulae. A weak relation between stellar temperature and expansion velocities has been found for WRPNe, indicating that older nebulae expand faster. This could be useful in testing the evolutionary sequence proposed for [WC] stars.

Key Words: **PLANETARY NEBULAE — STARS: POST-AGB — STARS: WOLF-RAYET**

1. INTRODUCTION

A small percentage of planetary nebulae (PNe) are ionized by central stars showing intense Wolf-Rayet features. In the Galaxy, all these stars belong to the WC-sequence (hereinafter [WC] central stars), showing almost pure He and C in their atmospheres. To date it is not clear what is the evolutionary process leading to the formation of such H-deficient low-mass stars, although several mechanisms have been proposed (see De Marco et al. 2003). In recent years, many efforts have been devoted to determine the differences (if any) between PNe around [WC] stars (WRPNe) and PNe around "normal" central stars.

A few years ago we started a systematic observational program to obtain high resolution spectroscopic data of a large sample of WRPNe and non-WRPNe. All data have been gathered with the 2.1 m telescope and the echelle spectrograph at Observatorio Astronómico Nacional, San Pedro Mártir, México (OAN-SPM). The consistent data set obtained this way is useful to compare the properties of both kinds of nebulae and to analyze the WRPN nebular characteristics and their relation to the stellar properties of [WC] stars. Some results have already been published (Peña et al. 1998; Peña et al. 2001). At present we are analyzing the kinematical behavior of the sample and in this paper we present some preliminary results.

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2. LINE PROFILES

The sample consists of 24 WRPNe (late and early [WC] stars have been included) and 23 non-WR PNe, including 9 nebulae ionized by weak emission-line stars (wels). We have obtained well-resolved line profiles for most of the observed objects. With our spectral resolution (between 12 and 18 $\mathrm{km\,s^{-1}}$) we found that 25% of the objects (in general the more extended ones) show the classical split profiles produced by an expanding shell. The others present single line profiles, which are occasionally gaussian but, most of the time, asymmetrical or complex profiles (generally produced by knotty nebulae) are found. For some objects, high velocity components or extended wings have been detected.

3. DERIVING EXPANSION VELOCITIES

An important fraction of PN shells seem to be irregular expanding shells. Many of them present knots, filaments, irregular structures and in many cases, ansae, FLIERS, BRETS and other kinematical structures are found. Therefore, the line profiles are usually complex and deriving expansion velocities from nebular line profiles involves somewhat arbitrary choices of criteria (see, for example, Peña et al. 2001; Gesicki & Zijlstra 2000; Neiner et al. 2000, among others). Therefore, velocities obtained with different methods or by different authors cannot be easily compared.

In this section we compare WRPN and non-WRPN expansion velocities derived from our consistent data set. The validity of our results resides on a systematic treatment for all the objects.

For PNe showing split profiles, expansion velocities ($V_{\rm exp}$) can be measured as half the peak-to-peak separation. For the others, the half-width at half maximum intensity of lines (HWHM) can be interpreted as expansion velocity, although this is not a good definition, particularly for those objects with complex or asymmetrical profiles. For single profiles, turbulence, density and temperature structures, nebular morphology and even slit size are convoluted with the expansion velocity field.

From measuring $V_{\rm exp}$ from the [O III] 5007 Å line for the 12 objects with split profiles in our sample (6 WRPNe, 2 PNe around wels and 4 ordinary PNe), we have found that WRPNe present expansion velocities in the range from 23 to 43 $\rm km\,s^{-1}$ with an average value of $36 \pm 5\,\rm km\,s^{-1}$, while non-WRPNe show a range from 17 to 26 $\rm km\,s^{-1}$, with an average of $21 \pm 4\,\rm km\,s^{-1}$. Therefore, contrary to the results found by Acker et al. (2002) and in agreement with hydrodynamical models for WRPNe (Mellema & Lundqvist 2002; Mellema 2003), our results indicate that WRPNe expand faster. This is a consequence of the large mechanical energy provided by the [WC] stellar wind.

Expansion velocities were also measured for other lines such as Hβ, He I 5876 Å, He II 4686 Å, O II 3726,29 Å and [N II] 6584 Å. We found a very good linear correlation for the velocities of different ions, but low ionization species (O^+ and N^+) present higher expansion velocities. This is predicted by hydrodynamical models.

In addition, from measuring the individual line widths of the two components in these objects, we have found marginal indications that WRPNe present wider lines and therefore more turbulence. Further analysis of the data is required for a better understanding of this result.

For objects with single lines, the HWHM values for WRPNe are on average 5 $\rm km\,s^{-1}$ larger than for non-WRPNe but, as said before, in this case the effect could be due to larger expansion velocities and/or larger turbulence in WRPNe. Much better resolution data would be required to disentangle both effects.

Interestingly, expansion velocities of PNe around wels are, in general, similar to those of normal PNe. This discards the possibility of wels being a more evolved stage of [WC] stars.

4. NEBULAR EXPANSION AND STELLAR PARAMETERS

Looking for the effects of the mechanical energy of the [WC] wind on the nebular velocity field, we have analyzed the behavior of the expansion velocities as a function of some stellar parameters like stellar temperature, mass loss and terminal velocity of the wind. No clear correlation is found between $V_{\rm exp}$ and the wind parameters, demonstrating that the nebular velocity field is a consequence of many effects, but a weak correlation between stellar temperature (as derived from non-LTE expanding model atmospheres, see compilation by Koesterke 2001) and the expansion velocities seems to be present. WRPNe with higher T_* are expanding faster. If, as expected, T_* is an indication of age, then more evolved WRPNe would be expanding faster.

The $V_{\rm exp}$ versus T_* correlation is much less well defined for our sample of non-WRPNe (wels and normal PNe included). In other samples of non-WRPNe such a correlation has not been found (e.g., Gesicki & Zijlstra 2000). In our sample some non-WR high-T_* nebula do show larger $V_{\rm exp}$ than low-$T*$ objects, but this phenomenon is considerably more noticeable in WRPNe.

Thus, the expansion velocities of evolved WRPNe seem to have been accelerated by effects of the large mechanical energy of the [WC] stellar wind.

The increase in expansion velocities of evolved WR planetary nebulae could indicate that we are witnessing the effects of a massive stellar wind lasting for the whole PN phase. Possibly, the analysis of the evolution of the expansion velocities as a function of age in WRPNe would allow us to test the validity of the evolutionary path:

$$[\mathrm{WC}]\ \mathrm{late} \rightarrow [\mathrm{WC}]\ \mathrm{early\ stars},$$

which has been suggested by several authors (e.g., Hamann 1997; Acker, Górny, & Cuisinier 1996).

A dynamical evolutionary model analyzing the effects of a long-term massive stellar wind on a planetary shell is in progress (see Medina, García-Segura, & Peña 2003).

5. CONCLUSIONS

From a consistent data set of high resolution spectroscopic data for WRPNe and non-WRPNe we have found that:

- WRPNe present higher expansion velocities and probably more turbulence than non-WR planetary nebulae.
- PNe around weak emission-line stars (wels) show a kinematical behavior more similar to normal PNe than to WRPNe, demonstrating that wels are not a more evolved stage of [WC] stars.
- Expansion velocities for evolved WRPNe are larger than for younger objects. This could be indicating that the velocity field in WRPNe accelerates with time as a consequence of a long-lived massive stellar wind.

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Silvia Torres Peimbert, Miriam Peña, and Susana Lizano (Photo: Will Henney).

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