Rev. Mexicana Astron. Astrof., **18**, 75-79 (1989)

ENHANCEMENTS IN PLANETARY NEBULAE: SIGNATURE OF REGIONAL COLLIMATED OUTFLOW FROM A ROTATING PROGENITOR?

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RESUMEN. Se arguye que las estructuras bi-simétricas observadas en las imágenes de nebulosas planetarias -y en algunas regiones HII- dan evidencia que la salida del material dando origen a las nebulosas definitivamente no ha sido isotrópica. El mecanismo que sugiero para la formación de tales nebulosas es la eyección colimada del material de un área definida sobre el progenitor rotante. El material saliente de esta manera formará una hélice cuya proyección se observa como la nebulosa. He discutido el campo de velocidades en detalle de la planetaria A78 confrontandolo con la morfología de esta. Los resultados muestran que la NP se ha formado por la eyección del gas de una sola región que forma un ángulo pequeño con el ecuador del objeto central.

ABSTRACT. It is argued that the bi-symmetrical enhanced structures in the images of planetary nebulae -and in some HII regions- afford evidence that the outflow of matter from the central star which engenders the nebula has definitely not been isotropic. The mechanism I suggest for the formation of such objects -the model- is the collimated outflow from a definite area on a rotating progenitor. Such an outflow will form a helix of which the projection is the observed planetary. We have discussed the detailed velocity field of the planetary Abell 78 in confrontation with its morphology. The results show that this PN was formed by ejection from one single active region which makes a small angle with the equator of the rotating central object.

Key words: **INTERFEROMETRY — INTERSTELLAR KINEMATICS — NEBULAE PLANETARY — STARS-MASS LOSS**

I. INTRODUCTION

The physical processes in planetary nebulae have been studied intensively within the last, nearly three, decades but the mechanism of the formation of these objects had not been investigated until lately. To investigate the mechanism of the formation of these objects one needs to have data on the structure and internal kinematics, the latter being the more difficult to obtain. The assumption of spherical symmetry is usually made in order to interpret the spectra of planetary nebulae, but most planetaries are obviously far from being projections of a spherical figure; yet as a first approximation it appears to have rendered reasonably acceptable results; the deviation from spherical symmetry being probably a higher order effect in the derivation of physical parameters of the planetary nebula.

II. THE TWO-WIND INTERACTION MODEL.

A concerted attack towards investigating the formation mechanisms of planetary nebulae is being carried out at present by Balick and collaborators (Balick 1987 and references therein). As a first step, it is commonly accepted that planetary nebulae originate by the detachment of the extended atmosphere of a star which has evolved into a red giant. This stage is referred to as the slow wind outflow.

The progenitor by losing its outer layers becomes smaller and hotter. The outflow at this next stage is in the manner of a hot and tenuous fast wind with velocity of the order of 2000 km s^{-1}. Matter outflowing by the fast wind acts on the previously ejected atmosphere producing a shock wave and forms a bright, thin "snowplow" rim. This is the commonly observed component of the planetary nebula which later may break up into clumps and filaments (according to Balick 1987).

III. NEED FOR NON-ISOTROPIC OUTFLOW:

Clumps, filaments and other enhancements in the image of most planetary nebulae are as a rule symmetrically placed around the progenitor. Such symmetry is a striking property a planetary nebula image possesses. Although the "intracting wind model" appears to account for the smooth general shape of a large number of planetaries, it does not explain, in its present state, the enhanced symmetrical details, as also stated by Balick, unless **ad hoc** assumptions are made; for example, instabilities in the bright rim are invoked which may cause fragmentation; but the effect of these instabilities will be of a chaotic nature and not give rise to features symmetrical as observed. An additional mechanism, or a focussing agent, must be at work to ensure the observed symmetries. This author has believed that in all similar circumstances there is no escape but to assume an additional constraint on the mode of ejection, namely that the fast wind from the progenitor, is not isotropic but possesses structure. It is my contention that the bi-polar symmetry may be a property inherent in the small hot stellar core and not be an effect of the environment; "the fast wind" is presumably produced from active spots at the ends of a diameter. It is conceivable that magnetic phenomena are involved in the process of ejection.

IV. EARLIER WORK ON NON-ISOTROPIC OUTFLOW.

That a stellar wind is expected to show structure –and not be necessarily spherically symmetric– was suggested over a decade ago in relation to studies of emission nebulae (for a summary see Pişmiş 1979). In the first paper of a series on the internal motion in HII regions we had studied the double nebula NGC 6164-5. By confrontation of the internal velocities of this HII region obtained by the Fabry-Perot technique with the symmetrical emission images in H_α and [NII] λ6584 of NGC 6164-5 it was suggested that the nebula is formed by matter ejected from two localized opposite regions on the rotating central star. In this particular case the emitting direction makes a small angle with the axis of rotation of the star, and this axis is very close to the plane of the sky (Pişmiş, 1974). In a subsequent paper of the series the same model was shown to explain the double ring structure of the HII region NGC 2359 (Pişmiş *et al.* 1977); in the latter case the axis of rotation is very close to the line of sight. In both cases as well as in similar ones, magnetic phenomena were invoked for the collimation of the ejecta. (Pişmiş, 1979). The central star of NGC 6164-5, an $O6f$ star with P Cygni line profiles, is at present losing mass through a wind; hence the conclusion that if the central star of NGC 6164-5 has shed material in a bi-polar manner during the formation of the double nebula it may be losing mass at present in a similar fashion. The same argument was applied to NGC 2359. Thus, we should be prepared to consider that stellar winds may have structure and therefore are far from possessing spherical geometry. This sort of a model may also be applicable to all cases where a rotating star loses mass from specific localized areas and where the outflow direction is inclined to the rotation axis; expressed otherwise the latitude of the ejecting spots on the star may have any value in the range 0° to 90°.

The morphology of a nebula produced by the manner described above will depend on at least two additional parameters as compared to the spherical wind model, making an overall discussion of spectral properties difficult to handle. The two additional parameters are the position of the ejecting spot (or spots) on the emitting object and the orientation of its rotation axis, with respect to the line of sight. Thus the model will become rather complicated for theoretical treatment of spectral properties.

V. HELICAL OUTFLOW.

It is easily seen that the outflow from a spot at latitude (γ) between 0° to 90° on a rotating object will describe a helix. If $\gamma = 0$ the helix will degenerate into a torus or a disk, while for $\gamma = 90°$ the outflow will describe almost a straight line. In some planetaries the projection of a helix on the plane of the sky is observed. To check the model that I propose, one needs to confront the velocity structure of the planetary with the observed morphology.

One striking example of a planetary with helical geometry produced by localized outflow is the "Helix Nebula" itself. The velocity field of the Helix has been obtained by Carranza, Courtès and Louise (1968) by Fabry-Perot interferometry in the H_α and [NII]λ 6584 lines. Although the distribution of H_α velocities does not show kinematic structure deviating significantly from a "homogeneous spherical" distribution, the [NII] velocities plotted against the azimuthal angle suggest that the Helix Nebula is the projection of a helix, with constant step, and having its axis inclined to the line of sight by 36°. An independent confirmation that the Helix nebula is not a simple expanding spheroid –usually presumed for planetary nebulae– but has a helical structure hinges on the fact that **no splitting** of the interference rings in [N II] is detected by Carranza *et al.* (1968). Therefore, it is highly probable that the Helix Nebula has indeed originated by collimated ejection of matter from a rotating progenitor.

VI. KINEMATICS AND MORPHOLOGY OF ABELL 78: EVIDENCE FOR HELICAL OUTFLOW

I shall now discuss the planetary nebula Abell 78 of which the velocity field combined with the morphology afford evidence that the nebula is essentially the projection on the plane of the sky of a helical form engendered by an emitting region on a rotating central star (Pişmiş 1989).

Observational data on this planetary nebula are obtained with the 2.1 m reflector and a focal reducer of the Observatorio Astronómico Nacional at San Pedro Mártir, B.C.N. Narrow interference filters (10A FWHM) and two Fabry Pérot etalons with free spectral range of 100 km s^{-1} and 283 km s^{-1} respectively have yielded the observational material on A78 discussed below briefly (for a full account see Pişmiş 1989).

Our H_α narrow filter direct images of A78 exhibit a rather smooth oval shape with a typical dimension of ≅ 110 arc seconds though there are indications of filaments encircling the central star, and displaced along PA ≅ 75°, which is the direction of the apparent "major axis" of the oval image shown in Figure 1. On PSS red copies the circular filamentary features are clearly defined. Jacoby (1979) points out the striking difference in the appearance of this object in the [OIII] λ 5007 line radiation as compared to the PSS red image.

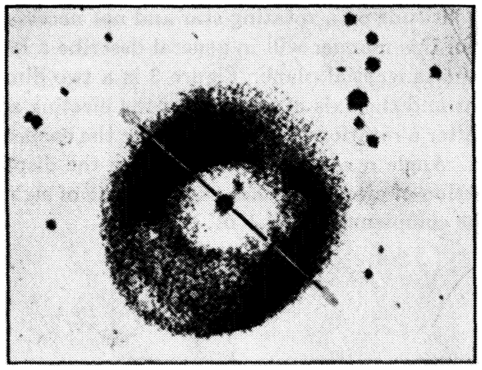

Fig. 1. The image of A78 in the H_α line radiation obtained with a focal reducer attached to the 2.1 m reflector of the Observatorio Astronómico Nacional at San Pedro Mártir. The black-white line segment marks the "minor axis" of the oval image, and divides the PN into two halves discussed in the text.

Radial velocities were measured on an H_α interferogram taken with the étalon having an inter-order separation of 100 km s^{-1}, and 88 reliable velocity points were retained for discussion. The velocities are referred to their standard of rest. At 16 points the interference rings showed either splittings or considerable width from which an overall expansion velocity of 27 km s^{-1} was estimated.

The velocity field was divided into 16 sectors centered on the star starting form the eastern end of the apparent "minor axis" of A78 (marked in black-white in Figure 1). For a display of the velocity field as well as the averages in the sectors around the central star see Pişmiş, 1989. The averages clearly showed that the NW half of the nebula is approaching the observer (−6 km s^{-1}) while the SE half shows recession (+6 km s^{-1}). The velocities of the ring-like filaments of the PSS image in the NW and SE halves agree with the recession and approach values of the region where they fall; this can be seen from Figure 2 which is the schematic representation of the circular filaments displaced in the direction of the major axis of the H_α image. These results show that the H_α image of this planetary nebula is definitely not the projection of a spherically expanding shell, for if it were so there would be no difference in the average radial velocities of the NW versus the SE.

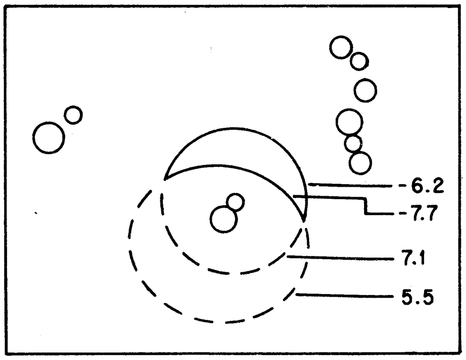

Fig. 2. Sketch showing the circular filaments of A78, adapted from the red copy of the Palomar sky survey.

It may be argued that A78 is a torus produced by an equatorial outflow from the progenitor star. There are two reasons against such a picture. First the existence of displaced rings cannot be explained by this mechanism and second, if the oval figure were due to the projection of a torus (or a thick disk) the radial velocities along the direction of the observed "minor axis" should show approach at one end of the minor axis and recession at the opposite end, which is not the case. The average radial velocites along the minor axis are nearly zero. In fact the elongation of A78 is caused by the displacement of the ring structure to the SE and not due the projection of a circular figure. I stress once again that the filamentary features in planetary nebulae maybe "signatures" of collimeted outflow from specific areas on the central object.

The model I suggest for the formation of A78 and of similar structures is as follows: matter is ejected from an active region (or two regions symmetrically located) at any latitude on a rotating star and not necessarly from the poles or the equator as commonly assumed. Matter outflowing in this manner will in general describe a helix. The planetary nebula will thus appear as the projection of a helix on the tangential plane. Figure 3 is a two dimensional sketch of our model projected on a plane formed by the line of sight and the axis of rotation of the ejecting star. The vectors in full line represent the velocity of ejection and its position after a rotation of π radians while the dashed vectors are velocites of outflow form a diametrically opposite active region. Angle α can be estimated form the displacement of the rings or of their centers (see figure 2). β is the angle the direction of ejection makes with the line of sight. In the case of A78 clearly cos $\beta = 6/27$. γ can therefore be obtained as the complement of $\alpha + \beta$.

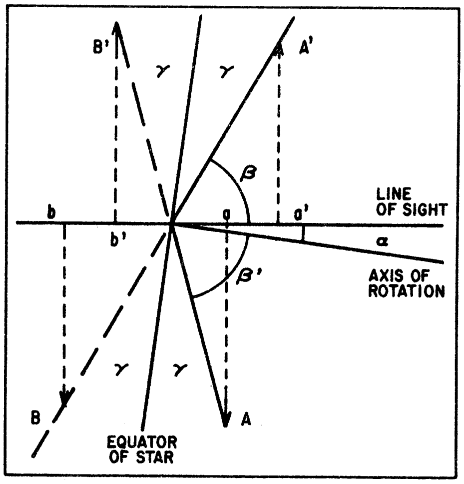

Fig. 3. A two-dimensional presentation of the model proposed for the formation of A78 and other helical similar nebulae. The projection is on the plane defined by the line of sight and the axis of rotation of the progenitor star. The vector SA, in full line, represents the outflow velocity while SA' is its position π radians from SA. In dashed lines are represented the outflow velocity SB from a diametrically opposite area on the star, and SB', the same velocity π radiaus from SB.

In the case of A78 $\alpha \cong 20°$, $\beta \cong 77°$ therefore $\gamma \cong -8°$. Furthermore the ejection appears to occur from one spot only. This is supported by the fact that the successive semi–circles in the NW (the convex ones) have negative velocities while the south–western semi–circles have positive velocites (see Fig. 2). It is easy to see that if we were observing ejection from two spots on the progenitor –a bi-polar ejection– the semi circles would alternate sign at the NW half; as well as in the SE half of the planetary nebula. We therefore state that according to our model the planetary nebula A78 is the projection of a **single helix** engendered by one active region only. A diametrically opposite outflow either does not exist or may be too faint to be detected by our observational means.

In conclusion I like to stress that the outflow of matter from a central object which gives rise to filamentary enhanced regions in A78 and in other similar nebulae is essentially not isotropic but collimated; perhaps the observed filaments are lying within an amorphous faint component which may be the extended atmosphere of an evolved red giant detached earlier.

Technical help received from M.A. Moreno, Ilse Hasse and A. García is acknowledged herewith.

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