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M27, A NEW TRIPLE-SHELL PLANETARY NEBULA[1]

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RESUMEN

En este trabajo se presentan imágenes monocromáticas profundas de M27 que muestran que esta conocida nebulosa planetaria es una de las pocas que tienen una envolvente triple. La compleja morfología de estas estructuras obliga a considerar a M27 dentro del conjunto de las nebulosas planetarias con envolventes múltiples.

ABSTRACT

In this work we study photographic narrow-band, overexposed images of M27 which present new secondary structures outer to the main body of this planetary nebula. It has been found that M27 is one of the few planetary nebulae that have a triple-shell. These structures have a very complex morphology and make it necessary to consider M27 a multiple-shell planetary nebula.

Key words: **PLANETARY NEBULAE**

I. INTRODUCTION

A significant number of planetary nebulae (PNe) have been shown to have an external shell to the main body (Jewitt, Danielson, & Kupferman 1986; Chu, Jacoby, & Arendt 1987). In some cases, these halos reach considerable dimensions (e.g., Moreno & López 1987; Rosado & Moreno 1991). They are being formed by one or more fractured spheroidal structures, these being either arcs, sharp filaments or material condensations. Studies such as those of Jewitt and his coworkers have established that the mass contained in these halos is at least similar to the one known in the main nebulae. Therefore their study could supply us with information on the possible precursors of the PNe, as well as on the formation and evolution mechanisms.

M27 = NGC 6853, PK 60−3°1, is the well-studied planetary nebula known as the Dumbbell Nebula. In conventional over-exposed photographs it appears to have an elliptical shape with the maxima of brightness at the ends of the minor axis. It has a generally accepted angular size of $8' \times 5'$, and is located in the direction of Vulpecula ($\alpha_{2000} = 19^h\ 59.6^m$, $\delta_{2000} = +22°\ 43'$). Its distance has been estimated to be 250 pc. This object has been morphologically classified by Balick (1987) as late elliptical. It was decided to do a photographic study of M27, that would permit us to register a possible unknown external shell to this planetary nebula, since from deep imagery of previously well-classified, apparently simple-structured PNe, complex morphology of their ejecta has been found.

II. OBSERVATIONS

A focal reducer, combined with a narrow band interference filters, and a one stage electrostatic

TABLE 1

FILTERS USED IN THIS STUDY

λ_0	Ion	FWHM[a]	T(%)
5008	[O III]	10	57
6563	Hα	8	33
6584	[N II]	7	37
6723	[S II][b]	13	...

[a] In angstroms.
[b] Both lines λλ6717+6731.

1. Based on observations collected at the Observatorio Astronómico Nacional in San Pedro Mártir, B.C., and at the Observatorio Astrofísico in Tonantzintla, Pue., México.

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intensifier tube was used in the Cassegrain focus (f/13.5) of the 2.1-m telescope of the Observatorio Astronómico Nacional at Sierra San Pedro Mártir, which yielded high quality photographs of M27 with a wide dynamical range. The plate scale of the resulting photographs is 49 arcsec mm^{-1}, and the useful field was 10.6 arcmin in diameter. On September 1988 and September 1989, 20 different deep-exposure images of NGC 6853 were obtained, centered on the emission lines of [O III], Hα, [N II] and [S II]. The characteristics of the interference filters used are given in Table 1. Figure 1 shows a selected group of monochromatic images of this nebula, while Table 2 gives the technical information. Two Fabry-Perot interferograms were also taken in Hα in order to determine the radial-velocity field. In August of 1990, using the 30″–26″ Schmidt Telescope of the Instituto Nacional de Astrofísica, Optica y Electrónica (INAOE) in Tonantzintla, a blue plate of M27 was taken to search for any change in the shape or size of the main nebula compared to another image taken with the same instrument in 1947. Our results will be discussed further on.

TABLE 2

CHARACTERISTICS OF THE IMAGES USED IN THE PRESENT WORK

Image	Filter	Emulsion	Exp. Time[a]	Date
1a	[S II]	103aG	10	Sept. 88
1b	Hα	103aG	10	Sept. 88
1c	[N II]	103aG	10	Sept. 88
1d	[O III]	103aG	10	Sept. 88
	Hα	103aG	30	Sept. 89
Ac621	none	103aO	10	July 47
ST8083	none	103aO	10	Aug. 90

[a] Minutes.

III. RESULTS

The monochromatic images presented here show several structural details not reported before (see Figures 1b, 1c, and 1d). The sizes of each and the corresponding wavelengths of observation are reported in Table 3. The more important morphological aspects are described below.

a) *Monochromatic Photographs*

Figure 1a is an image of M27 in the lines [S II] λλ6717+6731 A. From it one is able to see the elliptical shape of this nebula, with its brightness maxima at the ends of the minor axis as expected, together with the so called "second internal shell" (Maury & Acker 1990). This structure surrounding the central star has an ellipsoidal form, even if the NW side has not been defined. Its major axis is NW-SE oriented, and its angular dimensions on the [S II] image are 1.2′ ×0.8′. One can also appreciate from the image a considerable number of condensations, such as the ones indicated by Hua & Louise (1981). Along the NE-SW direction there are very outstanding condensations of 6.0 arcmin in size.

TABLE 3

DIMENSIONS FROM THE MONOCHROMATIC IMAGES OF M27

Image	Angular size (arcmin)	Linear projected dimensions[a] (pc)	R_0/R_i
Hα	7.8 × 6.2	0.57 × 0.45	1.27
[N II]	7.8 × 6.6	0.57 × 0.47	1.21
[O III]	8.4 × 6.1	0.61 × 0.45	1.36
[O III][b]	10.6 × 6.1	0.77 × 0.45	1.71
[S II]	6.2	0.45	...
POSS	8.0 × 5.6	0.58 × 0.41	1.41
Chu *et al.*	...	...	2.02

[a] Distance to M27 = 250 pc.
[b] If the third fragmented halo is considered.

Figure 1b shows the ionization structure of M27 in Hα, it clearly presents a well-defined elliptical form, with its major axis also in the NW-SE direction. Along the minor axis the Hα image is about the same size as the [S II] image in Figure 1a. Superposed to the ellipsoidal Hα shell there are several spoke-like features, all pointing toward the central star, independently of diffuse material condensations. This photograph clearly shows two diametrically opposed ray structures with respect to the central star that seem to be connected with the condensations along the NW-SE direction seen on the [S II] image (see Fig. 2).

Figure 1c is the image of M27 in the [N II] λ6584 line, on it the ellipsoidal structure appears again, only somewhat wider in the NW-SE direction. A large number of low excitation radial filaments protruding from the secondary external shell are clearly observed. The ones separated from the main nebula, situated along the W direction are specially thin.

Figure 1d shows the aspect of M27 in the [O III] λ5007 emission line. In addition to the presence of the secondary shell also obtained in the

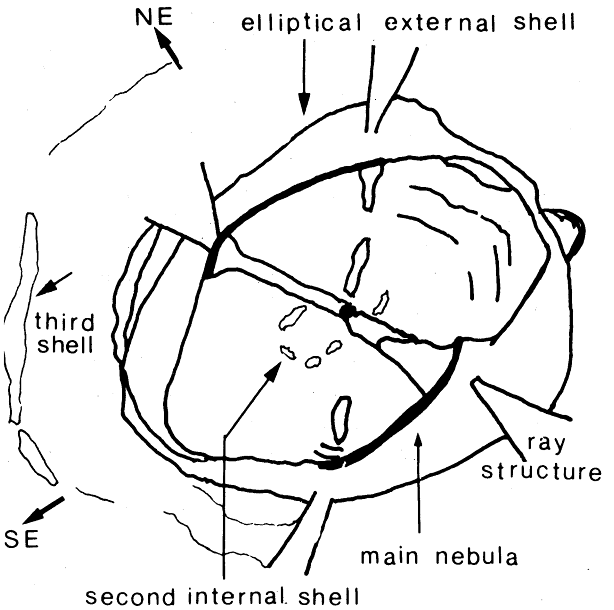

Fig. 2. Diverse structural details present in the different images of M27. The sketch has the orientation and scale of Figure 1.

previous figures, this image reveals the presence of a third outer shell, it appears well-defined and fragmented. Because only one [O III] photograph was available for the present study where this third envelope is partially visible, we can only estimate a minimum size of 10.6 arcmin in diameter for it. Four structures are well marked in form of rays, diametrically opposite with respect to the central star. The one situated in the SW-NW direction "breaks" the ellipsoidal structure of the secondary external shell, coinciding with the beginning of the so called "jet in absorption" reported in 1990 by Maury & Acker. Less prominent are the others, one being situated along the NE-SE, the other on the SE-SW side, and less apparent is the fourth one in the NW-NE direction.

b) *Velocity Field and Shell Expansion*

Even if the radial velocity for the M27 shell has been determined in the past (Liller 1965; Bohuski, Smith, & Weedman 1970; Hua & Louise 1970), it only covers the main nebula. We decided to extend the radial velocity field studies in order to include the secondary shells reported here. For this purpose, two Fabry-Perot interferograms were acquired in the Hα line. The interferograms cover the external secondary shells completely. The reductions were done according to procedures described by Courtès (1964). Radial velocities were determined for a total of 109 different points; the mean heliocentric radial velocity is $v_r = -31.1 \pm 0.7$ km s^{-1}. Even though significant variations were found in the velocity from one point to another, it was not possible here to quantify them, since this information is convoluted with photographic effects caused by over-exposure.

The expansion rate for the main shell of M27 varies from 0.64$\pm$0.24 to 6.8$\pm$1.8 arcsec per century (Liller 1965). A high-quality plate of NGC 6853 was found in the plate archives of Tonantzintla Observatory. It was taken in 1947 by G. Haro with the 30$''$-26$''$ Schmidt Telescope. This same instrument was again used by us to obtain a second-epoch plate (see Table 2), in an attempt to determine an independent measurement of its expansion rate from proper motions. Both plates were measured with INAOE's PDS microdensitometer. The plate constants were obtained by a simple process of adjusting by least squares the measurements for 10 SAO stars located in the field. Since the plate scale is 95.86 arcsec mm^{-1}, and since the microdensitometer has a precision of 0.7 arcsec in determining the absolute position on the plates, it is possible for us to determine relative movements of the M27 main nebula with a precision of 1 arcsec.

IV. DISCUSSION

From the images reported here it was possible for us to determine the existence of two very low surface brightness outer components not obviously present on the POSS images. The existence of a fragmented third shell of bigger dimensions was also found. In all cases, when overexposing the nebula on the photographic images, more ionized material appears concentrated in the NW-SW direction. Perpendicular to this direction, no more material was seen by us. Concerning the outer edge of the secondary shell, a considerable number of filaments were found, especially four structures having the appearance of rays which are present in the [O III] image and are symmetrically located with respect to the central star. The geometrical position of these filaments suggests that they are related to the two main condensations that can be seen clearly on the [S II] image. Less clearly defined, these structures in the form of rays remind us of the thin "cometary" forms that exist in the inner part of the Helix nebula. The third shell reported here shows that M27 has a more complicated and bigger structure than that known previously, possibly indicating several matter-ejection phases undergone by the central star. The dimensions and complexity of the outer secondary shells shown in the images obtained for M27 through the [N II] λ6584 and [O III] λ5007 filters are outstanding, specially at this last wavelength. This should not be a surprise, since the central star of this planetary nebula has an effective temperature of 125000° K (Kaler 1986).

Once the corresponding measurements on the

Schmidt plates were made, no appreciable displacements between the images of the two epochs were found, and it is reasonable to conclude that if any expansion is present, then its rate is less than or equal to the minimum value given by Liller, since in the 43 years between the epochs of the two plates no changes in the shape or size of the main nebula of M27 were detected within our accurancy ($\leq 1''$). This yields an upper limit for the expansion rate of the main body nebula of 2.3 arcsec per century.

To determine the size of the different ionization structures in M27, the ratios R_o/R_i were calculated using the values of the major and minor axes, as was done by Chu *et al.* (1987) for non-spherical shells. The results are shown in Table 3 and can be compared to the values of these authors, who give a bigger value than the one resulting from our images and from the POSS plates. Should $10.6'$ be considered as a minimum size for the third shell's major axis, R_o/R_i is larger, although it never reaches the value determined by these authors.

The image obtained in [O III] shows the largest angular size and a bigger number of structural details of the external shells, in agreement with the results of a study on other five PNe done by Feibelman (1971). The morphologies in Hα and [O III] are similar. The [O III] picture resembles the results of an explosive event.

Comparing our M27 images with those of other nebulae with low surface brightness halos such as NGC 6720 and NGC 6826, we are able to see more and finer structural details in our images (for comparison see the images of NGC 6720 shown in Moreno & López 1987, Jewitt *et al.* 1986, and Chu *et al.* 1987). This is due to the response of the spectroscopic plates with respect to that of actual CCD, and to the narrow bandpasses of our interference filters that permitted us to isolate properly the emission lines.

From the Fabry-Perot interferometric results, it is possible to make the following comments. The interference rings are wider in the direction of the major axis of the external secondary shell, narrowing as they move away from this direction, to end up with a constant width in the area of the minor axis. This effect is explained by the presence of matter in expansion along the major axis (Hua & Louise 1970). This preferential expansion could explain at least partially the elliptical shape of the secondary shells in M27. Since the 109 points measured here are all situated on the external shells, our analysis is a complement to the work done by Goudis *et al.* (1978).

Finally, the present analysis proves that M27 is a complex planetary nebula with different ionization structures. It has also been found that M27 is one of the few planetary nebula to have a triple-shell.

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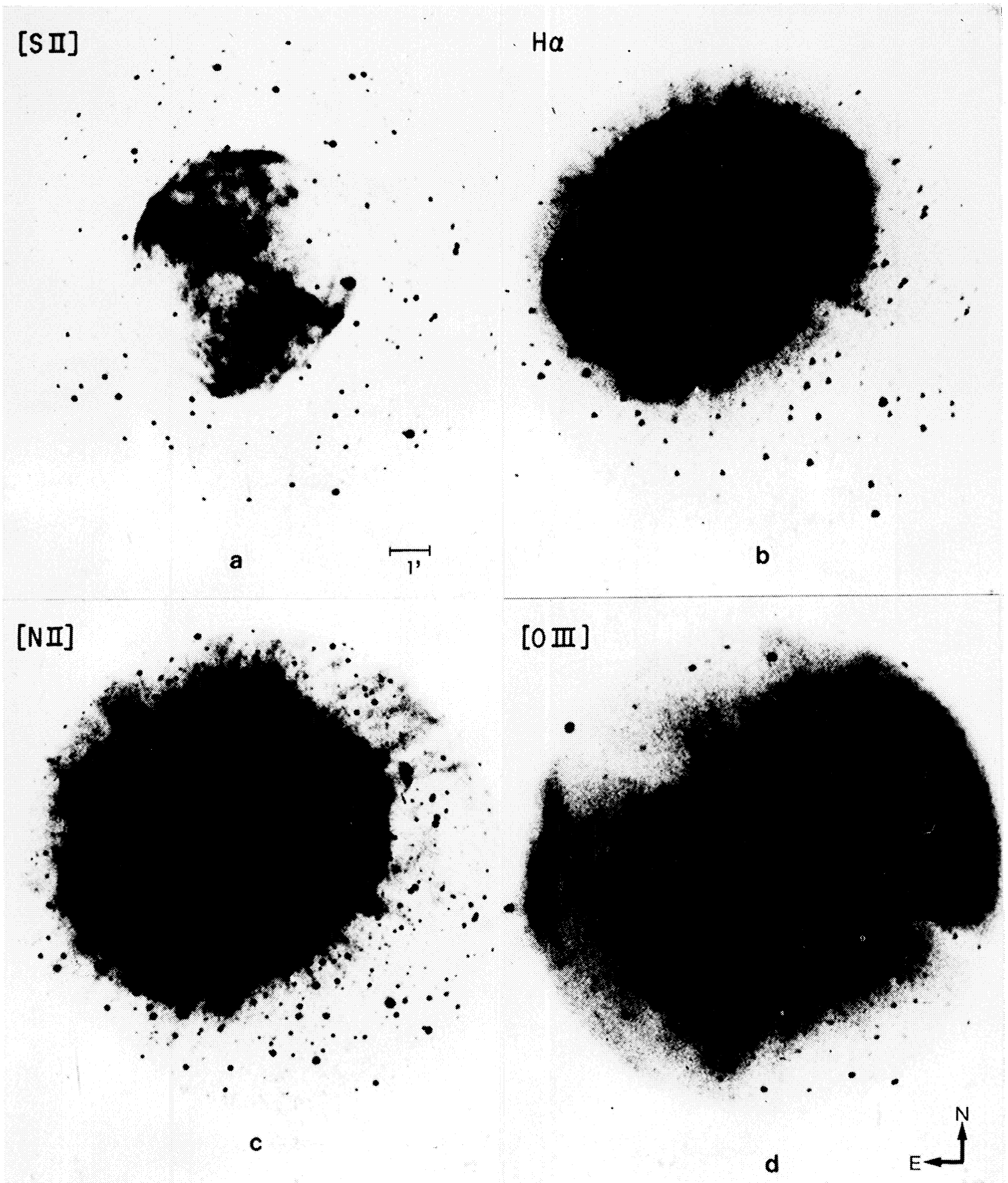

Fig. 1. Monochromatic images of M27. The scale and orientation are the same from a to d.

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