

ELECTRON DENSITIES IN TWO PLANETARY NEBULAE

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ABSTRACT

Direct photographs of the planetary nebulae NGC 6720 and NGC 650-1 suggest that they both are flattened ringlike forms, seen in different projections on the plane of the sky. Electron densities, measured from the $[\text{O II}] \lambda 3729/\lambda 3726$ line-intensity ratios, are generally higher in NGC 6720 than in NGC 650-1, but the density patterns are similar in the two nebulae. The electron-density measurements therefore tend to confirm, but do not prove, that these two planetaries do have similar forms.

I. INTRODUCTION

Of the many planetary nebulae which appear in the sky as ringlike objects, a considerable fraction can be understood as approximately ellipsoidal shells, seen in projection as rings (Curtis 1918). However, it is known that certain planetaries are not hollow shells of this type, because they are nebulae in which the surface brightness of the "hole" inside the ring is too faint to be the result of the projection of such a shell (Curtis 1918). For instance, the well-known Ring Nebula in Lyra, NGC 6720, must be an example of a true ring, for in it the ratio of brightness in the ring to brightness in the center has been estimated by Curtis (1918) to be about 20, while the shell model would predict a ratio of only 2. Curtis' photographs are taken essentially in the light of lines of low ionization and therefore do not actually show the distribution of density, but rather the distribution of ions of low ionization potential.

Once it is realized that there are some true ring structures among the planetary nebulae, the further question arises as to whether any of these ring planetaries are oriented nearly edge-on to the line of sight to the earth and therefore do not appear as rings in projection on the sky. Curtis (1918) has suggested that NGC 650-1, which has a roughly rectangular shape, might be an example of such a form, and this idea has also been considered by Minkowski (Aller 1956). We have made a further attempt to understand these structures by mapping the electron densities in the two nebulae NGC 6720 and NGC 650-1, the one a good example of a nebula appearing on photographic exposures as a true ring, the other as possibly an edge-on example of the same structure. The electron densities were determined by measuring the $[\text{O II}] \lambda 3727$ intensity ratios (Seaton 1954; Seaton and Osterbrock 1957), and these densities, together with the appearances of the two nebulae, do indeed suggest that two planetaries are roughly similar in form but seen in different projections.

II. DIRECT PHOTOGRAPHS

Figure 1 shows direct photographs of NGC 6720, the Ring Nebula in Lyra, all taken with the 200-inch telescope. Figure 1, *a*, is a comparatively short exposure in the light of $H\alpha$ and $[\text{N II}] \lambda 6548/\lambda 6583$ and shows clearly the pronounced fine structure in the ring. The appearance of the nebula in the light of $[\text{O II}] \lambda 3727$ is practically identical with that in $H\alpha$, and Curtis' photograph is quite similar to both of these. Figure 1, *b*, shows the nebula in the light of $[\text{O III}] \lambda 4959/\lambda 5007$. Here the ring is smaller and slightly less pronounced than in $H\alpha$, and the fine structure is somewhat more diffuse.

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Figure 1, *c*, shows the nebula in the light of He II λ 4686, with the ring structure now much less distinct than in [O III] and somewhat smaller. The photographs suggest that the nebula is a flat disk whose center has higher ionization than its edge. Only the edge is seen in lines of low ionization; only the center appears in lines of high ionization. A quantitative analysis based on line intensities would be necessary to decide whether the density near the edge is higher than that in the center. Finally, Figure 1, *d*, shows a very long exposure, taken in the light of H α and the red [N II] lines, again with the 200-inch telescope. This picture shows the faint outer envelope of NGC 6720 (Duncan 1937), which is about twice as large in diameter as the main body of the nebula. This outer envelope has the appearance of a thin shell of emitting gas rather than a thick shell extending all the way out from the outer boundary of the ring.

For comparison, two direct photographs of the planetary NGC 650-1 are reproduced in Figure 2; these pictures were also taken with the 200-inch telescope in the light of H α and [N II]. In short exposures the nebula is roughly rectangular, with greatest brightness at its two ends; indeed, the ends are catalogued separately as NGC 650 and NGC 651 in the *New General Catalogue* (Dreyer 1888). This form is roughly the same as the form that a ring nebula, seen edge-on, would exhibit, and it is for this reason that Curtis (1918) suggested that NGC 650-1 might indeed be a ring. The direct photographs show considerable fine structure, though not so much as in the case of NGC 6720. Longer exposures show faint material, forming, in projection on the plane of the sky, roughly semicircular arcs connecting the ends of the bright rectangle. We suggest that these faint arcs in NGC 650-1 and the faint envelope NGC 6720 represent two different views of fundamentally the same object, a thin outer shell roughly centered on the center of the ring. According to this interpretation, in the case of NGC 6720 we see the ring at an angle of about 45°, while in the case of NGC 650-1 we are looking parallel to the plane of the ring, and in both cases the faint shell is seen outside the bright part of the nebula. The direct photographs alone cannot prove this interpretation, though they do not contradict it and, in fact, suggest it, and so we have made the spectral observations described below to provide additional information.

III. SPECTRA

All the spectra intended for measurement of the [O II] λ 3729/ λ 3726 intensity ratio were taken either with the Newtonian-focus spectrograph on the 100-inch telescope, as used for the previously published study of the Orion Nebula (Osterbrock 1955), or with the cassegrain-focus spectrograph of the 60-inch telescope (Wilson 1956). In this spectrograph the *F*/1 camera was used, together with a grating giving a dispersion of 55 Å/mm at λ 3727, and the calibration was provided either by a step slit and the 100-inch coudé optics or by a separate linear-wedge spectrograph. Both the 60-inch and the 100-inch spectrographs have offset guiding eyepieces, with graduated motions in two co-ordinates, so that the slit may be set to any desired position in the nebula, if measurements with respect to visible reference stars have been made on a direct plate in advance. In addition, the 100-inch spectrograph may be rotated so that the slit lies in any desired position angle, while in the 60-inch spectrograph the slit is always oriented east-west. For each nebular plate there was a calibration plate, exposed for a time not different by more than a factor of 3 from the spectral plate and developed with it. The plates were traced on the microphotometer at the Astrophysics Laboratory of the California Institute of Technology to reduce them to intensities.

The results for NGC 6720 are collected in Table 1 and illustrated in Figure 3, in which each slit position is indicated by a line, with the measured λ 3729/ λ 3726 intensity ratio in the middle of it. In Table 1 the spectra of the positions marked "north end" and "south end" of the ring were actually taken by trailing the nebula back and forth, while the other positions were all taken with the slit fixed with respect to the sky. The mean measured intensity ratio for each point is tabulated in the third column,

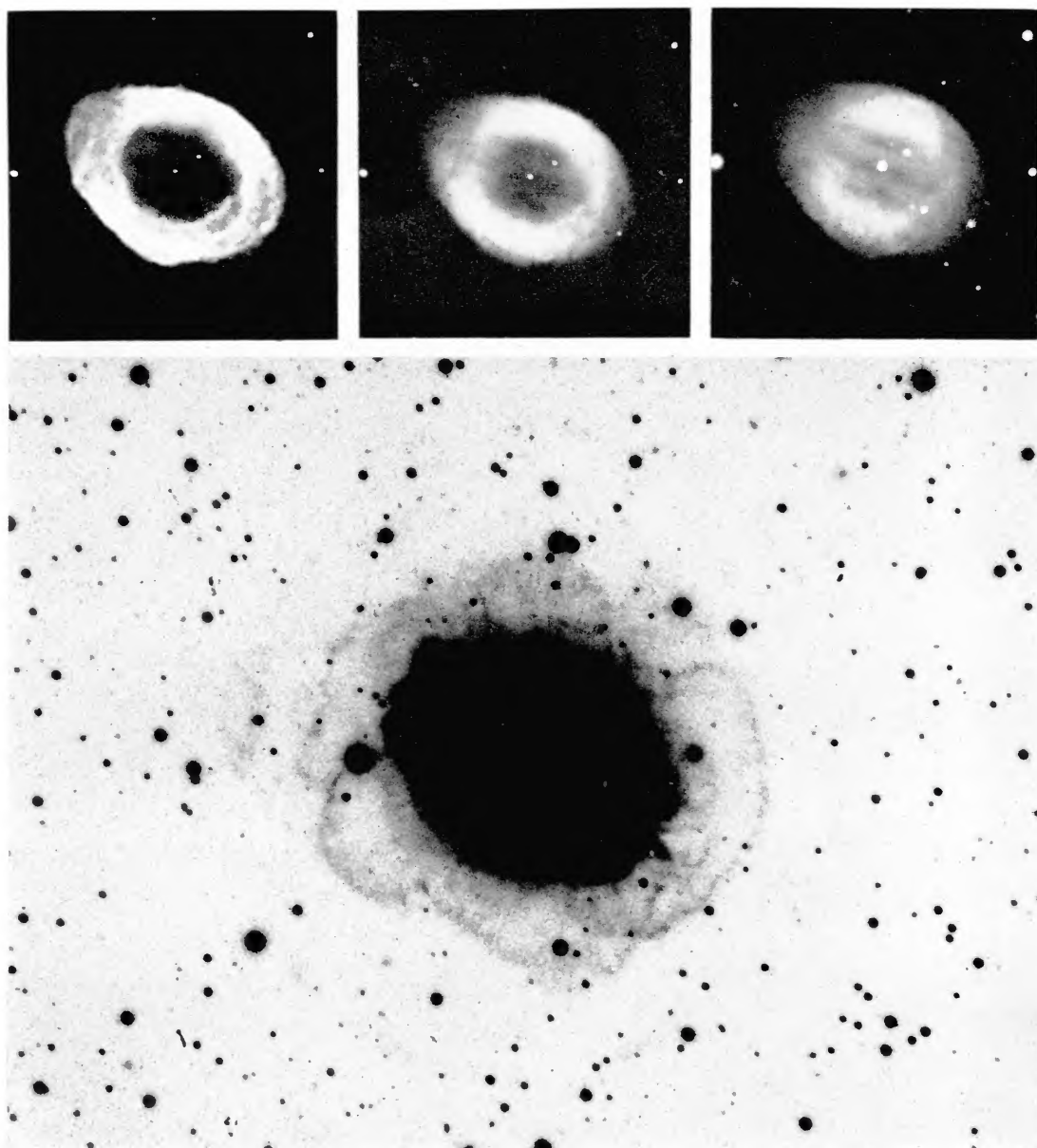


FIG. 1.—Direct photographs of NGC 6720, taken with 200-inch Hale telescope. Scale $3''/mm$. *a* (*top left*), short exposure in $H\alpha$ λ 6563 and $[N\ II]$ λ 6548, λ 6583; *b* (*top center*), exposure in $[O\ III]$ λ 4959, λ 5007; *c* (*top right*), exposure in $He\ II$ λ 4686; *d* (*bottom*), long exposure in $H\alpha$ λ 6563 and $[N\ II]$ λ 6548, λ 6583.

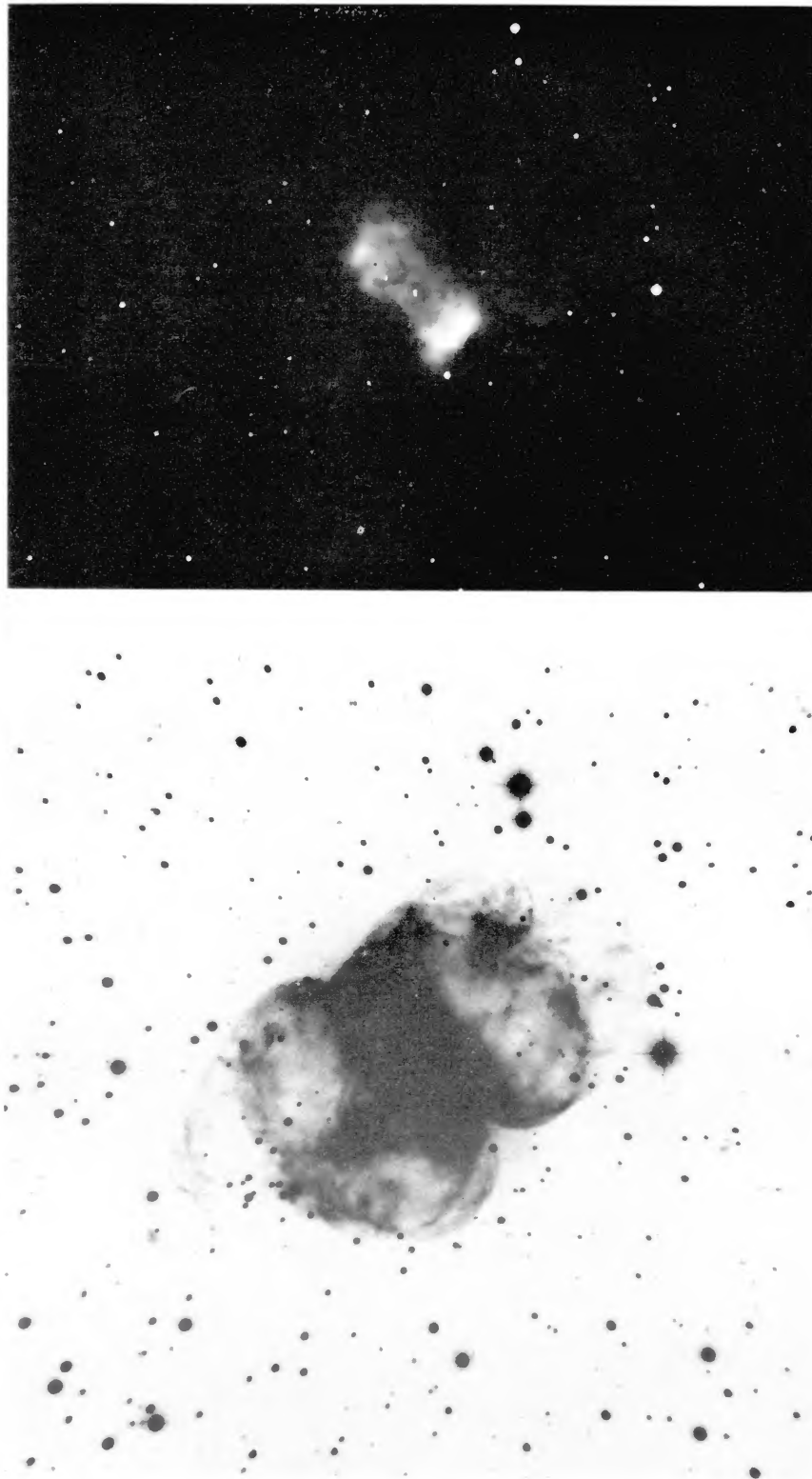


FIG. 2.—Direct photographs of NGC 650-1, taken with 200-inch Hale telescope, in $H\alpha$ λ 6563 and $[\text{N II}]$ λ 6548, λ 6583. Scale 3'.8/mm. *a* (top), short exposure; *b* (bottom), long exposure.

and in the next column n stands for the number of plates, B those taken with the 100-inch telescope, X those with the 60-inch. The average deviation of a single plate from the mean is listed in the next column. The least secure data are the measurements inside the ring, because they were all taken with the 60-inch at a considerably smaller scale ($129''/\text{mm}$ on the plate) than the 100-inch plates ($54''/\text{mm}$) and refer to rather small features, so that the whole length available for measurement was only a few tenths of a millimeter. Even so, the observations clearly show a progression in measured intensity ratio, from an average of $\lambda 3729/\lambda 3726 = 0.99$ for six positions in the ring, through 1.07 for three positions inside the ring, to 1.23 for two positions in the envelope. The spectra of the

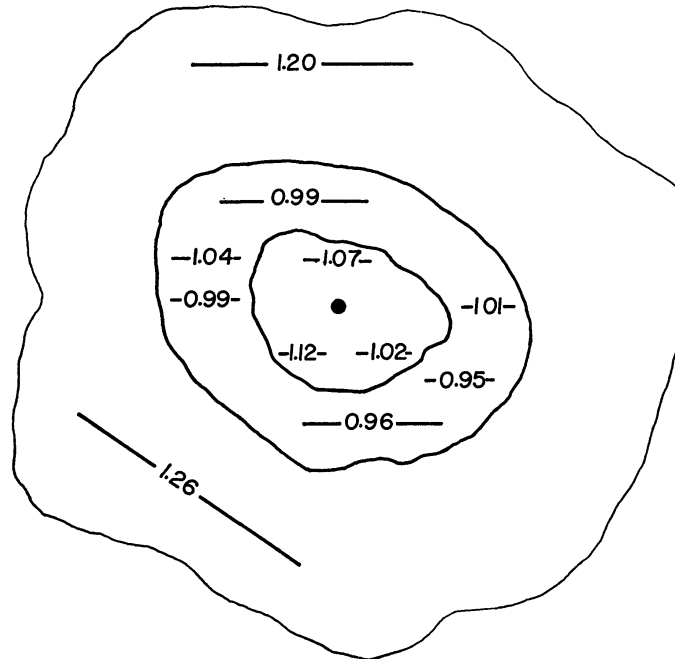


FIG. 3.—Slit positions for $\lambda 3729/\lambda 3726$ intensity ratios in NGC 6720

TABLE 1

$\lambda 3729/\lambda 3726$ INTENSITY RATIOS IN NGC 6720

POSITION	POSITION OR DISTANCE FROM CENTRAL STAR	$\lambda 3729/\lambda 3726$	n		A D	N_e (cm^{-2})
			B	X		
Inside ring	{ 10" south, 8" east	1 12		2	0 07	450
	{ 10" south, 12" west	1 02		1		650
	{ 10" north	1 07		1		540
Ring	{ North end	0 99	4	1	02	720
	{ South end	0 96	3	2		810
	{ West end	1 01	1		670	
	{ East end	0 99	1		720	
	{ West end, 16" south	0 95	1		840	
	{ East end, 10" north	1 04		1	600	
Faint envelope	{ North	1 20	2		0 02	320
	{ Southeast	1 26	1			230

envelope and of the ring show other emission lines with roughly similar relative intensities with respect to the [O II] pair, thus indicating similar levels of ionization for these two regions.

The intensity ratios have been reduced to electron densities, using the formulae of Seaton and Osterbrock (1957) and an assumed electron temperature of 10000° , with the results given in the last column of Table 1; the average densities are 730 electrons/cc in the ring, 550/cc inside the ring, and 280/cc in the outer envelope. Another possible assumption is that the mean density inside the ring is equal to the mean density of the ring; in this case, if the temperature of the ring is 10000° , the temperature inside the ring is approximately 27000° . It is also possible to assume that the density inside the ring has some value lower than 730 electrons/cc, and then the temperature has a value higher than 10000° but lower than 27000° . We cannot distinguish between these alternatives on the basis of the [O II] observations alone, but photometric measurements of say the [O III] lines would resolve the uncertainty. The densities are consistent with the relative surface brightness of ring and envelope only if the envelope is a thin shell of gas, as the appearance suggests. Since the envelope is about twice as large as the diameter of the ring, its surface brightness compared to that of the ring would, if it were a thick shell,

TABLE 2
 λ 3729/ λ 3726 INTENSITY RATIOS IN NGC 650-1

Position	Description	λ 3729/ λ 3726	n	A D	N_e (cm^{-3})
Bar	{ Northeast tip	1 34	3	0 06	140
	{ Toward northeast	1 23	3	04	180
	{ Near middle	1 15	2	00	400
	{ Toward southwest	1 22	1	.	290
	{ Southwest tip	1 23	3	0 05	280
Envelope	{ Southwest	1 36	1		120
	{ At southwest, near bar	1 34	1		140

have to be $2 \times (280/730)^2$, or 0.3. Obviously, the relative surface brightness is much smaller, and the thickness of the envelope therefore must be much smaller than its diameter.

The measured λ 3727 intensity ratios for NGC 650-1 are collected in Table 2. All these spectra were taken with the Newtonian-focus spectrograph on the 100-inch telescope. It can be seen, first of all, that the ratios are larger in NGC 650-1 than in NGC 6720, indicating that the electron densities are, on the average, smaller in the former nebula. There is considerable variation between the ratios at various points in the bar, indicating variations in density, but the mean density in the envelope, 130 electrons/cc, appears definitely smaller than the mean density in the bar, 280 electrons/cc. Thus the observed electron density pattern in NGC 650-1 is rather similar to that of NGC 6720, and these measurements are consistent with the idea that the two nebulae have the same general structure and form.

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