# MAGNETIC FIELDS IN PLANETARY NEBULAE

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## Abstract

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## ASTRONOMY

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# MAGNETIC FIELDS IN PLANETARY NEBULAE

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Attention was drawn long ago to one characteristic feature of the structure of planetary nebulae, namely that very often the brightness in two opposite parts of the nebula is maximal (^1). It is also characteristic that the maxima are located at the ends of the minor axis of the nebula. In some cases these maxima stand out so clearly and so sharply that they give the impression of a nebula divided in the middle into two parts; for this reason we gave such nebulae the name "separate" or "bipolar" (^2). In paper (^2) the idea was expressed that electromagnetic forces might play a role in the process of formation of such nebulae. Subsequently G. A. Shain offered certain considerations supporting this assumption ([3],4).

A careful study of the material now available shows that electromagnetic forces play a very substantial role in the dynamics of planetary nebulae, and that a number of features of their structure can be explained by assuming that magnetic fields exist in planetary nebulae. In the present note we shall dwell on the justification of this assertion by means of several examples.

In Figs. 1 and 2 are given photographs of typical representatives of bipolar planetary nebulae: NGC 7026 and the (unnamed) $16^h10^m.5$–$54°50'$. The first was obtained by us at the second focus ($F = 10500$ mm) of the 700-millimeter meniscus telescope of the Abastumani Astrophysical Observatory, and the second by Evans and Thackeray (^5). It is difficult to suppose that such two-sided, rather symmetrically arranged brightness maxima, and consequently maxima of the density of matter, could be a chance phenomenon. Most likely, matter was ejected from two opposite regions of the surface of the nucleus (^2).

Typical bipolar nebulae are also the well-known nebula NGC 3587 (Owl), 6058, 3195, 2371-2, etc. At present, of 100 planetary nebulae for which more or less good photographs are available, 25 have a well-pronounced bipolar structure ( "caps" ), and 10 nebulae, including NGC 6720 (in Lyra) and NGC 7293 (in Aquarius), have enhanced brightness at the ends of the minor axis. If to this we add another 15 spiral planetary nebulae, which are likewise the result of point outflow of gaseous matter from the central nuclei, we find that the observed bipolar structure is common to half of planetary nebulae.

So far not a single planetary nebula has been found in which the number of "caps" was, say, three or one. It is precisely the clearly expressed duality of such nebulae that compels one to connect the existence of "caps" in them with the action of a magnetic field. Here three possibilities arise. The first of them is connected with the possible action of the general magnetic field of the Galaxy on the highly ionized matter of the nebula. This action may cause a certain redistribution of the matter of the nebula,

as a result of which the density distribution over different cross sections of the nebula will become nonuniform. If this hypothesis is valid, one should expect a certain correlation between the direction of the Galactic magnetic lines of force and, for example, the major axis of bipolar planetary nebulae. The direction of the Galactic magnetic lines of force at a given point of the Galaxy can be judged, as is often done, from the direction of the plane of polarization of the light of nearby stars. In those cases where there are no stars with measured polarization nearby, the directions of the magnetic lines of force may, to a first approximation, be taken as parallel to the plane of the Galactic equator.

Even a cursory examination shows that the "caps" of bipolar planetary nebulae are oriented with respect to the Galactic equator in a completely arbitrary manner; a parallel arrangement of the major axis of a bipolar nebula with the Galactic equator occurs just as often as a perpendicular one. A clear example is provided by a group of nebulae consisting of 5 members, concentrated in a comparatively small region of the southern hemisphere of the sky. Only one nebula in this group has a clearly expressed ring-like form, without noticeable signs of bipolarity; the rest are bipolar (good photographs of these nebulae are given in (5)). A list of these nebulae is given in Table 1, where $\theta$ is the position angle of the major axes, and $\theta_0$ is the position angle of the Galactic equator.

**Table 1**

| Nebula | $l$ | $b$ | $\theta$ | $\theta_0$ |
|---|---|---|---|---|
| $15^h47^m,4; -51°21'$ | 290° | −2° | – | 45° |
| $15^h30^m,2; -58°59'$ | 297 | +1 | 166° | 45 |
| $16^h10^m,5; -54°50'$ | 297 | −4 | 21 | 45 |
| $16^h13^m,3; -51°52'$ | 300 | −1 | 93 | 45 |
| NGC 6153 | 310 | +4 | 4 | 33 |

It should be noted that all these nebulae are located very close to the plane of the Galaxy ($|b| \leq 4°$), where the strength of the magnetic field should be assumed to be greatest. Nevertheless, comparison of the values $\theta$ and $\theta_0$ given in the table completely rules out any role of the general magnetic field of the Galaxy in the process of formation of these nebulae, if one assumes that the magnetic fields in the region of the Galaxy under consideration have a regular character.

This conclusion is also supported by other facts, namely:

1. Of 25 typical bipolar nebulae, about 10 have Galactic latitude greater than $\pm 10^\circ$. For some of them the Galactic latitude is even greater than $\pm 40^\circ$ (for example, for NGC 3587 $b = +58^\circ$, and for NGC 6058 $b = +47^\circ$). It goes without saying that the magnetic field, even if it exists at such great heights above the plane of the Galaxy, cannot be so effective as to noticeably influence the motions within the nebula.
2. Near the plane of the Galaxy there exist ring-shaped nebulae without noticeable brightness maxima ("caps"), for example NGC 1501 ($b = +7^\circ 4$); $15^h 47^m, 4 - 51^\circ 21'$ ($b = +1^\circ$), etc.

However, the possibility is not excluded that the general magnetic field of the Galaxy affects planetary nebulae that are in the last phase of their existence, i.e. strongly expanded and having passed into a semi-diffuse stage ("transitional" nebulae). This is apparently true for the nebula NGC 5189, whose major axis is parallel to the Galactic equator. But there are still few such facts, and the facts themselves are not very convincing. Therefore we may assert that the general magnetic field of the Galaxy does not play a substantial role in the dynamics of planetary nebulae.

The second possibility is connected with the fact that the central nucleus-star may have a magnetic field of dipole character, whose lines of force

*To the article by G. A. Gurzadyan, p. 1232*

Fig. 1

Fig. 2

**Fig. 1.** Bipolar planetary nebula NGC 7026. Reprod. 7×

**Fig. 2.** Bipolar planetary nebula
$\alpha = 16^h 10^m.5$, $\delta = -54^\circ 50'$. Reprod. 7×

*To the article by P. P. Budnikov and V. S. Gorshkov, p. 1272*

**Fig. 2.** Character of the destruction of calcium hydrosulfoaluminate crystals during hydrothermal treatment. 750×. $a$ –original crystals $3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$, $b$ –after treatment at 40°, $v$ –after treatment at 80°

will become compressed in two opposite directions on the surface of the star. The ionized gas, which is in turbulent motion, will be redistributed in accordance with the magnetic lines of force. In other words, the distribution of the density of matter must correspond to the density of the magnetic lines of force. In particular, in the polar regions, where the density of the magnetic lines of force is greater, cone-shaped protrusions should form with their vertices resting on the poles of the star. Such a picture is indeed observed in some bipolar planetary nebulae. The brightness of a nebula at a given point is proportional to the square of the density of matter at that point. Therefore even a slight redistribution of density caused by the magnetic field may lead to a noticeable change in the distribution of brightness over the nebula.

This explanation encounters difficulties connected chiefly with the fact that the stellar nucleus has its own axial rotation, as a result of which the entire system of magnetic lines of force must also rotate. In this case it is difficult to imagine the formation of "caps" ; rather, on the contrary, all inhomogeneities in the nebula will be "washed out," and the nebula will appear as a homogeneous sphere. Moreover, the cubic law (approximate) for the decrease of the intensity of a dipole field with increasing distance should lead to extremely small values of the magnetic-field intensity in the region of the "caps."

However, as V. A. Ambartsumian has pointed out, in some cases, when the magnetic axis and the axis of rotation of the star have approximately the same directions, the formation of stable "caps" may take place.

A third possibility seems more acceptable: namely, that the magnetic field may be carried away together with matter liberated in some way from the central nucleus, as a result of which the planetary nebula is formed. Judging from observational data, the mechanism by which matter is liberated is such that it leads to an accumulation of gaseous matter in the region of the poles in the form of "caps." The latter form a kind of large independent dipole, inside which the central star rotates with its own dipole field. It should not be thought, however, that the fields of these two dipoles are sharply isolated from one another. It is very probable that the "magnetic viscosity" is continuous throughout all space —from the "caps" to the star—although in these regions it is maximal. With the recession and spreading of the "caps" away from the nucleus, the magnetic field also recedes and spreads, and in parallel with this the "magnetic viscosity" of the medium decreases. Further recession leads to a stronger decrease in the intensity of the magnetic field, and the "caps," joining one another, may form, in particular, a ring-shaped nebula.

The existence of turbulent motions inside planetary nebulae is beyond doubt. Therefore the ionized matter of the "caps" must experience, especially at the initial stage of expansion, a magnetic pressure directed opposite to its motion. As a result the nebula must expand along the direction of its "magnetic axis" (minor axis) with a velocity somewhat smaller than in the direction perpendicular to this axis. This, apparently, is how the elongated forms of planetary nebulae should be explained.

The existence of the phenomenon of magnetic braking in planetary nebulae is indicated by the fact that the edges of nebulae in the directions of their minor axis are, as a rule, sharp, whereas in the direction of the major axis the boundary of the nebula is sometimes even difficult to determine.

The hypothesis of the removal of a magnetic field with matter ejected from stars was considered by G. A. Shajn ([6]) and E. R. Mustel ([7]) as applied to novae and supernovae. It should be pointed out, however, that the processes occurring in novae and supernovae have nothing in common with the pro-

involved in the origin and formation of planetary nebulae.

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*Note: Figure translations are in progress. See original paper for figures.*