Kinematics of the central stars of the planetary nebulae

Y. P. VARSHNI
Department of Physics, University of Ottawa, Ottawa, Ont., Canada K1N 6N5
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A study of some statistical properties of the transverse motion of the central stars of 62 planetary nebulae is presented. It is found that, at low values, the observed proper motion is almost independent of the distance.

On présente une étude de quelques propriétés statistiques du mouvement transversal des étoiles centrales de 62 nébuleuses planétaires. On trouve qu'aux basses valeurs le mouvement propre observé est presque indépendant de la distance.

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Introduction

The central stars of planetary nebulae represent a very interesting phase in the life history of an appreciable fraction of stars (1). Apparently, because of their faintness, they have not received the observational attention that they deserve. In this paper we present a study of some statistical properties of the transverse motion of the central stars of planetary nebulae. We make use of the best available data on their proper motions and distances. Minkowski (2) has plotted the radial velocities of planetary nebulae against galactic longitude.

Proper Motions of Planetary Nuclei

The existing measurements of proper motions of planetary nebulae, made prior to 1967, have been summarized by Perek and Kohoutek (3) in their *Catalogue of Galactic Planetary Nebulae*. During the last few years two investigations on this problem have been published, those of de Vegt (4) and Cudworth (5). The latter author has obtained the absolute values of the components of the proper motion, $\mu_\alpha \cos\delta$ and μ_δ, for a total of 62 nebulae, using his own measurements and also those of van Mannen (6) and Anderson (7). We shall make use of Cudworth's (5) data in the following discussion. (We may note here that Cudworth has followed the practice that μ_α, if expressed in seconds of arc, actually represents $\mu_\alpha \cos\delta$.) The absolute proper motion, μ, and the mean error present in its determination were obtained as follows. μ is connected with $\mu_\alpha \cos\delta$ and μ_δ by the following well-known relation

$$[1] \quad \mu = [\mu_\alpha{}^2 \cos^2\delta + \mu_\delta{}^2]^{1/2}$$

where δ is the declination. If ε_α, ε_δ, and ε represent the mean (standard) errors in $\mu_\alpha \cos\delta$, μ_δ, and μ, respectively, then from the standard theory for determining the mean error of a compound quantity (see, e.g., ref. 8) we obtain the following expression for ε:

$$[2] \quad \varepsilon = [(\mu_\alpha{}^2 \cos^2\delta)\varepsilon_\alpha{}^2 + \mu_\delta{}^2\varepsilon_\delta{}^2]^{1/2}/\mu$$

The transverse velocity V_t of individual planetary nuclei was calculated from the well-known relation

$$[3] \quad V_t = 4.74\mu d$$

where V_t is in kilometres per second, μ is in seconds of arc per year, and the distance d is in parsecs.

A word on the uncertainties in the distances of planetary nebulae may be in order. About eight different distance systems are known at present for planetary nebulae (9, 10). For the purposes of [3], we have used the distances as given by Cudworth (5), except for five nebulae (A14, A36, A45, A78, and A82) for which Cudworth does not list any values. For these five, the values adopted are those given by Cahn and Kaler (11), multiplied by 1.5, to allow for the fact that Cudworth's distance scale appears to be ~50% larger than that of Cahn and Kaler (11). In view of the fact that the absolute distances of planetary nebulae may be uncertain by as much as a factor of two, any inferences drawn concerning velocities will also be subject to this limitation. However, as far as relative magnitudes of these quantities are concerned, they should be reasonable.

In Figs. 1, 2, and 3 we show the number of planetary nuclei, n, vs. the proper motion, the distance, and the transverse velocity V_t, respectively. In plotting Figs. 1 and 3 no account was taken of the error ε.

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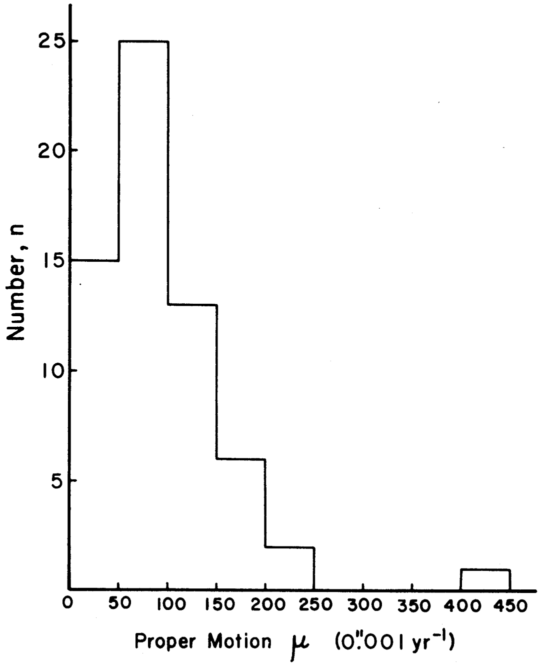

FIG. 1. Histogram showing the number of planetary nuclei vs. the proper motion.

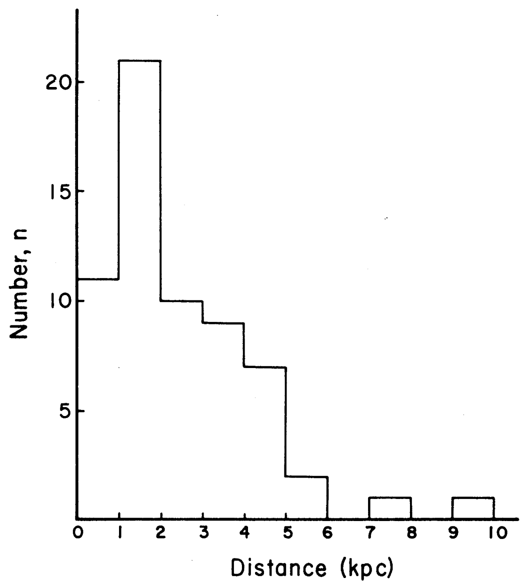

FIG. 2. Histogram showing the distance distribution of 62 planetary nuclei for which proper motions are available.

Discussion

Figure 1 shows that there is a predominance of small proper-motion planetary nuclei. For $\mu > 0''.05\ \mathrm{yr}^{-1}$, n continuously decreases with μ. The dip for $\mu < 0''.05\ \mathrm{yr}^{-1}$ may or may not be real. It could be

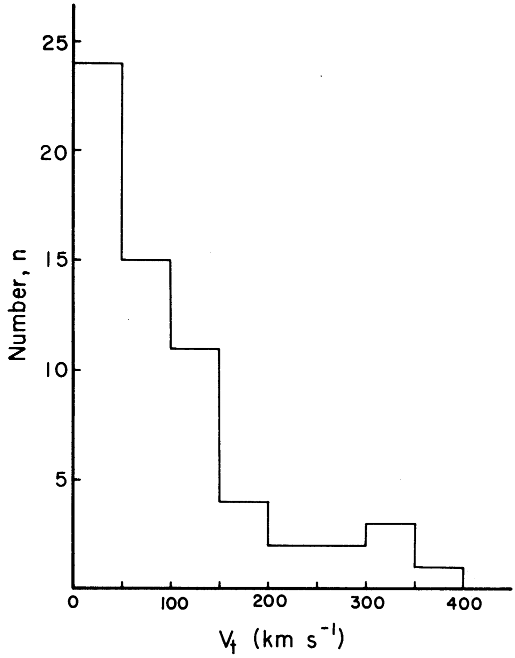

FIG. 3. Histogram showing the number of planetary nuclei vs. the transverse velocity, V_t.

spurious, being due to one or more of the following reasons: (*a*) fluctuations because of the small sample size, (*b*) an artifact arising from rather large errors in the available data, and (*c*) influence of selection effects, because very small proper motions would be hard to measure. The central stars of planetary nebulae may be the ancestors of some of the white dwarfs (12–15). If this hypothesis is correct, and if a planetary nucleus does not go through a cataclysmic event before it becomes a white dwarf, Fig. 1 provides some evidence on the question of the frequency of white dwarfs in space. For years white dwarfs have been searched for (14, 16) by looking at faint nonred stars with large proper motion. Figure 1 suggests that this procedure may be missing many small proper-motion white dwarfs. Luyten (15) from surveys of large proper-motion stars finds a frequency of $\simeq 2.3\%$ of all stars in space in the neighbourhood of the sun, while theoreticians working from theories of stellar evolution have generally obtained much higher values, some running as high as 10%. It is possible that the source of this discrepancy lies in Luyten's method. The histogram in Fig. 3 shows a trend of n decreasing continuously and rapidly as V_t increases. We shall discuss Fig. 3 in conjunction with Fig. 4. The average value of V_t comes out to be $98 \pm 89\ \mathrm{km\ s^{-1}}$, where the standard deviation refers only to the dispersion in the velocities and does not take

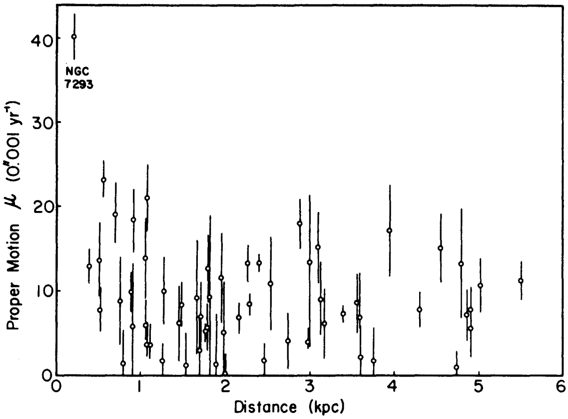

FIG. 4. Proper motions of 60 planetary nuclei plotted vs. their respective distances (Cudworth's distance scale).

into account the uncertainties in the individual velocities themselves. We hasten to add that in the present case, where the distribution is completely non-Gaussian, the standard deviation is of little significance.

The proper motions and their uncertainties, determined from [1] and [2], for 60 planetary nuclei are plotted against their respective distances in Fig. 4 (two planetary nuclei in Cudworth's list, whose distances are much greater than 6 kpc, have not been shown). It will be noticed from Fig. 4 that the nearest planetary NGC 7293 has the largest proper motion and it stands out from the rest. However, its proper motion is only $0''.040 \pm 0''.003\ \mathrm{yr}^{-1}$ and it is an isolated case. Proper motions for all other planetary nebulae (in Cudworth's list) are smaller than $0''.024\ \mathrm{yr}^{-1}$, with considerable uncertainty in many cases.

It will also be noticed from Fig. 4 that at low values ($\mu \lesssim 0''.015\ \mathrm{yr}^{-1}$), the proper motion is almost independent of the distance. It is an interesting result and it has an important bearing on distance estimates of objects which have small proper motions. Suppose a planetary nucleus has a proper motion of about $0''.015\ \mathrm{yr}^{-1}$. What estimate can we make as regards its distance? From the trend of points in Fig. 4, all that we can conclude is that very likely its distance is greater than 500 pc.

The next thing is to try to understand this result. The observed proper motion (and velocity) represents the combination of intrinsic proper motion and that due to the galactic rotation. However, it is not easy to disentangle the two. As Bok and Bok (17) remark "Unfortunately, it is very difficult to detect and measure the galactic-rotation effects in the proper motions. The quantities to be derived from an analysis of the proper motions are small, of the order of a few thousandths of a second of arc per year. Their signs and precise values are made uncertain by possible systematic errors in the basic system of proper motions and we do not know the constants of precession and nutation sufficiently well for dependable analysis of most large bodies of proper-motion data".

Trumpler and Weaver (18) have given a theoretical development of the effect of galactic rotation on the proper motion of stars on the basis of the Oort–Lindblad theory. By making certain approximations, these authors derive expressions for the effect on the proper motions, but these expressions are valid only for the solar neighbourhood (out to about 1 kpc). The available evidence (18, 19) indicates that the effect of the galactic rotation on the proper motion of stars is about $0''.005\ \mathrm{yr}^{-1}$. In other words if we are dealing with stars which have low ($< 0''.015\ \mathrm{yr}^{-1}$) observed proper motions, the intrinsic proper motion is of the same order of the magnitude as the effect of the galactic rotation. Quite often, when one thinks of a group of astronomical objects, one assumes that they have some sort of an average random velocity—perhaps approximating a Gaussian distribution. Even if this were true for planetary nuclei, the effect of the galactic rotation would strongly distort it and the observed velocity distribution may be very much different. This is possibly the explanation of Fig. 3.

The lack of dependence of proper motion on the distance can be similarly interpreted. The galactic rotation effect on the proper motion depends on the galactic longitude and latitude and certain constants, which depend on the galactic force law, $K(R, z)$, the form of which is only poorly known. Even if the intrinsic proper motions exhibited a dependence of the form $\mu \propto 1/d$ (which would follow if the intrinsic velocities had a narrow distribution), it is probably highly distorted by galactic rotation effects leading to the observed result that μ, for low values, is practically independent of d.

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1. L. H. ALLER. J. R. Astron. Soc. Can. **71**, 67 (1977); Mem. Soc. R. Sci. Liege, **9**, 271 (1976).
2. R. MINKOWSKI. Galactic structure. *Edited by* A. Blaauw and M. Schmidt. The University of Chicago Press, Chicago, IL. 1965. p. 321.
3. L. PEREK and L. KOHOUTEK. Catalogue of galactic planetary nebulae. Czechoslovak Academy of Science, Prague, Czechoslovakia. 1967.
4. C. DE VEGT. Z. Astrophys. **68**, 366 (1968).
5. K. M. CUDWORTH. Astron. J. **79**, 1384 (1974).
6. A. VAN MAANEN. Astrophys. J. **77**, 186 (1933).

7. C. M. ANDERSON. Lick Obs. Bull. **17**, 21 (1934).
8. J. TOPPING. Errors of observation and their treatment. Chapman and Hall, London, England. 1972.
9. W. IWANOWSKA and J. KANTHAK. Bull. Acad. Pol. Sci., Ser. Sci. Math., Astron. Phys. **13**, 155 (1965).
10. C. GORDON. Astrophys. Lett. **1**, 121 (1968).
11. J. H. CAHN and J. B. KALER. Astrophys. J. Suppl. **22**, 319 (1971).
12. C. R. O'DELL. Astrophys. J. **138**, 67 (1963); D. H. MENZEL. Publ. Astron. Soc. Pac. **38**, 295 (1926).
13. R. J. HARMAN and M. J. SEATON. Astrophys. J. **140**, 824 (1964).
14. V. WEIDEMANN. Ann. Rev. Astron. Astrophys. **6**, 351 (1968).
15. J. H. CAHN and S. P. WYATT. Astrophys. J. **210**, 508 (1976).
16. W. J. LUYTEN. Adv. Astron. Astrophys. **2**, 199 (1963).
17. B. J. BOK and P. F. BOK. The Milky Way. Harvard University Press, Cambridge, MA. 1974.
18. R. J. TRUMPLER and H. F. WEAVER. Statistical astronomy. University of California Press, Berkeley, CA. 1953.
19. W. M. SMART. Stellar dynamics. Cambridge University Press, London, England. 1938.