Session I

BASIC DATA

PLANETARY NEBULAE AS A PART OF THE GALAXY

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1. Introduction

Planetary nebulae form one of the most important subsystems of the Galaxy. If we knew more about this subsystem, an important gap in our ideas about the galactic structure would be filled. Very briefly, we are facing the following situation:

Population I, which contributes to the total mass of the Galaxy by hardly more than 7%, can be tracked almost over the entire Galaxy thanks to the radio observations of neutral hydrogen at 21 cm wavelength. Other data, for a wide solar neighbourhood, follow from observations of Cepheids and early-type stars.

Population II, at the other extreme, is more massive and may contain up to $\frac{1}{4}$ of the total mass of the Galaxy. RR Lyrae stars and globular clusters are bright enough to allow observations far beyond the galactic centre. Data for density distribution and kinematics of this population are available.

The most massive is the disk population with its $\frac{2}{3}$ of the total mass. It is, however, not as well observed as the other populations are. Only a few typical categories of objects are known to belong to the disk population, and out of these the stars of the galactic nucleus and weak-line stars are not observed or easily recognized at large distances; novae are few, and the short-period RR Lyrae stars have small amplitudes and are thus not easy to discover. The last item on the list of disk-population objects is planetary nebulae.

Planetary nebulae, though not extremely luminous, are observable beyond, or at least up to, the galactic centre. They can be systematically detected and are thus the most promising trackers of the disk population. If we knew, e.g., the density of planetary nebulae close to the centre of the Galaxy, we would have an independent check on the mass of the disk population contained in the central bulge, and thus also on the rotation curve derived from the radio observations of neutral hydrogen. Another important problem is the dependence of velocity dispersion on the position in the Galaxy. Its knowledge would help in constructing a dynamical model of the Galaxy representing the velocity distribution as well as the space densities.

2. Discoveries

There are basically two methods for discovering planetaries. If a planetary nebula

Osterbrock and O'Dell (eds.), Planetary Nebulae, 9–22. © *I.A.U.*

is discovered by one of the methods, it is the confirming evidence of the other method which makes the classification reliable.

The more straightforward method is to recognize planetaries according to the form. It has been in use since the concept of a 'planetary nebula' has come into being towards the end of the 18th century and is still up to date. Only the telescopes have changed. It was William and John Herschel and their contemporaries who first discovered planetary nebulae with this method. One of the most recent applications was to the Palomar Atlas. Several discoveries were made on the paper prints by Krasnogorskaja, Vorontsov-Velyaminov and others, but it was Abell who surveyed the original plates and found 86 new planetary nebulae. A complete survey of the paper prints by Kohoutek yielded 31 more discoveries. The original plates made it possible to discover planetary nebulae with a surface brightness as low as 25 magnitudes per square second of arc ($=16^{m}_{\cdot}5$ per circle $1'$). On the other hand, a planetary nebula can be recognized on a direct plate only if it shows a disk. The two smallest of Abell's planetaries have dimensions of $13 \times 13''$ and $17 \times 15''$, two have diameters of $20''$, and all the others are larger. But among the 1036 known planetary nebulae at least 40% are smaller than $13''$. These small objects, which are very frequent, especially in the direction of the centre, escape detection with this method even if they are fairly bright. Also over-exposed nebulae in the range $20''$ to $40''$ might be mistaken for stars on Schmidt camera plates because the only difference is the absence of the diffraction cross.

The second method, based on the emission spectra, came into practice between 1880 and 1910 and some 50 'gaseous nebulae' were discovered at Harvard. In recent applications of the method plates are taken through an objective prism and the planetary nebula is recognized by its emission lines and by the absence of a continuum. In the crowded regions of the Milky Way stellar spectra overlap all too frequently and some information is lost. A red filter is therefore sometimes used to shorten stellar spectra and thus to minimize the overlaps. The emission spectra of faint nebulae are in this case, however, restricted to the Hα line only and the classification is not as reliable as if more lines are observed.

There are several factors that influence the completeness of the survey. One of them is the intensity of the Hα line. An analysis by Henize (1967) of his survey of the Southern hemisphere showed that the incompleteness of one search was 0·23 and 0·03 for Hα intensities 1 and 2 respectively. For medium intense and strong Hα lines the search was practically complete. The repetition of the search reduced the incompleteness to 0·05 and 0·001 respectively.

The effect can also work in reverse, i.e. objects are included in the survey which are not planetary nebulae. Henize (*loc. cit.*) also investigated the purity of his survey. The purity is very high if the Hα image can be resolved, or if there is no continuum at all. The presence of the forbidden lines N1, N2, is a most helpful criterion. If even a faint continuum is present the situation becomes complicated. It is impossible to reject all these objects because even some bright planetary nebulae exhibit a faint continuum. If the Hα line is at least widened, or if it is sharp *and* the forbidden lines show up, the purity is of the order of 0·8. Great line strength, if combined with a faint continuum, is not sufficient for classifying the object as a planetary nebula, the purity being only about 0·2.

The two methods for discovering planetary nebulae complement each other. Large faint planetaries are discovered on the direct plates while small bright objects appear on the spectral plates.

Table 1 lists the telescopes which were used for systematic surveys and Figure 1 shows the areas of the surveys. The survey with the Metcalf telescope by Minkowski in the Northern hemisphere, extended by Henize to the South, is the most comprehensive and homogeneous one, although there is a difference of about $0^{m}.5$, the Southern survey reaching fainter magnitudes.

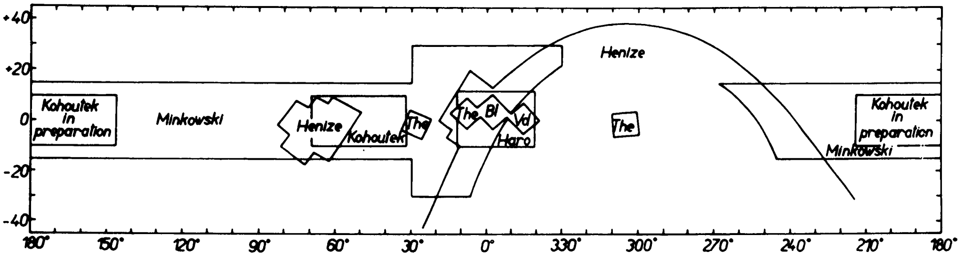

FIG. 1. *Areas of surveys for planetary nebulae.*

Table 1

Telescopes used for surveys of planetary nebulae

Telescope Type	Diameter Focus (cm)	Objective prism Angle	Objective prism Dispersion (Å/mm)	Author and approx. number of discoveries	
Metcalf	25	15°	450 at Hα	Minkowski	200
Refractor	132			Henize	150
				survey of	470
Bima Sakti	51	6°	312 at Hγ	The	64
Schmidt	126			Blanco	30
				Vandervoort	9
Tonantzintla	66	4°	~ 300 at Hγ	Haro	120
Schmidt	231			Peimbert, Batiz, Costero	24
				Perek	30
Hamburg	80	4°	570 at Hγ	Kohoutek	109
Schmidt	240				
Abastumani	70	8°	180 at Hγ	Apriamašvili	14
Maksutov	210				
Palomar	120	Direct plates		Abell	86
Schmidt	300			Kohoutek	31

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No meaningful data can be given for the limiting magnitude of the individual surveys. The limiting magnitude of a typical Schmidt camera of 60 to 70 cm diameter is about 17^m, but this refers to stars. The emission spectra, the non-stellar images, the small difference between the brightness of the background and the surface brightness of some nebulae, and other effects do not allow the definition of a simple limiting magnitude. It is evident, of course, that larger instruments reach fainter objects and thus it appears highly important to complete the survey of the Northern hemisphere with the Hamburg Schmidt and to cover the Southern sky with an equally powerful telescope.

It is interesting to follow the increase of the number of known planetary nebulae with time. The first nebula was discovered and classified by Darquier in 1779. The number increased to more than 60 in the following 80 years. After the appearance of the NGC and the two Index Catalogues, Curtis (1918) listed 102 planetary nebulae. Vorontsov-Velyaminov and Parenago (1931) compiled a list of 131 objects in their study of photographic magnitudes. The catalogue appended to the *Gaseous Nebulae and Novae* by Vorontsov-Velyaminov (1948) contained 288 planetaries and the second catalogue published by the same author in 1962 had 592 entries. Minkowski (1965) mentioned a total of 672 known in 1962. The preliminary catalogue by Perek and Kohoutek (1963) listed 704 nebulae and the printed edition (1967) lists 1036 objects known in 1964. Since then only two discoveries of possible planetary nebulae were published by Kazarjan (1966).

Original observations and measurements of planetary nebulae have been published in a large number of papers and they cannot be mentioned here. We can only refer to the literature given in the *Catalogue of Galactic Planetary Nebulae* by Perek and Kohoutek (1967). A large collection of photographs is contained in the classical paper by Curtis (1918), and a complete set of photographs, intended primarily as finding charts, appeared in Perek and Kohoutek (1967). Among the best photographs available are those taken by Minkowski (1964) with the 200-inch (508-cm) Palomar telescope.

3. Distances

The problem of determining distances of planetary nebulae stands at the base of all further studies. Some nebulae have a unique property which yields the distance of that single object. In this class belong the trigonometric parallax of NGC 7293, the distance of NGC 246 computed from the companion of the central star, the distance of the planetary nebula in the globular cluster M 15, etc. These distances are very important for the individual objects, but unless the methods can be applied to a large group, they can serve as zero points only. The distance scale itself cannot depend on more or less unique circumstances, such as exceptional brightness, size, or closeness, but must be based on physical properties common to all planetary nebulae.

Such properties are in the first place:

Angular dimensions, known for	60% of all planetaries
Proper motions	5%
Angular expansion	< 1%
Radial velocities	33%
Integral or wide-range magnitudes	>50%
Monochromatic magnitudes or surface brightnesses in absolute units	25%

and more refined,

Relative intensities of lines	27%
Central star observations	19%.

The low percentage of *proper motions* can be somewhat increased due to new discoveries but the increase will be slight at best and the mean parallax of $0\overset{''}{.}00079 \pm 11$ derived by Parenago (1946) can hardly be much improved. *Integral* or *wide-range magnitudes* are known for a large number of objects but the information content is low because the ratios of intensities of individual lines change from one planetary nebula to the other, and thus it is unknown, without other data, which lines enter the integral magnitude with what amount.

Radial velocities can be measured for many more objects. Strictly speaking, they can be used for distance determinations for objects moving in circular orbits only. The dispersion of velocities diminishes the accuracy of distance determinations. It is tolerable for Population-I objects which have small dispersions. Planetary nebulae, however, have dispersions of 25–45 km/sec, depending on direction, and the distances derived from radial velocities are subject to considerable errors. Besides, it is the kinematics of planetary nebulae which we wish to determine from radial velocities and we cannot have both kinematics as well as distances at the same time.

Angular expansion which, compared with the radial expansion, yields a very neat method of distance determination, is limited to very close objects. So are *central star observations*. Of the 19%, most are included in the simple statement that a central star has been observed. Detailed observations, however, are rare. Intensities of spectral lines of central stars are known for 1% of the planetary nebulae, and a description or classification of the spectrum is available for only 6% more.

Angular dimensions are known for many nebulae and the number and accuracy of observations can be increased with relatively little effort. Short exposure times are sufficient to register even rather faint planetary nebulae. Good seeing and a long focus are, however, mandatory to show the tiny disks of a very few seconds of arc. *Monochromatic magnitudes* or surface brightnesses have been measured for a considerable number of planetary nebulae and there is no obstacle in principle to extending the measurements to a vast majority of objects. *Relative intensities* of lines require repeating photometric measurements at other wavelengths unless the lines are so close as to require lengthy spectral treatment.

Methods of distance determinations based on angular dimensions and monochromatic magnitudes at a very small number of well-spaced wavelengths have the best chance to give a distance scale of the system of planetary nebulae.

Distance scales were discussed in many papers. We refer to Minkowski (1964, 1965) and to Seaton (1966). Here, we state briefly that the scale of optically thick nebulae can be set up if a mean absolute magnitude is introduced. The methods differ in either neglecting the spread in absolute magnitudes or in respecting it by introducing a term in $(m_s - m_n)$. We quote some representative formulae

Berman (1937):

$$\log r = 0{\cdot}2(H\text{–}A) - \log d + 0{\cdot}064(m_s - m_n) + \text{const.}$$

Vorontsov-Velyaminov (1934):

$$\log r = 0{\cdot}2(H\text{–}A) - \log d + \text{const.},$$

where H is the surface brightness, A the correction for extinction presented here in a uniform way in order to make the formulae comparable, d the diameter in seconds of arc, r the distance, and m_s, m_n the magnitudes of the central star and nebula respectively.

Optically thin nebulae, where the whole nebula is observed, require the knowledge of, or an assumption about, the mass. If the deviations from the mean mass are neglected, the corresponding term vanishes into the zero point of the scale. Some representative formulae follow:

Shklovsky (1956):

$$\log r = 0{\cdot}08(H\text{–}A) - \log d + \text{const.}$$

Abell (1966):

$$\log r = 0{\cdot}08\, m_{pr} - 0{\cdot}2 \log v + \text{const.}$$

O'Dell (1962):

$$\log r = -0{\cdot}2 \log F\ (H\beta) - 0{\cdot}6 \log d + \text{const.}$$

Kohoutek (1960, 1961):

$$\log r = 0{\cdot}13(H\text{–}A) - \log d + \text{const.}$$

It is interesting to note that this second group of methods is much less sensitive to the interstellar extinction. Compare the coefficient 0·08 with 0·2 of the previously discussed methods! The formula by Shklovsky goes back to Ambarcumjan (1939) and was first used by Minkowski and Aller (1954) for the determination of the mass of the Owl Nebula. Shklovsky established a distance scale with its help. The formulae by

Abell and O'Dell, with the integrated photored magnitude m_{pr}, the volume of the nebula v in cubic seconds of arc, the flux in absolute units $F(H\beta)$, are modifications of the Shklovsky formula. Kohoutek tried to derive masses by assuming that the difference between the absolute magnitude of the nebula and the absolute bolometric magnitude of the star remains constant during its evolution.

In any case, it is necessary to know if the nebula is optically thick or thin. Making the wrong assumption results in a distance which is too large. Minkowski (1964) therefore determined distances of planetary nebulae with sufficiently good photometric data according to both the methods for optically thick and for optically thin nebulae, and the comparison of results gave an indication of which method was the correct one. This seems to be the best proceeding at the present for faint and small planetary nebulae.

Seaton (1966) proposed a method for distance determination using electron densities deduced from relative intensities of forbidden lines. Further the surface brightness at $H\beta$ and the angular dimensions were needed. Spectrophotometric measurements are indispensable for this method because the [N II] lines cannot be separated photometrically from the $H\alpha$ line. Therefore this method can be applied only to bright, well-studied planetary nebulae.

Gershberg (1962) brought forward the fact that practically all planetary nebulae are transparent at centimeter wavelengths and he modified Shklovsky's method by using radio fluxes instead of surface brightnesses in the optical range. His distance determinations are limited to six objects. The radio fluxes can be used directly in Shklovsky's formula for nebulae optically thin both in the Lyman continuum and in the radio range.

An attempt to determine the best distance scale was made by Pskovskij (1959). He compared the distance scales of Vorontsov-Velyaminov, Berman, and Shklovsky by grouping planetaries according to larger (smaller) distances by one scale or other. Then he computed the Oort constant A for these groups and concluded that the best scale would have the least variation in A. The comparison, which spoke in favour of the Shklovsky distance scale, of course carries some weight but two important points should be considered. Although mostly NGC objects were used by Pskovskij, the distances of planetary nebulae are too large to warrant the constancy of A. Second, the value of A itself is dependent on the systematic velocity of the subsystem. Planetary nebulae need not yield the same value of A as Population I does.

4. Galactic Distribution

The distribution of planetary nebulae on the sky (Perek and Kohoutek, 1967, Fig. 2) gives at once the impression of a flattened galaxy seen edge-on with the obscuring layer in the plane of symmetry. This particular distribution is still more conspicuous in the frequencies plotted over galactic longitudes (*loc. cit.*, Fig. 1). The distribution is not quite symmetric, a part of the asymmetry being due to surveys with large Schmidt cameras. There is also an asymmetry present close to the centre (*loc. cit.*, Fig. 3). The deficiency in the South sets in approximately at declination $-35°$ which is about the limit of the Northern observations. It is, however, not easy to reconcile this explanation with the fact that the central region, both North and South of declination $-35°$, has been covered with the same telescopes. Another source of asymmetry may come from the irregular interstellar extinction.

The asymmetry in galactic latitude (*loc. cit.*, Fig. 5) is entirely caused by interstellar extinction. It is prominent near the centre and absent far from that direction.

The very high peak of the frequencies at the centre suggests at first sight that the nebulae seen in that direction are also at the distance of the galactic centre. It is interesting to see how this impression compares with numbers of planetary nebulae observed in other directions.

The comparison is based on the direction towards the centre and on a direction 65° away from the centre. In the last-mentioned direction the distance from the centre varies only between 9 and 11 kpc for the first 10 kpc from the Sun. The average numbers of planetary nebulae per square degree in the individual regions are shown in Table 2. The regions were selected between latitudes 2° and 5° so as to avoid the heavy extinction in the galactic plane. They coincide with the regions of maximum density of planetary nebulae in the direction to the centre.

Table 2

Average observed numbers of planetary nebulae per square degree

$l^{II} \diagdown b^{II}$	$+2°$ to $+5°$	$-2°$ to $-5°$
355° to 0°	3·0	2·5
0° to 5°	0·7	2·8
60° to 70°	0·23	0·30
290° to 300°	0·17	0·13

To compute the numbers of planetary nebulae per square degree, we need first the density near the Sun and second the variation of the density with distance.

If the density near the Sun is computed from a large volume, the incompleteness and the steep fall-off of the density with z might lead to a wrong estimate. On the other hand, a too small volume with a very small number of nebulae inside is subject to random fluctuations. Figure 2 shows the densities (numbers of nebulae per kpc^3) inside spheres of radius r. Each curve bears the name of the method of distance determination. Shklovsky's method leads to about 200 while other methods give about 30 as the extrapolated intersection of the curve with the axis of ordinates. Numerical results of Minkowski's method are not available but his graph of the distribution in the galactic plane contains 49 and 13 planetary nebulae inside squares of 2 and 1 kpc

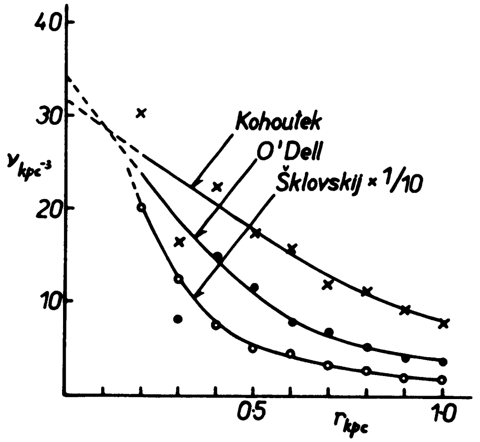

FIG. 2. *Space density of planetary nebulae in the solar vicinity inside spheres of radius r.*

respectively. With respect to a mean distance from the galactic plane of 0·3 to 0·5 kpc, we arrive at values between 26 and 40. It may be concluded that in the solar vicinity there are, as a rough estimate, 30 planetary nebulae per kpc^3.

Assuming, for the sake of simplicity, an exponential density law

$$\nu = \nu_c \exp(-pR - qz),$$

the number $N(r)$ of planetary nebulae in 1 square degree up to a distance r from the Sun is

$$N(r) = \frac{\nu_0 k}{m^3}\left[(x^2 - 2x + 2)\, e^x - 2\right],$$

where

$$x = rm,$$

$$m = \frac{\mathrm{d} \ln \nu}{\mathrm{d} r},$$

$$k = 0{\cdot}01745^2,$$

and ν_0 is the density at the Sun. The logarithmic density gradient m along the radius vector r is readily deduced from the gradients in the principal directions. Let us take values which are characteristic for the disk population

$$\frac{\mathrm{d} \log \nu}{\mathrm{d} R} = -0{\cdot}20; \quad \frac{\mathrm{d} \log \nu}{\mathrm{d} z} = -2{\cdot}00.$$

These values are close to those quoted by Plaut (1965) for novae which belong to the same population. At the latitude of 3°.5 (centre of the investigated regions), the z-gradient enters with a coefficient of sin 3°.5. The R-gradient enters with the full

Table 3

Computed numbers of planetary nebulae per square degree up to the distance r from the Sun

r_{kpc}	Direction 65° off the centre	Direction to the centre
1	0·003	0·003
2	0·016	0·03
3	0·045	0·12
4	0·087	0·34
5	0·14	0·75
6	0·20	1·54
7	0·26	2·8
8	0·32	4·8
9	0·38	7·9
10	0·44	15

amount in the direction towards the centre and can be neglected in the direction 65° off the centre. Thus we arrive at the values in Table 3.

Let us assume for the moment that we see all planetary nebulae up to the distance *r*. The observed numbers correspond to the computed numbers at 5 to 8 kpc from the Sun in the direction 65° off the centre. In the direction to the centre the observed and computed numbers tally at about 7 kpc from the Sun.

If we do not see all planetaries up to a certain distance, the ratio of the numbers may still be used. The only condition is that the numbers are affected in the same way in both directions. This is fulfilled if the interstellar extinction does not differ appreciably in the first two kiloparsecs in the two directions. The line of sight at that distance reaches a height of 120 pc above the galactic plane and most of the extinction occurs in the layer below. The ratio of the observed numbers is between 10 and 13 and this range of values is attained by the computed numbers not far from 7 kpc from the Sun.

We conclude that a disk population observed to only about 7 kpc from the Sun would show much the same distribution on the sky as the planetary nebulae do. Thus the apparent concentration of planetary nebulae to the direction of the centre cannot be considered a proof that the majority of these nebulae are really close to the centre. Some other evidence is needed to prove that *some* planetary nebulae lie beyond 7 kpc from the Sun. This supporting evidence comes from the radial velocities.

The distribution of planetary nebulae in the galactic plane is illustrated by a graph in Minkowski's (1964) paper. The distribution reaches to 3 or 4 kpc from the Sun, only occasional planetaries lying at larger distances. This is caused by the lack of adequate photometric data for distant objects. An analogous figure by Perek (1963), with distances computed according to Kohoutek's formula from photometric estimates, reaches further from the Sun but fails to show an important concentration at the centre. This is due to the fact that planetary nebulae at the centre have mostly very small or even stellar images, and that their distances could not be determined.

5. Radial Velocities

One hundred radial velocities have been known since the pioneer work of Campbell and Moore in 1918. Very few velocities were added in the following 40 years, until Minkowski and Mayall substantially enlarged the observing material in the late 'fifties by measuring 142 and 134 velocities respectively. Smaller programs or individual velocities were contributed by many astronomers interested in the field.

The total of 348 known radial velocities makes the system of planetary nebulae one of the best studied. It compares more than favourably with the 70 radial velocities of globular clusters, with the 160 velocities of RR Lyrae stars and even with the sample of about 300 velocities of Mira-types stars.

It is quite pleasant to note that there is no part of the Milky Way utterly devoid of radial-velocity measurements. The region of the galactic centre has the largest number of determinations. The numbers drop rapidly toward the Southern Milky Way and somewhat more slowly towards the North. Extensive programs can be set up even today for measuring radial velocities in both hemispheres, and these would serve a very good purpose as will be seen from the following discussion.

The distribution of radial velocities of planetary nebulae in galactic longitudes (galactic latitude below 20°) is quite remarkable (Figure 3). Although the range of velocities near the centre exceeds 500 km/sec, compared to 100–150 km/sec at other directions, the overall picture shows some regularity.

We note at once the straggler M 1-67 at $l^{\mathrm{II}}=50°$, $V=+215$ km/sec, which is the known planetary nebula around Merrill's star. This star is possibly in a hyperbolic, or at least in a very eccentric, galactic orbit (Perek, 1956). There is hardly any doubt

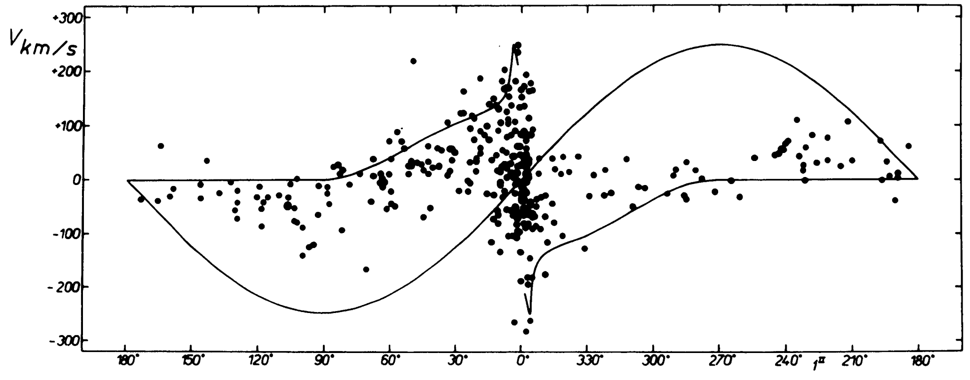

FIG. 3. *Radial velocities plotted against galactic longitudes for nebulae below 20° latitude. The curves limit the permitted area of radial velocities of objects moving in circular orbits.*

about the reality of the large positive value of the radial velocity. It was measured by Merrill in 1938, by Wilson in 1946, by Minkowski (nebula) in 1957, and by Bertola in 1964. All measurements give large values for the star as well as for the nebula.

Other planetaries which may be expected not to conform to the overall picture appear in Figure 4, which shows objects above 20° galactic latitude. There is Ps 1, at

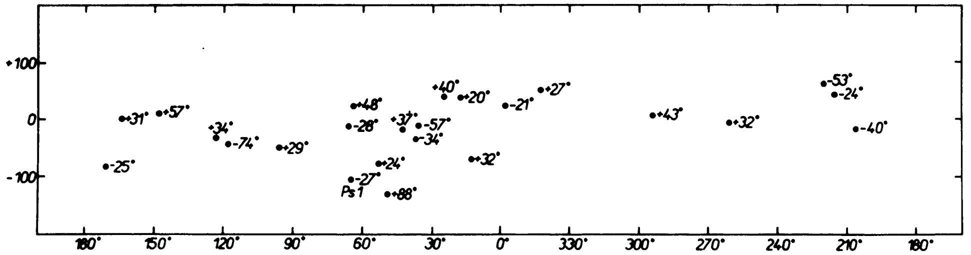

FIG. 4. *Radial velocities of planetary nebulae above 20° latitude with latitude shown.*

$l^{\mathrm{II}} = 65°$, $V = -143$ km/sec, the planetary nebula in the globular cluster M 15. Its kinematics are those of the globular cluster itself. Another is H 4-1, $b^{\mathrm{II}} = +88°$, $V = -133$ km/sec, situated close to the galactic pole.

It was shown by Minkowski (1965) that radial velocities of objects moving in circular orbits should lie inside a permitted area limited by two curves. The first is the sine curve of the reflected motion of the Sun around the centre and the second curve gives the extreme radial velocities with respect to the Sun. The extreme velocities occur in the interval $270° < l^{\mathrm{II}} < 90°$, at points subtending a right angle over the base centre–Sun, and are equal to the circular velocities at those points plotted from the sine curve. The extreme velocity is zero in the interval $90° < l^{\mathrm{II}} < 270°$.

Minkowski (1965) used Schmidt's model (1956) which represents the hydrogen 21-cm observations. He found that too many velocities near the centre lie outside the permitted area and concluded that the kinematics of planetary nebulae could not be explained in terms of circular orbits.

In 1960, Rougoor and Oort published hydrogen observations from the central regions between 100 and 600 pc from the centre. This curve, adjusted to a distance of the Sun from the centre of 10 kpc, shows a conspicuous hump. This hump is prominent in Figure 3 and fits the observed peak velocities of planetary nebulae.

Further we note that, if the orbits are not strictly circular, the limits of the permitted area may be exceeded by amounts roughly equal to the velocity dispersion. The data on velocity dispersions are rather scarce. Delhaye (1965) quotes the results by Wirtz giving 45, 35, 20 km/sec for the dispersions in the R, θ, z directions respectively. Parenago (1946) gives 29 km/sec for the z-dispersion. We find from 23 planetaries above 20° latitude an average projection into the z-axis of 24 km/sec, which is equivalent to a dispersion of 30 km/sec, in agreement with Parenago. Thus the limits of the permitted area may be exceeded by amounts between 35 and 45 km/sec. These values being root-mean-square, correspond to 28 and 36 km/sec average excess velocities respectively. We find from Figure 3 that the limits – with the exception of the sine curve between $355° < l^{II} < 5°$ – are exceeded by 48 nebulae and that the average excess velocity is 24 km/sec, well within the expected range. The average excess velocity in the remaining small part is 72 km/sec, i.e. it is larger by a factor of 3 than anywhere else! This is well illustrated in Figure 5, which shows the central part of Figure 3 with the scale of abscissa blown up.

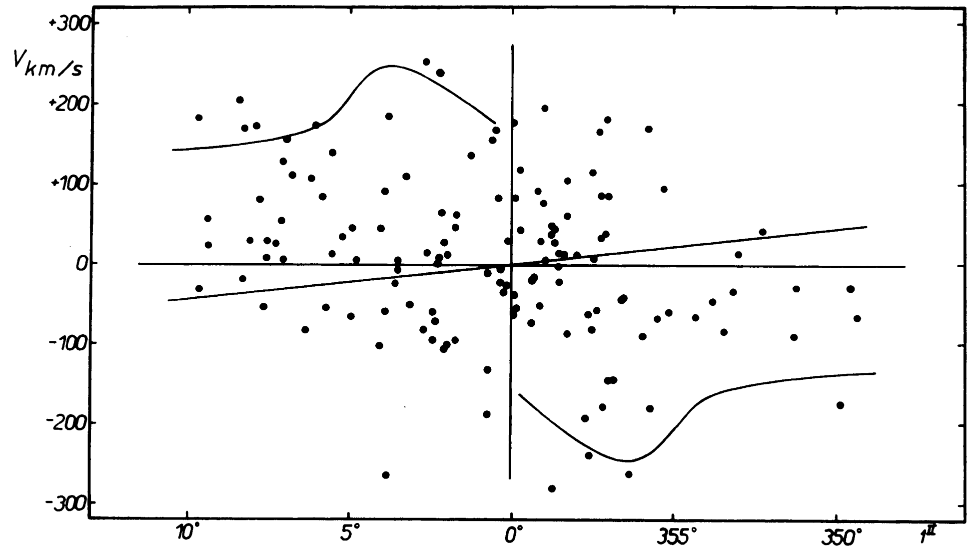

FIG. 5. *Radial velocities in the central region. The central part of Figure 3 with the scale of abscissa blown up.*

Let us discuss the planetaries exceeding the sine curve and lying thus in the 'wrong quadrants' in more detail. These planetaries are mostly small, under 10″ or even under 5″, and stellar images are frequent. The distances of stellar planetaries cannot be determined at all, and those of small objects as determined by Perek (1963) are very uncertain. They are subject to errors in measuring very small diameters affected by seeing and in measuring surface brightnesses heavily affected by interstellar extinction. The photometric distances range between 3 and 10 kpc and a small weight should be attached to them.

Since the large velocity dispersion shows only in the direction to the centre and not in other directions, we conclude that this is due to planetaries situated close to the centre. Then we have a velocity dispersion of about 30 km/sec (root-mean-square)

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everywhere with the exception of a small central region with a dispersion of 90 km/sec (root-mean-square). This is a lower limit because an admixture of foreground objects might reduce the true value. The region of the large dispersion coincides with the region of the hump on the rotation curve. Further, the value of the dispersion is close to that of population-II objects. This suggests an interesting hypothesis that the disk population in the central region moves with kinematics very similar to population II. It is tempting to extrapolate this hypothesis also to population I and to attribute the hump on the rotation curve to maximum velocities in rather eccentric orbits and not to circular velocities. The kinematic distinction between the populations, which is so prominent outside the centre, might have been prevented from being established in the centre. Should this hypothesis be supported by other evidence, we might change our ideas about the density of mass near the centre.

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