Sky and TELESCOPE

To S. A. G[illegible] — with the compliments of Otto Struve (see p. 208-211)

Star trails over Texas

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In This Issue:

Planetary Nebulae — I
American University Observatory
The Local System
Some Observations of Mars in 1956
American Astronomers Report
A Swedish Chart of the Photographic Milky Way
Northern and Southern Star Charts

One of the nearest of the planetary nebulae is NGC 7293, in Aquarius, its apparent size being 12 by 15 minutes of arc. At its distance of about 600 light-years, this corresponds to linear dimensions of 2 by 2½ light-years. The filamentary structure of the shell is revealed in this 200-inch photograph in red light by Walter Baade. Mount Wilson and Palomar Observatories photograph.

Planetary Nebulae—I

OTTO STRUVE, *Leuschner Observatory, University of California*

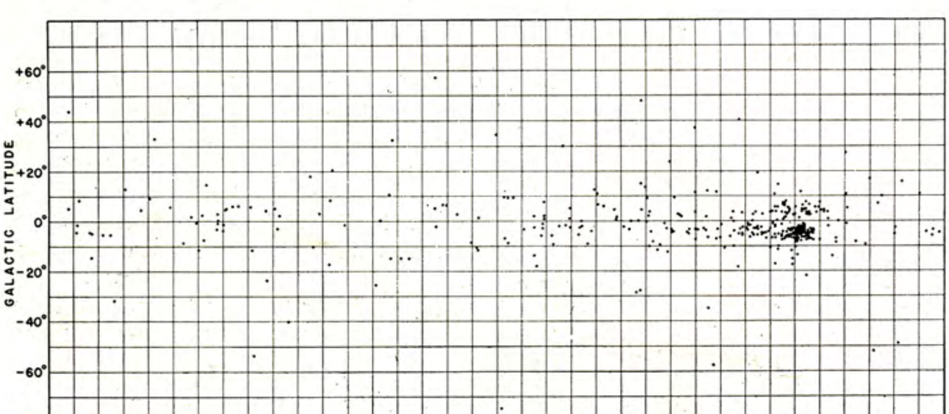
WHEN observed visually through a small telescope, a planetary nebula such as the Owl in Ursa Major appears as a small green disk, looking somewhat like the planet Uranus or Neptune. From this resemblance comes the name *planetary*. These two planets owe their pale greenish color to abundant methane gas in their atmospheres, which strongly absorbs yellow and red light, whereas the planetary nebulae are green because of intense emission lines in their spectra, due to the fluorescence of doubly ionized oxygen. These radiations, usually designated N_1 and N_2, have wave lengths of 4959 and 5007 angstroms and appear green to the eye. They are *forbidden* lines, which can be emitted only by gas of extremely low density.

On photographs made with large telescopes, the planetaries show much variety in structure. The largest, NGC 7293 in Aquarius, is a luminous ring appearing about half as large as the moon. W. Baade's photograph of this nebula, reproduced here, shows a vast amount of detail; in the dark inner portion of this object, narrow jetlike streamers suggest violent motions. Some other planetaries are so small that they appear almost starlike. Although this is partly caused by differences in their distances, the true dimensions of the planetaries range from about 20,000 to almost 200,000 astronomical units.

The number of recognized planetaries in our Milky Way galaxy is relatively small. Until about a decade ago only some 100 were known. Since then, R. Minkowski has added several hundred in the central bulge of our galaxy, mostly at great distances; and K. G. Henize has found more than 100 in the southern sky. We now know some 500 planetary nebulae, at distances up to about 10,000 parsecs from the sun, and there must be hundreds more within this distance that are obscured by interstellar dust clouds. The total number of planetaries in the entire Milky Way may be of the order of 10,000.

The distribution of the planetary nebulae over the sky shows a marked concentration in the direction of the galactic central bulge, but there are a few at distances of more than 10,000 parsecs from the galactic center. The planetaries are not strongly crowded toward the central line of the Milky Way. Their arrangement in space is a slightly flattened system, resembling that of the RR Lyrae variable stars, and differing from the very flat system of the *O* and *B* stars and of the diffuse nebulae, both bright and dark.

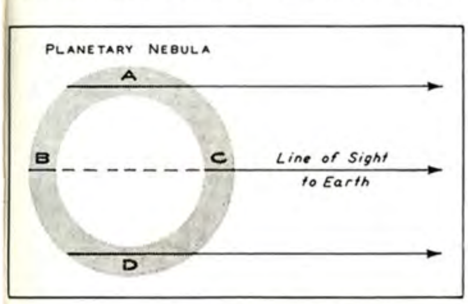
This large planetary, M97, the Owl nebula in Ursa Major, is well-known to amateurs. It is about 200 seconds of arc in diameter, and about 7,000 light-years away. Lick Observatory photograph.



The distribution of 371 planetary nebulae, by R. Minkowski. Reproduced from the "Publications" of the University of Michigan Observatory.

Planetary nebulae, therefore, seem to belong to Baade's Population II, which includes the very old stars of our galaxy (like those in globular clusters), the RR Lyrae variables, and the high-velocity stars. Indeed, one planetary nebula is known to belong to a globular cluster, NGC 7078.

Hence it appears that at least some of the oldest stars, as they evolve, may develop the characteristics of planetary nebulae. Since only one such object is known amid some 10 million stars in globular clusters, we may infer either that the planetary nebula stage is of relatively short duration or that many stars by-pass this stage altogether.



An observer's line of sight passes through much more of the nebular shell at A or D than it does through B and C combined; therefore the shell seems brighter at A and D and the planetary looks like a ring in the sky.

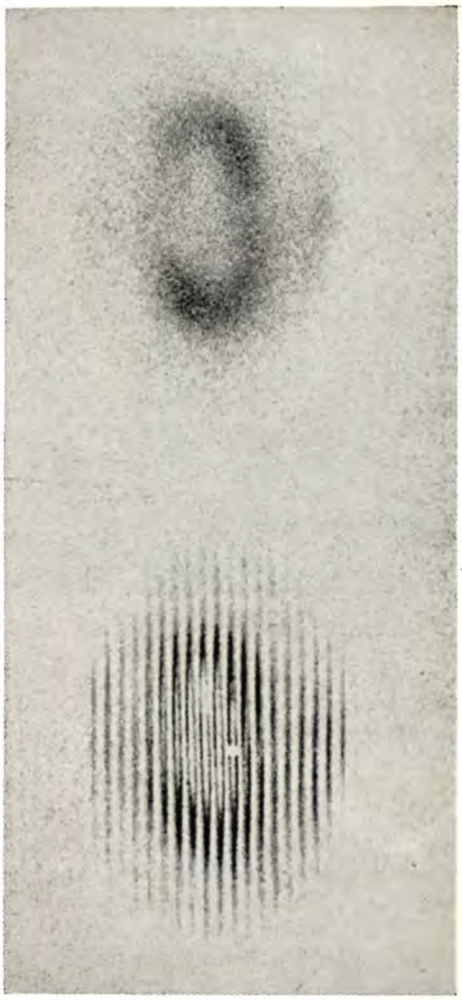
Inside a typical planetary is a very hot central star, whose surface temperature may be of the order of 50,000° to 100,000° K., and which is much smaller than the sun, but with about the same mass. The absolute photographic magnitude of such a star is about 0 or +1.

A planetary nebula itself appears much brighter than its central star. Although all of the light of the planetary is derived by fluorescence from the central star, the latter is so hot that it radiates mostly ultraviolet light, and thus appears relatively faint to the eye or photographic plate. The density of a planetary nebula is low—in fact, there are only 10^4 atoms per cubic centimeter—and its temperature as indicated by the random motions of the free electrons is about 10,000°.

All planetary nebulae are expanding, with velocities of about 10 to 50 kilometers per second. This is best seen on the spectrograms obtained by O. C. Wilson with a high-dispersion spectrograph that had many parallel slits instead of the customary single slit. Compare the photograph of NGC 7662 with its multislit appearance; both pictures show only the light of doubly ionized neon at a wave length of 3868 angstroms. Near the center of the nebula the lines are split into two components, which are caused by relative radial velocity shifts, one to the violet and the other to the red. This shows that the nearer side of the planetary is approaching us (violet shift) while the more distant side is receding. Such observations have given some indication that the intrinsically larger planetaries expand at a slower rate than smaller ones.

Two recent books,* one by the Soviet astronomer G. A. Gurzadian, the other by L. H. Aller, University of Michigan Observatory, contain a wealth of new information on planetary nebulae. The first book treats their structural features, while the second deals particularly with atomic processes that produce the complicated nebular spectra. Yet, the reader of either book will be struck by how much is still to be learned.

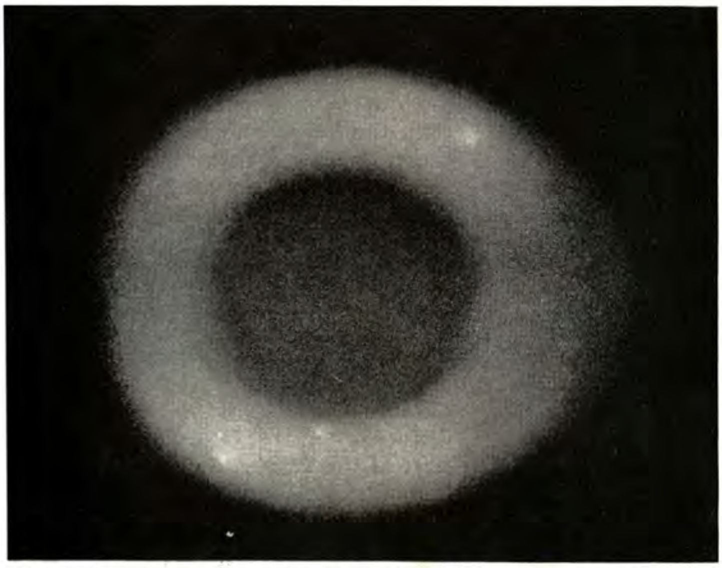
Gurzadian starts with a study of the stability of the planetary nebulae. Many of these objects show a ringlike form; the most famous is NGC 6720—the Ring

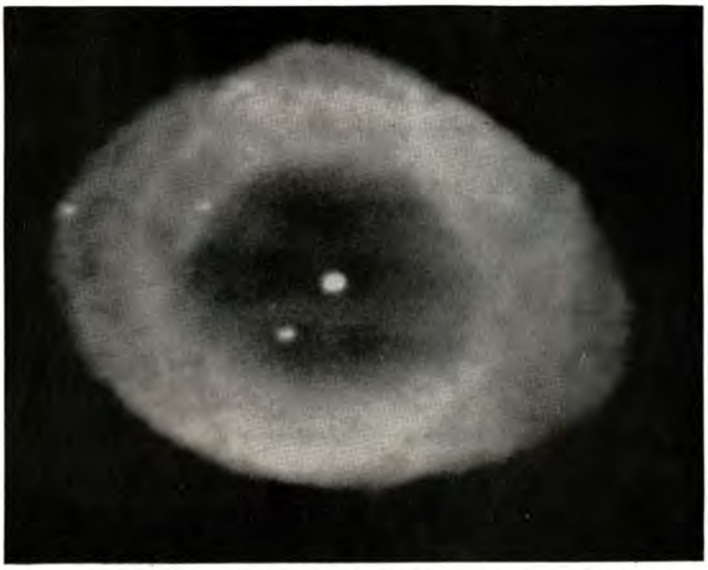


A negative print of neon images of NGC 7662, made by O. C. Wilson in October, 1952, with the 100-inch reflector of Mount Wilson Observatory.

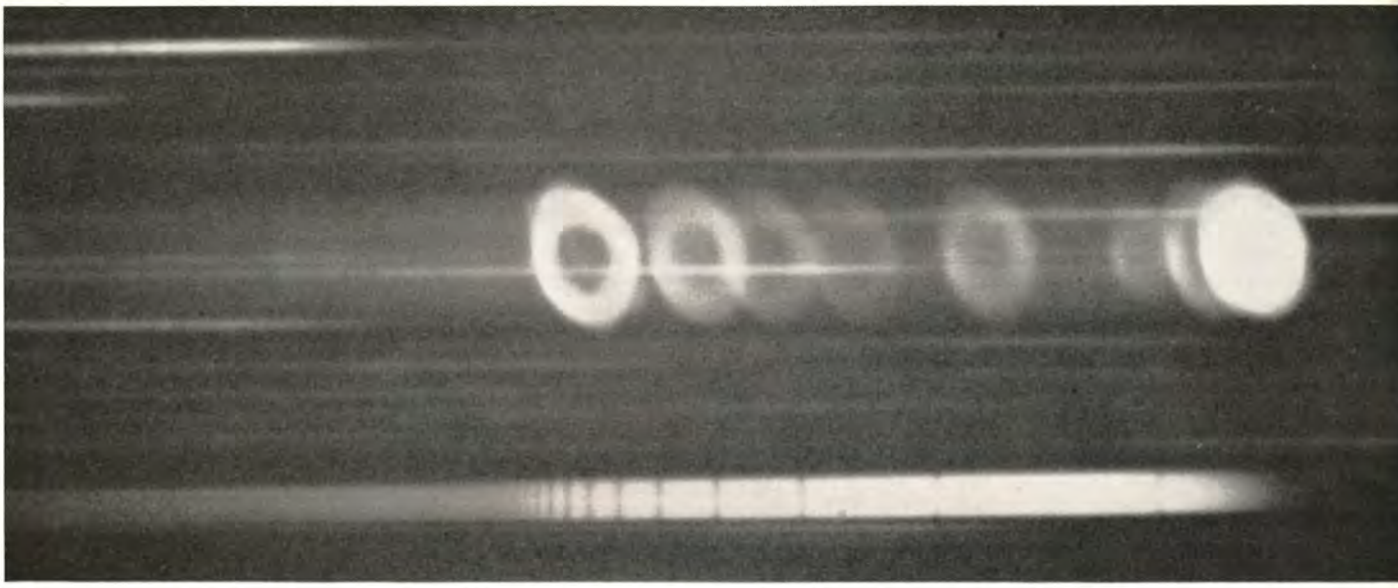
nebula in Lyra. It was shown by H. D. Curtis many years ago that this appearance can only be explained by assuming most of the nebulous matter to form a relatively thin shell surrounding the central star. As the diagram shows, such a

*G. A. Gurzadian, *Dynamical Problems of the Planetary Nebulae,* 1954, Erivan (in Russian). L. H. Aller, *Gaseous Nebulae,* 1956, John Wiley and Sons, Inc.





The drawing at the left, of the Ring nebula in Lyra, was made by the famous astronomical artist L. E. Trouvelot in 1874. He gives an accurate impression of this planetary's appearance in the Harvard Observatory 15-inch refractor. The one-hour photograph at the right was made with the 100-inch Mount Wilson Observatory reflector on August 5, 1921. The central star is about 15th magnitude photographically and very blue; thus it is conspicuous on the photograph but Trouvelot did not see it.



A slitless quartz spectrograph attached to the Crossley 36-inch reflector at Lick Observatory was used to obtain this spectrum of the Ring nebula in Lyra, showing the different sizes of this planetary in various wave lengths. From right to left (red to violet), the eight principal images are at wave lengths 5007 and 4959 angstroms blended (O III), 4861 (hydrogen beta), 4686 (He II), 4340 (hydrogen gamma), 4102 (hydrogen delta), 3969 (Ne III + hydrogen epsilon), 3868 (Ne III), and 3727 (O II). The Balmer continuum extends to the left of the 3727 image. Narrow horizontal streaks in the field are spectra of neighboring stars. The spectrum of the central star is faintly visible, and the comparison star at the bottom is Gamma Lyrae, of spectral class A0. Courtesy L. H. Aller, University of Michigan Observatory.

shell of luminous gas would appear as a disk with a bright periphery and darker center.

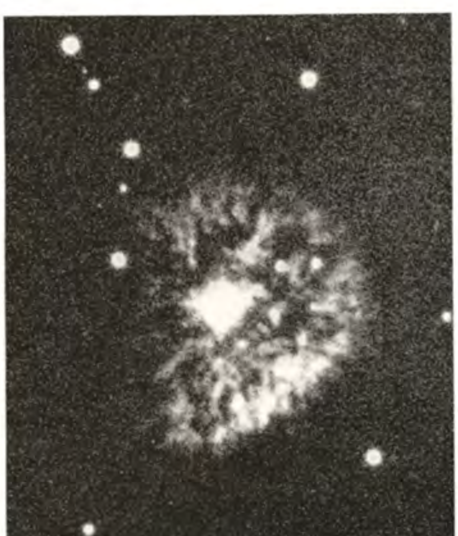
The expanding shell of gas that constitutes a typical planetary nebula was presumably once part of the central star. Gurzadian suggests that the actual outflow of gas from the star was of short duration—how short he does not say—and is no longer going on. The ejection of the shell took place within a brief interval, perhaps as long ago as a few thousand years.

(This reminds us of a nova outburst, in which a star blows off its outermost layers. But a planetary nebula contains about 1/10 as much mass as the sun, while in a normal nova the mass of the expanding gases is only about 10^{-5} or 10^{-6} the sun's.)

As the gaseous shell continues to expand, it encounters a certain amount of interstellar matter, which may be regarded as stationary with respect to the planetary. The shell sweeps up the interstellar atoms and dust particles, and they tend to slow the expansion and to condense the outer parts of the nebula. This explains why many planetaries have well-marked outer edges, which do not gradually fade away as might be expected if the nebula were expanding into a vacuum.

In its earliest stages the shell was fairly dense, and it was expanding at a larger velocity than at present. Gurzadian believes the initial speed of outflow was 100 kilometers per second or somewhat less (very much smaller than the velocity of expansion of a typical nova or supernova). At first the expanding shell suffered practically no braking action from the surrounding interstellar medium. Thus for a time the nebula grew at a constant rate, but meanwhile the density decreased, and finally the resistance from the interstellar material became significant.

Now let us suppose that the shell was not exactly spherical at the start, but had bulges and hollows in its surface. Then this irregular shape would remain unaltered as long as the braking action of the interstellar medium was negligible. But how would the shape be affected when the resistance became appreciable? To solve this problem requires a complicated hydrodynamical study, but Gurzadian's physical ideas are relatively simple to understand.



Long after Nova Persei brightened to magnitude zero in the year 1901 and faded again, the gaseous shell ejected during that great stellar explosion could be directly observed. This picture was taken some 48 years later, in 1949, with the 200-inch telescope, and shows that the shell's disintegration is far advanced. Such rapidly expanding nova shells contain far less mass than planetary nebulae. Mount Wilson and Palomar Observatories photograph.

He attempts to answer the question: Will the braking action of the surrounding medium tend to shrink the bulges along the outer surface of the shell, or will it tend to exaggerate them? In the first event the shell would remain stable, retaining its ringlike appearance. In the second case, the shell would become unstable and would ultimately break up into a series of detached blobs of gas resembling in structure the large diffuse nebulae of the Milky Way.

Up to the time when the resistance of the interstellar medium becomes significant, the bulges and hollows expand together with equal speed—that of the initial outburst from the central star. Because they extend farthest from the star, first the bulges enter the region where the resistance acts, and some time later the hollows enter the same region. But because of the expansion, the over-all density of the shell is decreasing steadily, and when a hollow reaches the critical distance from the star, it has a smaller density than that a bulge had at the start of the deceleration. Therefore, the hollow experiences a greater retardation from the interstellar material, and the bulge moves forward faster than the hollow. The irregularities in the shell's surface become more pronounced; the nebula becomes unstable and must break up into detached clouds.

Gurzadian has computed the radius of

The planetary nebula NGC 2392 in Gemini, photographed in ultraviolet (left), violet, green, and red light, with the 200-inch telescope. The third image from the left records the radiation of doubly ionized oxygen at wave lengths of 4959 and 5007 angstroms. The faint outer portions of this double-ring planetary show an irregular structure suggestive of the breakup considered by Gurzadian as the ultimate fate of planetary nebulae. Mount Wilson and Palomar Observatories photograph.

the shell when instability sets in; in centimeters it is approximately equal to the cube root of the ratio of the total mass of the nebula (0.1 sun or 2×10^{32} grams) to the density of the interstellar medium (5×10^{-24} grams per cubic centimeter). The result is $(2 \times 10^{32}/5 \times 10^{-24})^{1/3}$ or 3×10^{18} centimeters—about 200,000 astronomical units. This value, Gurzadian remarks, is close to the limit of size actually observed among the well-defined planetaries. According to B. A. Vorontsov-Velyaminov, there are only nine planetary nebulae out of 132 whose radii exceed 100,000 astronomical units.

If we make the same computation for a typical nova in which the expelled mass is only 10^{-5} solar mass or 2×10^{28} grams, the nova shell is found to become unstable when its radius has become about 10,000 astronomical units. With the rapid expansion typical of novae, this size will be reached in about 30 years. Thus, the shell of Nova Aquilae (1918) may be expected to reach the stage of instability at the present time, while the shell of Nova Persei (1901) is already unstable—as indeed the observations seem to show. Gurzadian concludes that the planetaries cannot be regarded as the end products of ordinary nova explosions. On similar grounds he also rules out the Wolf-Rayet stars and the supernovae as possible ancestors of the planetary nebulae.

How long can a planetary last before it breaks up into separate blobs of material? This begins to happen, as we calculated above, when its radius is about 3×10^{18} centimeters. The average velocity of expansion may have been about 50 kilometers per second, which is 5×10^{6} centimeters per second. Dividing the radius by this velocity gives 6×10^{11} seconds, or about 20,000 years for the lifetime of a planetary nebula until it begins to disintegrate.

Thus the planetaries are old compared with the few observable nebulous shells of novae, but when compared with the evolutionary cycles of even the hottest stars they are exceedingly short-lived. This, in turn, explains why there are so few observable planetaries at the present time.

Gurzadian estimates that the ancestors of the planetary nebulae must be extremely rare in space—about 10^{-10} objects per cubic parsec. By contrast, in the vicinity of the sun there is one star per cubic parsec. Recently, G. H. Herbig has made the interesting tentative suggestion that the rare variable stars of the R Coronae Borealis type may in fact be the earliest stages of the planetary nebulae.

(To be continued)

Sky and TELESCOPE

In This Issue:

Dean of American Astronomers

Planetary Nebulae — II

Mars Symposium

American Astronomers Report

The Transit of Mercury in May

Here and There with Amateurs

Stars for April

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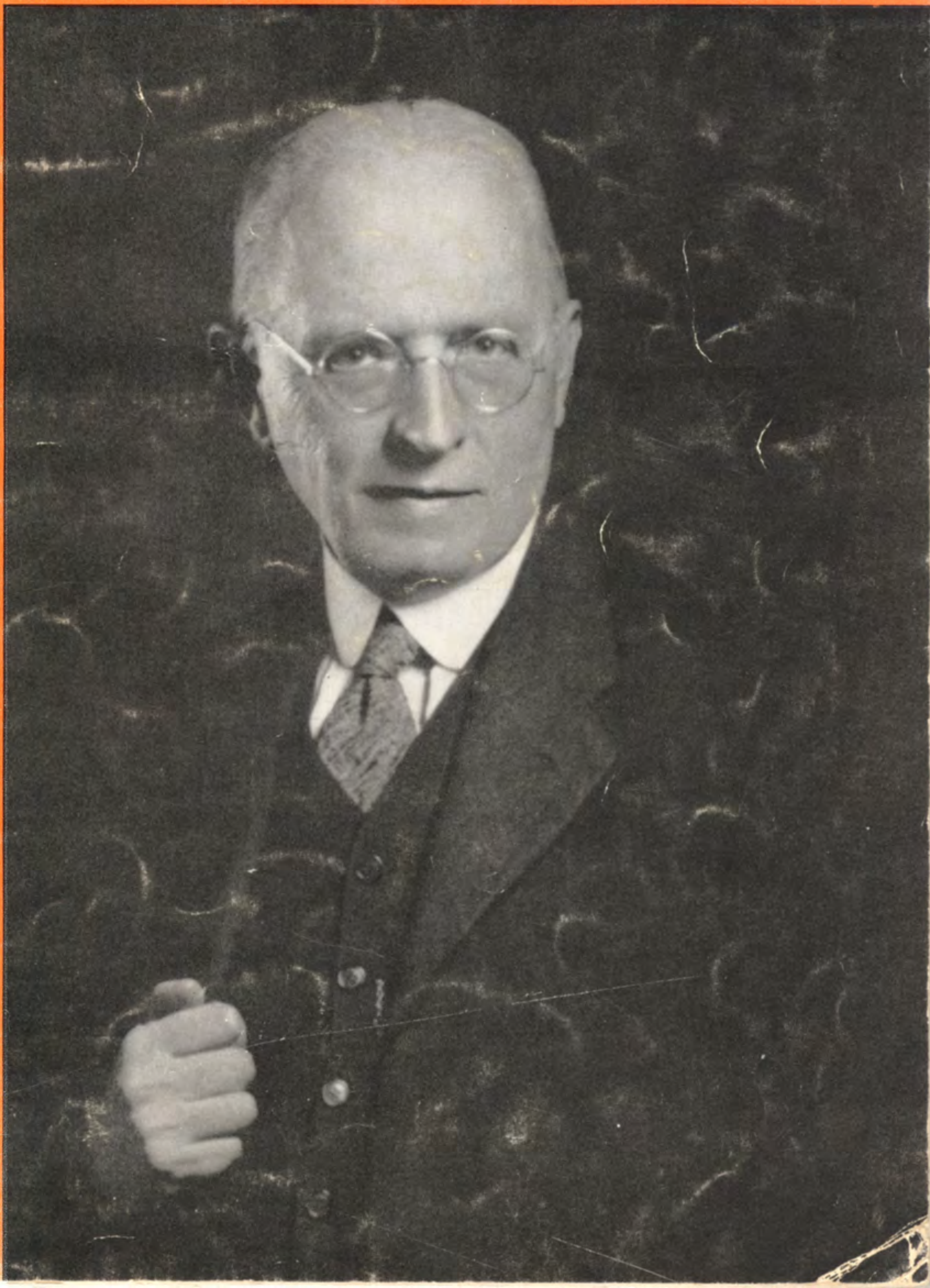


Henry Norris Russell
(1877-1957)

The planetary nebula NGC 4361, as photographed by R. Minkowski with the 200-inch Hale telescope, in the red light of the hydrogen-alpha line. Mount Wilson and Palomar Observatories photograph.

Planetary Nebulae—II

Otto Struve, *Leuschner Observatory, University of California*

LAST MONTH we discussed some recent studies of the planetary nebulae that show these great shells of gas to be unstable, expanding so rapidly their lifetimes are only a few tens of thousands of years. We shall continue with some of the ideas on the origin and evolution of the planetaries presented by the Russian astronomer G. A. Gurzadian in his 1954 book, *Dynamical Problems of the Planetary Nebulae.*

It must be pointed out that some of the material on which Gurzadian based his work is seriously out of date. His information on the structural details of the planetaries came from H. D. Curtis' collection of nebular photographs taken with the 36-inch Crossley reflector and published in 1918 in Volume XIII of the *Publications* of the Lick Observatory. Fine as the drawings and photographs in this work are, many have been surpassed by recent photography at Mount Wilson and Palomar Observatories by J. C. Duncan, R. Minkowski, and others.

For the distances and dimensions of planetary nebulae, Gurzadian used the catalogue in B. A. Vorontsov-Velyaminov's book, *Gaseous Nebulae and New Stars.* These values have been criticized by L. H. Aller, because they are based on the incorrect assumption that planetaries share the rotation of the galaxy shown by *B*-type stars. We now know that the planetaries belong to Population II (old stars), while the *B* stars represent Population I (young stars). Hence, the distances and sizes cited by Vorontsov-Velyaminov should be regarded as very rough approximations.

On the other hand, Gurzadian has used the best available data for planetary expansion velocities, mostly those of O. C. Wilson described last month. Present rates of expansion are between 10 and 50 kilometers per second, very much smaller than the 1,000 kilometers per second typical of the expanding shells of old novae. But could the *initial* expansion of a planetary shell have been this rapid?

There can be little doubt that the outward motion of the gaseous shell is being slowed down. Three processes tend to decelerate it. The first of these is the gravitational attraction of the central star. The velocity of escape from the surface of the star is of the order of 1,000 kilometers a second. If the initial expansion were much under this value, the planetary could never have reached its observed size. If it started with this speed or a little more, by the time it became as large as we see it now the attraction of the star would have slowed the expansion to about 10 kilometers a second—about what we observe. But if the growth started at 1,500 kilometers per second, the outward velocity would still be about 1,100.

This would make it appear as if the initial velocity of all planetaries were almost identical with the velocity of escape from the central star. But there is no apparent reason for such near identity, and the behavior of exploding stars is by no means so consistent. Hence, it is believed that gravitational deceleration cannot alone explain the fact that *all* planetaries are expanding with low velocities.

A second cause of deceleration may be resistance by the interstellar medium. Gurzadian has shown that, as a first approximation, the ratio of the initial velocity to that at a distance r from the star is equal to $1 + 4r^3d/m$, where d is the density of the interstellar medium (say 5×10^{-24} gram per cubic centimeter), and m is the mass of the planetary (some 2×10^{32} grams or 1/10 the mass of the sun). Then, at a distance r of 10,000 astronomical units (1.5×10^{17} centimeters), the ratio of the two velocities would be 1.0003, or almost unity. It would require about 10 times as great a distance

Left: Compare this photograph of NGC 7009, in Aquarius, made with the 60-inch Mount Wilson reflector, with the Curtis drawing near the top of the facing page.

Right: This is the Curtis drawing of NGC 4361, from Lick photographs; it is the same object as pictured above by the 200-inch.

Fig. 68

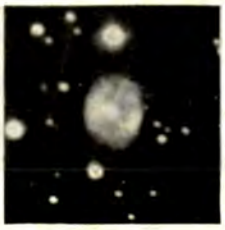


Fig. 68*a*

N.G.C. 6905; $20^h\ 17^m.9$; $+19^\circ\ 47'$

Exposures 5^m to 3^h. H.C.O. magn. 10.8 (total effect?). The central star is 14th magn. visually (Burnham) and 13th or brighter photographically. The main portion is a very patchy truncated ellipse $44'' \times 37''$ in p. a. 163°. Very faint cone-shaped ansae extend from each end. A star of magn. 12 lies nearly at the end of the southern ansa (not shown in drawing), but is probably not physically connected with the planetary. Moderately faint; the nebular matter just shows in 5^m on S23. Rel. Exp. 20.

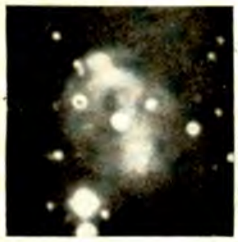


Fig. 69

N.G.C. 7008; $20^h\ 57^m.6$; $+54^\circ\ 9'$

Enlarged 11 times from a negative of $2^h\ 30^m$ exposure time. Central star magn. 12. Irregular ring structure indicated; the dimensions are $86'' \times 69''$ in p. a. 20°. The two brightest patches are at the north, and three stars which lie in roughly circular gaps in the nebulosity must either be physically connected with the nebula or, if nearer to us, be surrounded by absorbing atmospheres. Moderately faint. Rel. Exp. 20.

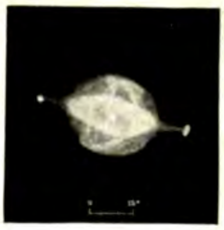


Fig. 70

N.G.C. 7009; $20^h\ 58^m.7$; $-11^\circ\ 46$

Exposures 10^s to 2^h. Central star of magn. 11 (Burnham, 12 visual). Of wonderfully intricate structure; the slightly oval central disk is about $30'' \times 26''$, while the almost stellar condensations at the ends of the ansae are $44''$ apart in p. a. 79°. The inner ring shows considerable detail in the shortest exposures; in moderate exposures it is $25'' \times 12''$, and slightly fainter along its major axis. Exceedingly bright; the nucleus and inner ring show in 10^s on S27. Rel. Exp. 0.2.

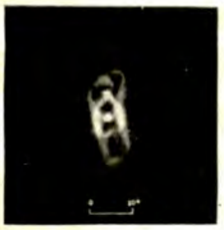


Fig. 71

N.G.C. 7026; $21^h\ 2^m.9$; $+47^\circ\ 27'$

Exposures 30^s to $2^h\ 10^m$. H.C.O. 11.4 magn. Central star of magn. 14. Very irregular; there are two bright lobes $5''$ long in the shorter exposures symmetrically placed with regard to the central star, and about $6''$ apart from center to center. A bridge of nebulosity connects these and involves the central star, so that it resembles the letter H. Irregular wisps extend from each end of this formation, making the total length about $25''$ in p. a. about 10°. Fairly bright; the lobes show in 1^m on S27. Rel. Exp. 0.8.

The great variety in appearance and structure of planetary nebulae is illustrated by this reproduction of five of the H. D. Curtis drawings and photographs. His lucid descriptive captions are also included. From Volume XIII, "Publications" of the Lick Observatory, 1918.

central star, and a larger ring surrounding the two spiral features. From the shape of this nebula, Gurzadian decided that the outflow of gas must be more or less localized, coming mainly from two ends of a diameter of the inner spherical shell. The flow may actually be from two spots on the central star itself.

The radius of the inner disk of NGC 4361 is about 28,000 astronomical units or 4.2×10^{17} centimeters. From photographs we can estimate that the width of a spiral arm, where it meets the inner disk, is roughly 10^{17} centimeters, but this estimate may be incorrect by a factor of several times. Through this arm or "spout" we are assuming that gas is ejected at a velocity of about 100 kilometers per second and with a density of about 10^{-21} gram per cubic centimeter—about the average density of a planetary nebula.

We can very roughly calculate the amount of material ejected in each second; it is the product of the cross section of the spout (8×10^{33} square centimeters) times the density times the velocity (10^7 centimeters per second). This amounts to 8×10^{19} grams per second, or about a millionth of the sun's mass in a year. To make up 1/10 solar mass, the typical planetary's total mass, the ejection from the two spouts would have to last some 50,000 years.

Thus the formation of a planetary nebula requires a much longer period than that of a nova shell, for which only a few days are needed. In the case of NGC 4361, our estimates of spiral arm sizes may be too small, and the density of the ejected matter may be larger than we have assumed. For the average planetary, the ejection may well last some 10,000 years, and even for those that evolve most rapidly it is hard to reduce the period of ejection below 1,000 years.

Note that 10,000 years is not the same as the time required to lift any given portion of the nebular mass beyond the dynamical barrier imposed by the 1,000-kilometer-a-second escape velocity from the surface of the central star. That portion of the star's material that becomes the planetary nebula needs to be lifted only to a height of a few hundred stellar radii (less than one astronomical unit) to reach a region where the escape velocity is below 100 kilometers per second.

The spiral structure of NGC 4361 is unusual but by no means unique among

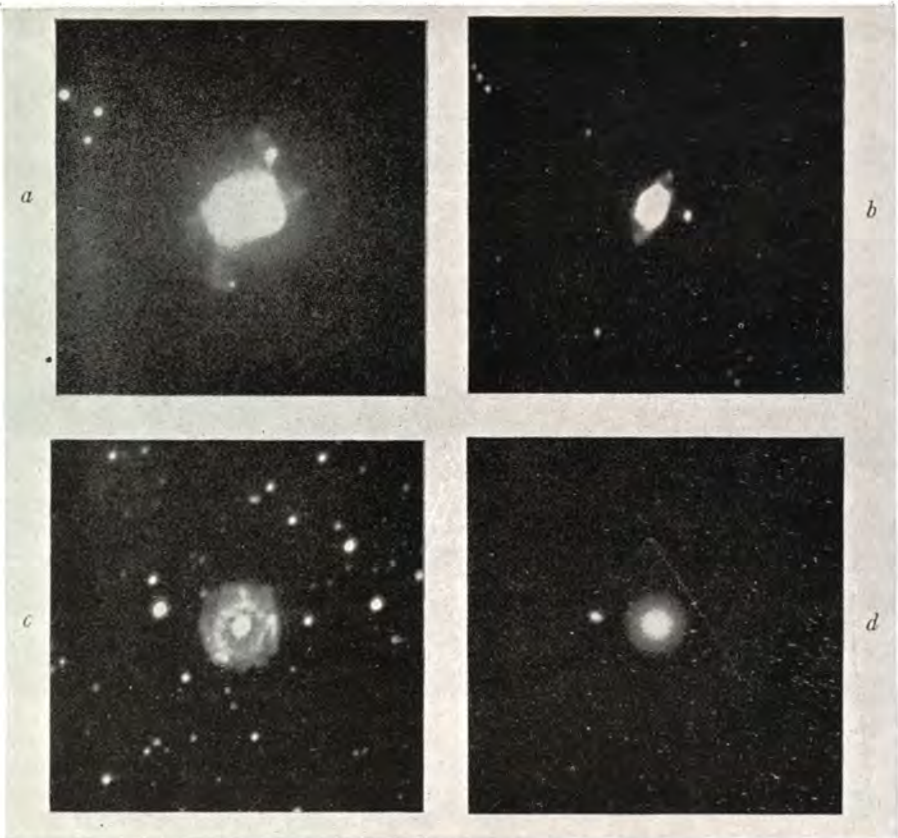
from the central star to reduce the velocity of expansion to half its initial value. Thus it seems that the braking action of the interstellar medium is insignificant until the nebula has grown to very large dimensions.

The third factor is radiation pressure, resulting from the emission of Lyman-alpha radiation by hydrogen within the nebula, which causes the inner part of the shell to be decelerated. But this effect is also relatively small, as earlier studies by H. Zanstra and V. V. Sobolev have shown.

Taken together, these three braking actions can account for a moderate deceleration, perhaps by a factor of 2 or at most 10, but certainly not by a factor of 100. We must conclude that the initial velocity of expansion was of the order of 50 or 100 kilometers a second, and not 1,000. This small starting speed is, however, well below the velocity of escape from the star. Hence the gases that form the nebula must have been propelled by a force acting during an appreciable time interval (as in a rocket) and not by an instantaneous impulse (as for the case of a projectile).

Gurzadian explains this process in terms of the specific case of NGC 4361. As can be seen in the accompanying pictures, this is a peculiar spiral-shaped planetary, with a small, uniform inner patch around the

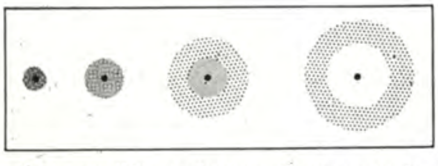
At the left is the Curtis drawing of NGC 6543, and at the right the same planetary recorded by R. Minkowski with the 200-inch telescope, on a night when the seeing was good. From Lick Observatory and Mount Wilson and Palomar Observatories photographs.



The first three of these pictures were taken by John C. Duncan with the 100-inch telescope, the fourth (d) with the 60-inch. The telescopes were used at full aperture and with aluminized optics. All are to a scale of two seconds of arc per millimeter: (a) NGC 6210 in Hercules, June 25, 1936, 35-minute exposure; (b) IC 4634 in Ophiuchus, July 12, 1937, one-hour exposure; (c) NGC 6751, Aquila, July 12, 1937, 20-minute exposure; and (d) IC 3568, Camelopardalis, August 2, 1937, 10-minute exposure. The last is an excellent example of a double-ring planetary. Reproduced from the "Astrophysical Journal."

planetaries. To explain this appearance, Gurzadian suggests that the spiral arms lie approximately in the equatorial plane of a slowly rotating central star, whose axis of rotation is nearly in the line of sight.

The stream velocity of the jet flowing from the spout decreases because the stream widens outwards; this effect is in addition to the braking actions discussed above. As the outward velocity slackens, the sidewise motion of rotation causes the stream to curl around in the form of a spiral whose outer portions gradually approach a circular ring. From the shape and size of the spiral structure in NGC 4361, Gurzadian has computed that the rotation period of the star is about 400 years. Although his hydrodynamical calculations may be somewhat uncertain, the star must rotate exceedingly slowly if his



The possible evolution of an expanding planetary nebula, according to G. A. Gurzadian, who suggests the third stage is observable as a double ring.

proposed model of this planetary is correct.

Other planetaries showing spiral arms, according to Gurzadian, are IC 320, IC 4634, NGC 6210, NGC 6587, NGC 6881, and NGC 6886, but for these the structure is less obvious. Other cases, which he calls "zeta-type" planetaries, are NGC 2452 and NGC 6778, while he describes NGC 6543 as "snail-type." Gurzadian believes that in each of these objects the fundamental mechanism is the same as in NGC 4361. In the zeta-type planetaries, the drastic bending of the streams is attributed to a rapid outward decrease in density, due to interaction with interstellar material. In all these cases he believes the periods of axial rotation are to be counted in hundreds of years. This is a most unexpected result; the rotation periods of normal stars range between a few hours (Phi Persei) and a month (the sun).

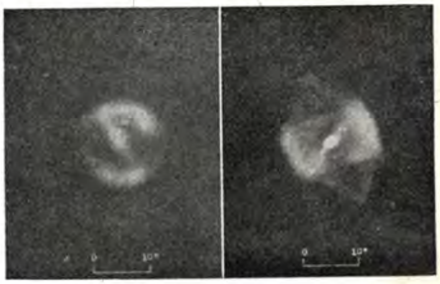
From entirely different considerations, C. F. von Weizsäcker, the present writer, and several other astronomers have suggested that young stars (Population I) have fast rotations and old stars have slow rotations, as a rule. Several processes have been suggested (the best by H. Alfvén) by which the rotation of an aging star would become slower. But whether any of these processes can virtually arrest the rotation of a star remains to be seen. In any case, a simple observational check on Gurzadian's result could be easily made by comparing the orientation of the streams as photographed at Lick Observatory some 40 years ago and as they appear at the present time.

Some of the more conventional ringlike planetaries have a faint outer ring of about twice the diameter of the brighter inner ring. Among the best photographs of the double-ring planetaries are those made by Duncan at Mount Wilson, of which some examples are reproduced here. It is scarcely logical to attribute the rings to two outbursts of the central star separated by some thousands of years: Why should there be almost invariably just two rings, and not three or more? Why should the mass of the outer rings always be a small fraction (about 1/10) the mass of the inner? And why does the more rapidly expanding inner ring not sweep up the less dense and slower-moving outer shell? Gurzadian suggests that the latter ring owes its existence to the outward radiation pressure from the original shell. This occurs when the latter becomes sufficiently transparent, on attaining a diameter of about 25,000 astronomical units. Thus, the evolution of a typical ring-type system would proceed as schematically shown in the diagram. The outer ring becomes invisible first, so at the end of the sequence only a single ring is observable, with very little gas inside it.

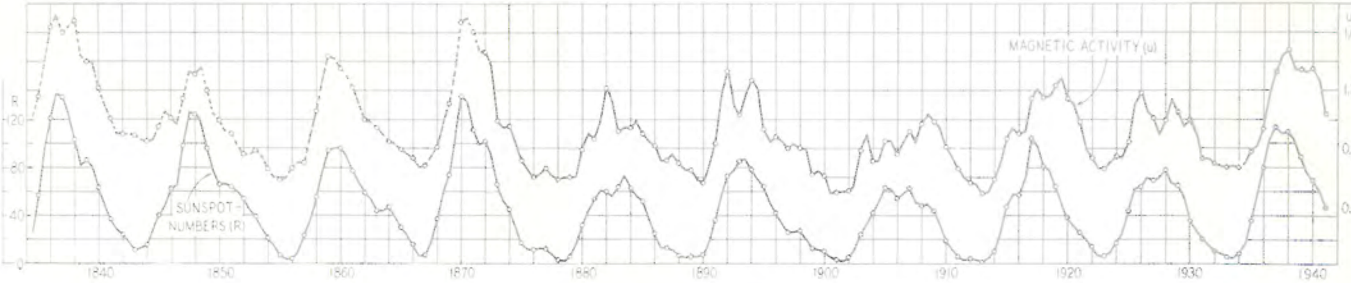
While these ideas of Gurzadian are novel and stimulating, they are also highly controversial. At Palomar Observatory, Minkowski has obtained a superb series of direct photographs of planetaries, a few of which accompany this article. He has recently told me that he is not certain the spiral forms are real, although he does not deny the possibility of their existence. He points out that it is often difficult to distinguish between a spiral and parts of two circular rings whose centers are slightly displaced.

Compare the two pictures of NGC 4361 on page 262; one is by Minkowski with

(Continued on page 275)



These Lick drawings by Curtis illustrate Gurzadian's zeta-type planetaries, NGC 2452 at the left, and NGC 6778 at the right. Curtis noted the hourglass shape of the latter, and the faint ansae above and below the main part of the planetary.



A well-marked correlation between the magnetic activity of the earth and the occurrence of spots on the sun is evident in this diagram. The upper curve is of annual means of daily geomagnetic character numbers, which are plotted on the scale at the right: 0 for a magnetically quiet day, 1 for a moderately disturbed day, and 2 for a greatly disturbed one. Below these are plotted relative sunspot numbers (scale at left) for the same years, 1835-1941.

ber; it even mirrors the short-period fluctuations revealed by the sunspot counts.

In concluding his talk, Dr. Nicholson pointed out that, as we understand better the effects of sunspots and their radiations on the ionosphere and on the lower layers of the atmosphere, correlations between solar and terrestrial phenomena will become more definite.

Mars Drawings at Ottawa

To avoid preconceived ideas while observing Mars at its recent opposition, Peter M. Millman, National Research Council of Canada, did not study any detailed maps of the planet during 1956. Thus, his work at the 15-inch refractor of the Dominion Observatory, Ottawa, from August 17th to October 20th, was completely independent.

No Mars charts were taken to the telescope, and the central longitudes for the times of the individual drawings were not looked up in the ephemeris until some time after the observations had been made. The detail on Mars' disk was drawn by eye estimate alone, no micrometer being employed. Dr. Millman used a highly corrected 155x eyepiece. Higher powers, and orange and yellow filters, were tried repeatedly but did not improve the detail seen on the planet.

For a map of Mars as it appeared to Dr. Millman in 1956, Martian coordinates of the features observed were transferred from 68 drawings to a Mercator projection by a graphical method involving a globe and a projection disk. The final map shows the weighted mean positions of the features; it is being published in the March-April issue of the *Journal* of the Royal Astronomical Society of Canada.

Vegetation on Mars?

William M. Sinton, Harvard Observatory, pointed out that all terrestrial organic molecules show in their spectra a strong infrared absorption band at wave length 3.4 microns. This spectroscopic feature arises from the bond between carbon and hydrogen atoms. Accordingly, light from vegetation should have an absorption band close to this wave length, since the light penetrates beneath the surface before being reflected.

Dr. Sinton first verified the phenomenon for terrestrial plants, observing them with an infrared spectrometer. In fresh leaves, absorption bands of water tended to mask the expected feature, but relatively dry foliage showed a double absorption band centered on 3.45 microns and about 0.2 micron wide. In mosses and lichens the absorption of radiation was 20 to 30 per cent at this wave length, but the double band was only slightly separated.

After these control experiments, Dr. Sinton observed the infrared spectrum of Mars with the Harvard 61-inch reflector. As a detector he used a lead-sulfide cell, cooled in liquid nitrogen, which had good sensitivity to wave lengths as long as 3.6 microns. Since Mars is faint in this spectral region, it was necessary to combine many measurements made at each 0.1-micron interval of wave length in the vicinity of the carbon-hydrogen band.

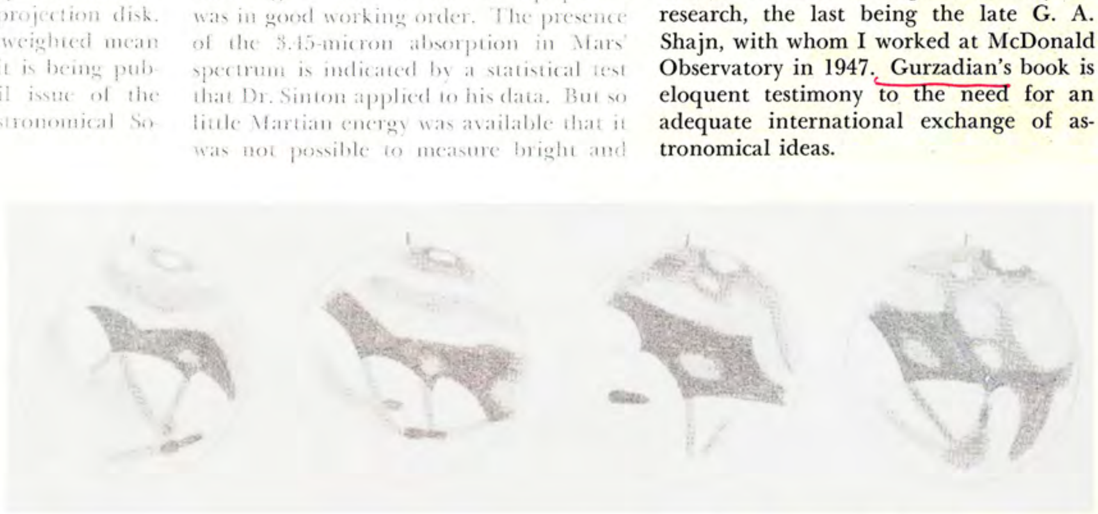
Such observations were carried out on four nights when all of the equipment was in good working order. The presence of the 3.45-micron absorption in Mars' spectrum is indicated by a statistical test that Dr. Sinton applied to his data. But so little Martian energy was available that it was not possible to measure bright and dark areas separately and intercompare them. This would have provided a more critical test than the observations of the planet as a whole. Nevertheless, he stated, "It seems highly probable that vegetation is present on Mars."

PLANETARY NEBULAE—II

(Continued from page 264)

the 200-inch, the other by Curtis was used by Gurzadian. It is evident that the 200-inch telescope shows far more complicated structure within planetaries than could have been inferred from the 36-inch Crossley observations alone. Minkowski and other astronomers are of the opinion that magnetic fields must play an important part in the development of a planetary. He believes there are indications that most of these nebulae have structural symmetry—for example, some have one or more narrow oval extensions, occasionally two or three at different orientations. But Gurzadian's discussion is still of great interest as a bold attempt to unravel the mystery of the planetary nebulae without invoking magnetic effects.

His work also reminds us that there is almost no contact between American and Russian astronomers. To my knowledge, hardly any American astronomer has visited Russia for research or teaching during this century. Also, there are only two or three isolated cases since 1914 of Russian astronomers visiting our country for research, the last being the late G. A. Shajn, with whom I worked at McDonald Observatory in 1947. Gurzadian's book is eloquent testimony to the need for an adequate international exchange of astronomical ideas.



Drawings of Mars by Peter M. Millman. The two at the left were made on August 25, 1956, at 6:10 and 7:20 UT; the others on August 18th at 5:00 and 6:50. The central meridian of Mars, left to right, was at longitude 177°, 194°, 223°, and 250° at these times.