STRUCTURE

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My first task is to give summaries of the sessions on observations of the spectra of planetary nebulae and on the spectra of the central stars.

About the spectra of planetary nebulae there is little more to say than that the observations of line intensities in the range from the near ultraviolet to the near infrared have made impressive progress. Most important is the extension of the observations into the infrared which has led to the discovery by Gillet, Low and Stein of unexpectedly high intensities in the continuous spectrum of NGC 7027 between 4μ and 14μ (75 to 22 THz). In this respect NGC 7027 and the Seyfert galaxy NGC 1068 resemble each other. Similarity of the compositions of the emission-line spectra of these two objects has been noted long ago; some lines of low ionization – [O II], [S II] –, however, are stronger in the Seyfert galaxies. The physical significance of the similarity of the infrared continua is not clear at this time, but I see no reason to reject the classification of NGC 7027 as a planetary nebula. It has a very irregular brightness distribution with much structure, but an outline which is roughly elliptical and the usual expansion pattern with a velocity of expansion of 21 km/sec.

Theoretical predictions of the line-emission spectra in the far ultraviolet and infrared have been made. These regions require observations from above the atmosphere. A predicted [S IV] line at $\lambda = 10{\cdot}53\mu$ may have been observed by Gillet, Low and Stein.

The far ultraviolet spectrum of the central stars is of fundamental importance for the understanding of the physical processes in planetary nebulae. We may hope that space observations will permit us in the not too distant future to check and to replace the computations of model atmospheres on which we must rely now to avoid the unrealistic assumption that the central stars have black-body spectra. The most important part of the spectrum, below the Lyman limit, may remain hidden forever by the interstellar absorption of hydrogen.

Few of the central stars are bright enough to be investigated spectroscopically in great detail. For the fainter stars, the superposition of the nebular emission lines of hydrogen and helium on the corresponding stellar absorption features adds to the difficulties of observations. New information becomes available only at a slow rate. Contradictions between stellar temperatures derived from Zanstra methods and from spectral information are not infrequent. Until such difficulties are understood, the HR diagram is not well established and not a safe basis for discussions of the evolution of the central stars.

Osterbrock and O'Dell (eds.), Planetary Nebulae, 456–462. © *I.A.U.*

Photometry of the central stars was a badly neglected field that now seems to find more attention. Variability of central stars has been established in some cases, and Kohoutek has succeeded in showing that, as has often been suggested, the A0 type central star in NGC 1514 is a binary whose unobserved companion is the real nucleus of the nebula.

Turning to the general aspects of our problems, I want to emphasize a point that concerns both observers and theoreticians and that has been disregarded almost completely, except for a remark by Abell and the report on chemical abundances by Aller, whose plea for increased attention to the complicated structure of planetary nebulae I want to join and to amplify. I believe that one of our most urgent problems is that of trying to assess the consequences of picturing a planetary nebula as an envelope or shell with constant density, constant ionization, and constant electron temperature. I would be foolish to ask for attempts to analyze even one planetary nebula in full detail. But we should try to estimate at least the order of magnitude of the errors that are now being committed by total disregard of the properties of real planetaries.

The problem concerns the observer. The photoelectric observations which are our most reliable source of information on the flux densities in the emission lines, and many photographic determinations, give us values integrated over the whole nebula. But, if we are to be able to assess the effect of filaments and condensations on the analysis of the results, we must know the conditions in these features. We need reliable spectrophotometry of small details and local areas. Even such observations give no more than an integral over the line of sight through the nebula. Differential observations of condensations and their surroundings are necessary to ascertain the conditions in condensations. Here is perhaps the moment to point out that differences between photoelectric and photographic results do not necessarily demonstrate the superiority of the photoelectric method, but often are likely to show differences between observations that integrate over the whole nebula and localized observations with a slit spectrograph. Good photographic photometry is difficult, but not necessarily much inferior, and possibly the method of choice for detailed studies.

The theoretician must remember that observed intensities are not proportional to volume emissivities, but to integrals over all or part of the nebula. Even crude models of inhomogeneities may be useful for estimating the errors that may arise from the use of unrealistic and oversimplified descriptions of a planetary nebula. It is easy to see that such errors can be very large. The errors concern all quantities that interest us. How much can we really trust, for instance, the evolutionary track derived for the central stars?

I will not try to show here how dangerous these errors easily can be. But I hope it will be instructive to show you a few photographs of planetary nebulae which demonstrate the problems.

NGC 1501, photographed in the red (Hα and [N II]) lines (see frontispiece), has a well-defined nearly elliptical outline. The appearance in the green [O III] is very

FIG. 1. *NGC 3587 photographed with the 200-inch telescope in* [O III]. *Scale 6·5″/mm.*

FIG. 2. *NGC 3587 photographed with the 200-inch telescope in Hα and* [N II]. *Scale 6·5″/mm.*

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FIG. 3. *NGC 6853 photographed with the 200-inch telescope in* [O III]. *Scale 8·6″/mm.*

FIG. 4. *NGC 6853 photographed with the 200-inch telescope in* $H\alpha$ *and* [N II]. *Scale 8·6″/mm.*

similar. The size obviously can be stated without difficulty. But the nebula is a mass of small irregular condensations, with some big holes. What is the filling factor? Which fraction of the stellar radiation escapes through the holes, and how much too low is the temperature of the star derived on the assumption that the star is completely surrounded by the nebula and that there is no loss of radiation?

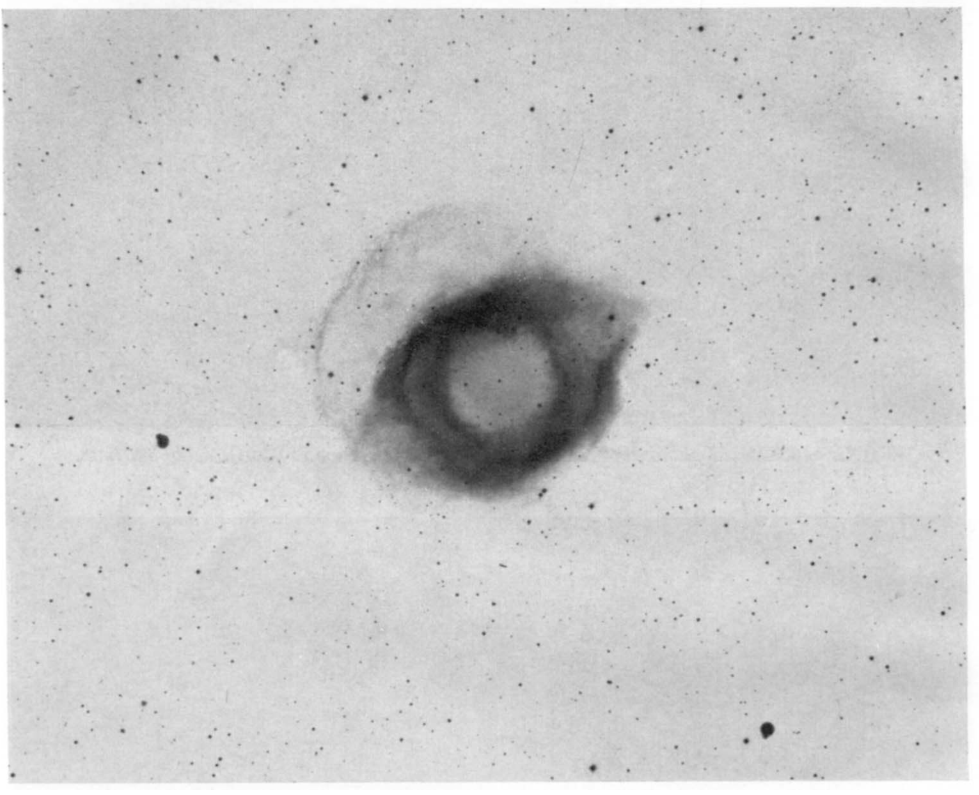

FIG. 5. *NGC 7293 photographed with the 48-inch Schmidt telescope in Hα and* [N II]. *Scale 28″/mm.*

NGC 3587 (Owl nebula) is shown in Figure 1 photographed in [O III], in Figure 2 photographed in Hα and [N II]. The main difference is the enhanced brightness of the filamentary structure near the Northern edge which is most likely caused by [N II]. The outline is fairly regular, the size not too uncertain. But, what is the filling factor, and how misleading is it to take the observed ratios of integral line intensities as ratios of volume emissivities?

NGC 6853 (Dumb-bell nebula) is shown in Figure 3 photographed in [O III], and in Figure 4 photographed in Hα and [N II]. The [O III] picture shows the structure which gave the name to this nebula, but the red picture looks quite different, with numerous small condensations which probably show mainly [N II]. [O II] probably would look quite similar. Stronger exposures show outer loops in position angle 115° where the diameter is 470″. There is an exceedingly faint approximately circular envelope with a diameter of about 840″. What is the size, what is the filling factor, how completely does the nebula surround the star? Slit spectra might show a wide variety of relative intensities, different from integral values, depending on where the slit is placed.

NGC 6781 appears as a ring in Hα and [N II], as a disk in [O III] (for illustrations see Minkowski, 1964). Broad-band photographs in the blue look similar to the red picture because [O II] is strong on the outside. The difference in appearance shows,

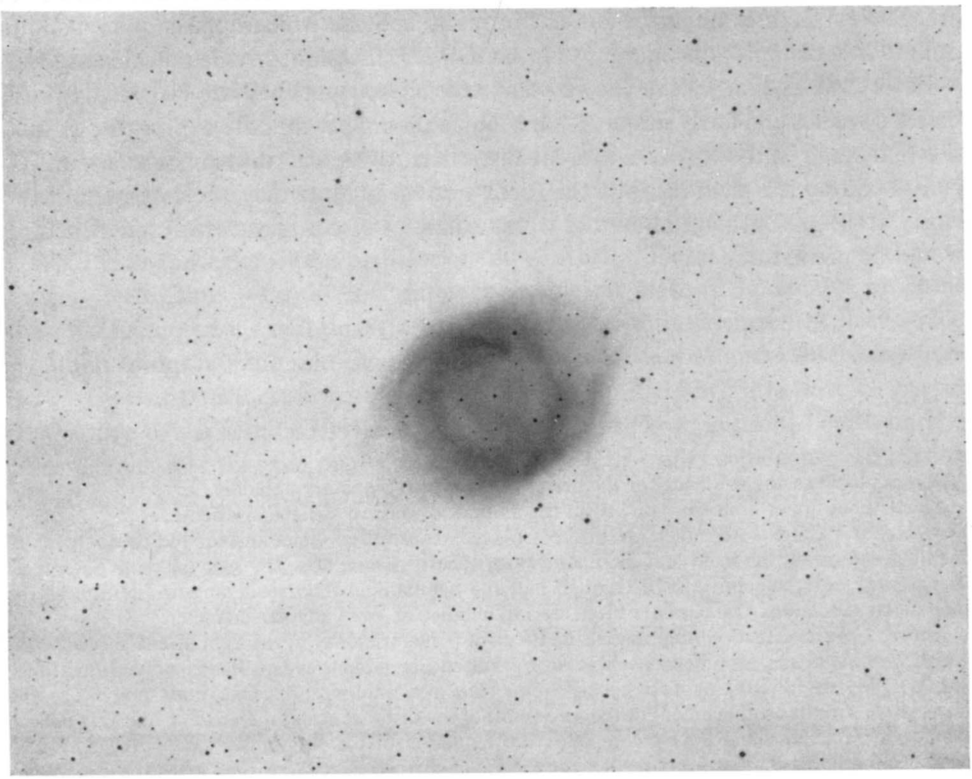

FIG. 6. *NGC 7293 photographed with the 48-inch Schmidt telescope in* [O III]. *Scale 28″/mm.*

of course, the ionization structure. Nebulae such as this might permit detailed tests of computations of the ionization structure such as those reported here by Williams who has compared for the first time computed integral values of line intensities with observed intensities without, however, considering the possible effects of structure and density variations in the nebula.

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NGC 7293 is shown from photographs with the Palomar 48-inch Schmidt telescope in Hα and [N II] in Figure 5, in [O III] in Figure 6. The red picture shows a faint outer arch in the North. Here, you may begin to wonder how to define the size. The difference between the red and the [O III] picture again shows the ionization structure. If the nebula were bright enough to be photographed in He II λ4686 Å, it probably would appear as a small disk. Photographs with the 200-inch telescope in Figure 1 of Seaton's introduction (p. 1) and Vorontsov-Velyaminov's paper (p. 256) (an enlargement of an area in the Northern part) reveal the full complexity of the structure which is beyond the resolving power of the 48-inch Schmidt telescope. The heads of the well-known 'comets' range down in size to unresolved features smaller than 1″ of arc. Such structures might be present in many nebulae which appear quite smooth, but are at a distance much larger than NGC 7293, the planetary nebula closest to us.

The examples that I have shown were selected because they are large enough for detailed studies and fairly simple. Such nebulae should permit us to explore the difficulties that stand in the way of a more realistic discussion. In smaller nebulae these difficulties will be less obvious, but this does not mean that they are not present. To worry at the present stage about the worst examples of complex forms and structures would be premature.

Reference

Minkowski, R. (1964) *Publ. Astr. Soc. Pacific*, **76**, 197.

DISCUSSION

Menon: Is there any evidence for the presence of dust in planetary nebulae?

Kahn: What upper limit can you set on the amount of dust in a planetary nebulae?

Minkowski: There is no indication of the presence of dust. The violet and the red components of the lines – showing the front and the back of the nebula – show no systematic intensity difference. The central stars, which are seen through half the nebula, show no reddening in addition to the interstellar reddening. Galaxies are often seen in nebulae of large angular diameter.

Miller: Are any direct photographs being taken of planetaries, say in the light of one spectral line, which would serve as good first epoch plates for measuring nebular expansions at some future time?

Liller: We are not taking first epoch monochromatic photographs. One must emphasize the uncertainties in the establishment of the zero point of the distance scale; therefore, I sincerely believe that when Mrs Liller and I have completed the reduction of the Mount Wilson photographs and have derived good angular motion rates for the *filaments* (not the edges), then it will be possible to evaluate the distance scale zero point to an accuracy not yet attainable.

Mathews: While I do not want to detract from the importance of proper motion measurements in planetary nebula, dynamic models indicate that the combination of proper motion data and measured radial velocities to determine nebular distances will be very difficult indeed. The same problems of interpretation may arise even when proper motions of smaller features are measured.

Liller: As we have pointed out, we are trying very hard to use well-defined filaments instead of edges for our expansion measures. We feel that by doing this, we are measuring true motion of material.