GENERAL DISCUSSION – SECOND SESSION

Aller: I would like to give a brief description of our spectrophotometric program on line intensities in planetaries. It is a joint effort by several investigators, including Czyzak, Walker, and Kaler. We measure the stronger lines with the photoelectric scanner on the Mt. Wilson 1·5-m reflector, comparing nebular scans with suitable standard stars. For the weaker lines, and the lines that fall close together in wavelength we rely chiefly on the Lick Observatory 3-m reflector. Prime-focus nebular spectrograph observations give relative line intensities, which can be converted to fluxes with the aid of Mt. Wilson data. Coudé spectra obtained with the image converter cover the region $\lambda\lambda$ 4700–5900. In each instance we calibrate with wide-slit spectra of suitable comparison stars. For photographic observations, a density-log$I$ relation is obtained by laboratory calibration. For the image converter, we use a combination of plate and developer that gives a linear relation between density and intensity. A few observations of bright planetaries have been obtained with the Mt. Wilson 2·5-m telescope. Kaler has secured a number of observations with the Kitt Peak 2-m telescope and coudé spectrograph.

Flower: What are the percentage errors in the line intensities obtained from high-resolution spectra? For example, what would be the probable error of a line intensity given as 10 on the scale $H\beta = 100$?

Minkowski: About 5% if the photometry is good.

Pottasch: What are the probable errors of the published $H\alpha/H\beta$ line-intensity ratios?

O'Dell: About 10%.

Terzian: I suggest that authors publishing Balmer-line fluxes should give the probable errors of these measurements. In the past few errors have been reported.

Gurzadian: It is necessary to make spectrophotometric measurements of the outer envelopes of planetary nebulae whenever possible.

Osterbrock: The similarity of the planetary nebula NGC 7027 and the Seyfert galaxy NGC 1068 in infrared emission is interesting, because these two objects also have very similar emission-line spectra.

Westerlund: Webster's survey of Southern planetary nebulae led to the detection of many peculiar objects. One of them, H 141, dominated by 2 bright knots, has a very flat Balmer decrement, $\log F(H\beta)/F(H\gamma) = 0{\cdot}28$, so the lines may be self-absorbed, presumably in the knots. It has very strong He II λ 4686 and [O II] λ 3727. No central star is seen on the direct plates. The object has a strong continuum with the color of a G9 dwarf and a strong ultraviolet excess. Interstellar reddening cannot be the explanation as the decrement is too flat. The nebula falls in a color-color diagram in

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the region of the white dwarfs, the nuclei of Seyfert galaxies, etc. It may be similar to NGC 7027.

Menon: The 109α line from NGC 7027 shows that it is an ionized-hydrogen region with density and temperature both higher than in a normal H II region. There is no similarity between NGC 7027 and a Seyfert galaxy as far as the radio spectra are concerned.

O'Dell: Seaton has shown that the observations by Bowen, Aller, and Minkowski of the ultraviolet continuum longward of the Balmer discontinuity in NGC 7027 do not fit thermal theory. This argues that an additional anomaly in the continuum exists.

Reeves: We should take into consideration the possibility that high-energy protons are irradiated from the central star into the nebula, and calculate if the infrared radiation and other phenomena could not be explained in this way.

Seaton: We have to consider whether the observed ionization in the nebulae can be understood in terms of purely radiative processes. If it turns out that this cannot be done, then we may have to suppose that fast particles also contribute to the ionization.

Menon: I would like to report on some measurements of the structure of 5 planetary nebulae made by Colomb at Green Bank using the interferometer at 10 cm and at spacings of 1·2 km and 2·7 km. The data consist of visibilities at various hour angles and at both spacings. On the basis of this data Colomb has constructed a model for each nebula, giving the best agreement with the observations. The parameters of the models are as follows:

(1) IC 418. A ring of inner radius 2″.1, outer radius 6″.0.
(2) NGC 6543. A uniform disk of radius 8″.5 × 10″.4 extended in position angle 15°.
(3) NGC 6572. A uniform disk of radius 3″.3 × 4″.7 extended in P.A. 10°.
(4) NGC 7027. A gaussian of 5″.4 × 8″.5 extended in P.A. 40°.
(5) NGC 7662. A uniform disk of radius 10″.4 × 12″.2 in P.A. 35°.

Gurzadian: If the existence of planetary nebulae with non-thermal radio emission is real, then the energy spectra of the relativistic electrons in some of these objects must be surprisingly steep. For example, in the cases of the nebulae NGC 6153 and NGC 6445, the observed frequency spectra ($F_\nu \propto \nu^{-\gamma}$) have observed exponents γ_{obs} = 4·4 and 3·0 respectively. These exponents must however be corrected to remove the effects of the underlying thermal emission, and when this is done the exponents of the pure non-thermal spectra are $\gamma = 8$ and $\gamma = 5$ respectively. From these values we must conclude that the energy spectra of the relativistic electrons in non-thermal planetaries differ from the spectra of the electrons in other well-known non-thermal sources. In fact the law $N(E) \propto E^{-\beta}$ cannot be used for the planetary nebulae. I think that a gaussian spectrum of electron energies is more probable.

There is some basis for thinking that the non-thermal and thermal emissions are generated in different parts of the same nebula: non-thermal in the centre, thermal, mostly in the other ring-like part of the nebula. Hence, it is very desirable to make special measurements with large angular resolution in order to obtain the spectra of radio emission in the central part of the nebulae as well as in the outer part.

It can be shown theoretically that the electron temperature in the central regions of a nebula must be larger at least by a factor of 1·5–2 relative to the electron temperature in the outer ring. However, it would be interesting to have observational evidence on this question from detailed measurements of the radio brightness across the nebula.

In many cases the outer envelopes of the two-envelope planetary nebulae are too faint to observe in the optical region. Perhaps these outer envelopes may be detected in some cases more easily by radio observations (some trace of the outer envelope of the nebula NGC 6543 may be seen in the results of Elsmore).

Thompson: I would like to emphasize that several planetaries, originally reported to have non-thermal spectra, have been shown to have been subject to confusion by nearby non-thermal sources. There is no evidence at the present time that any planetary has a non-thermal spectrum.

Flower: There may be considerable electron temperature gradients in planetary nebulae. When quoting a value for the electron temperature in a nebula it is important to state the part of the nebula which is the source of the radiation used to determine the electron temperature. I think this effect may be at least partly responsible for the discrepancies in electron temperatures that we have heard this morning.

Thompson: One can reasonably well understand the difference between the electron temperatures which I have deduced from the radio data and the forbidden-line values, in terms of temperature variations. Temperatures deduced from radio observations of the hydrogen recombination lines should, according to Peimbert, be weighted towards the cooler regions of nebulae. It therefore seems a little surprising that the temperature obtained by Mezger *et al.* from the 109α line in NGC 7027 is as high as the forbidden-line value.

Menon: I wish to emphasize that the determination of temperatures from radio data is very much handicapped by the lack of good-quality high-resolution radio and optical isophotes. The presence of a large number of small-scale irregularities could introduce serious errors in the temperatures determined by Thompson's procedure.

Thompson: I agree that the presence of filaments would produce fine structure in the distribution of optical depth over the nebulae, and that omission of such detail from the isophotes could decrease the values of electron temperature deduced from the radio data. In IC 418 such filaments must be small since they are not detected optically, and the effect of many small filaments would tend to average out over the volume of the nebula. Improved data may well increase by one or two thousand degrees the values that I have given, but I think that the radio temperatures will still be significantly lower than the forbidden-line temperatures.

Osterbrock: Are there any negative results on attempted observations of radio-frequency H I lines in other planetaries? Though NGC 7027 is the brightest in the continuum, the theories show there is a complicated dependence of the strength of the

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lines on density, temperature, and radiation field, so NGC 7027 may not necessarily be the brightest planetary in the 109α line.

Kaftan-Kassim: NGC 7027 has a flux of over 5 f.u. at 6 cm, which makes it the only suitable planetary in the Northern Hemisphere, since all the others have fluxes of 1 f.u. or lower.