Local Density Variations in Planetary Nebulae

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DENSITIES in ionized nebulae may be estimated from the surface brightness, which essentially gives an rms density,

$$n_e^{(\mathrm{rms})}=\left[\frac{1}{V}\int n_e^2 dV\right]^{\frac{1}{2}}.$$

Independent estimates may be obtained from deactivation rates deduced from relative forbidden line intensities. At the second Symposium[1] it was suggested that differences in the results obtained might be due to local density variations. Since that time, greatly improved brightness measurements have been made[2] and further accurate line intensities obtained.[3,4] An additional deactivation method has been developed[5] in which use is made of the measured Balmer discontinuity.

Densities deduced from various deactivation effects are all in fair accord,[5,6] with the exception of those obtained[7] from the [OII] 3729/3726 ratio, which are considerably smaller than the others. The explanation is that the 3729, 3726 lines have very small transition probabilities and will therefore be stronger relative to less highly forbidden lines in low density regions. For NGC 7027, models have been assumed[7] for which n_e is equal to $n_e^{(1)}$ in a volume V_1 and to $n_e^{(2)}$ in a volume V_2, where $V_1+V_2=V$. The following values of $n_e^{(1)}, n_e^{(2)}$ and V_2/V_1 are consistent with the observed [OII] ratios 3729/3726 and (3729+3726)/(7320+7330) (see Table I). The deduced values of $n_e^{(\mathrm{rms})}$ are in satisfactory agreement with the value $n_e^{(\mathrm{rms})}=1.1\times10^4$ cm^{-3} obtained from the surface brightness using a revised extinction correction.[8] It may be considered that $n_e=6\times10^3$ cm^{-3} in 99% of the volume and $n_e=9\times10^4$ cm^{-3} in 1% of the volume.

For other nebulae the results shown in Table II have been obtained.[7,9] In all cases the differences in the densities obtained by the three methods are such as to suggest the existence of local condensations. Condensation effects seem to be greatest for NGC 7662, which is very irregular in appearance. The only planetary considered[7] for which there is no evidence for purely local density fluctuations, is the particularly uniform object IC 418.

TABLE I.

$n_e^{(1)}$	$n_e^{(2)}$	V_2/V_1	$n_e^{(\mathrm{rms})}$
$\rightarrow 0$	3.5×10^4	$\rightarrow 0$	$\rightarrow 0$
2.5×10^3	4.6×10^4	0.024	0.75×10^4
5.0×10^3	7.3×10^4	0.0155	1.03×10^4
7.5×10^3	23.5×10^4	0.0016	1.20×10^4
8.5×10^3	$\rightarrow \infty$	$\rightarrow 0$	1.26×10^4

TABLE II.

NGC	$10^{-4}\times n_e$ a	b	c
6543	2.4	1.5	0.6
6572	4	1.9	1.0
7009	2.8	1.0	0.6
7027	4.5	1.1	0.85
7662	5	1.2	0.44

[a] Density from deactivation methods other than 3729/3726.
[b] Density from surface brightness.
[c] Density from 3729/3726.

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