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IRAS[1] SPECTRA OF PLANETARY NEBULAE

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ABSTRACT

Low-resolution spectra in the 7–23 μm range of five planetary nebulae observed with *IRAS* are presented and analyzed. The Ne III line at 15.5 μm is observed for the first time. This line is a sensitive indicator of electron temperature. The Ne III line and the S IV line at 11.5 μm dominate the short wavelengths in the spectra of the three observed medium-excitation nebulae.

Subject headings: infrared: spectra — nebulae: planetary

I. INTRODUCTION

In this *Letter* we present the first five spectra of planetary nebulae observed with the *IRAS* low-resolution spectrometer (Neugebauer *et al.* 1984).

II. OBSERVATIONS

IC 418 and Cn 1-1 are examples of young low-excitation nebulae, NGC 6153, NGC 6210, and NGC 6543 are of medium excitation. At least two spectra have been measured for each of these objects. The averaged spectra are given in Figure 1.

The preliminary calibration applied to the spectra is expected to be accurate to 30%. It has been derived from the calibration of the survey array (Neugebauer *et al.* 1984).

a) *Line Emission*

The intensities of the observed lines and other emission features are listed in Table 1. The 15.5 μm line of Ne III has not previously been observed because of the strong absorption by CO_2 in the Earth's atmosphere. The line widths imply upper limits of about 20″ for the sizes of the emitting regions.

For those lines already observed from the ground or from airplanes, a comparison of the intensities is shown in Table 2. For a few lines, Table 2 lists intensities corrected for diaphragm size by the authors. In view of the good agreement between results from the spectrometer and the survey array for a large variety of objects, we believe that our relatively high line intensities are realistic. We agree with the conclusion of Roche, Aitken, and Whitmore (1983) "that correction for beam size effects tended to be underestimated" in earlier work.

b) *Continuum and Solid State Resonances*

Continuum flux densities in the observed spectra are listed in Table 3. The errors may be of the order of 50% for the very weak continua. No continuum could be seen below 13 μm for NGC 6543, NGC 6153, and NGC 6210. The survey measurements are shown for comparison. These are probably a good measure of the continuum in the 25 μm band, but the line emission is an important contributor in the 12 μm band, particularly in the higher excitation nebulae.

The unidentified feature at 11.3 μm, which probably originates from solid state grain material resonances, appears in the two low-excitation nebulae. In IC 418 the feature agrees in shape and intensity with the observation by Willner *et al.* (1979).

III. ANALYSIS OF THE LINES

a) *Electron Temperature*

Observed line intensities are determined by the electron density N_e, the electron temperature T_e, and the ionic abundance in a nebula. One of the best ways of determining T_e will be from the ratio of the [Ne III] lines $I(\lambda 3869\ \text{Å})/I(\lambda 15.5\ \mu\text{m})$, now that the λ15.5 μm line has been measured. This line ratio is very sensitive to T_e and hardly depends on N_e, for values of N_e which are found in most nebulae, as is illustrated in Figure 2. The calculations are based on collision cross sections (which ignore low-lying resonances) and transition probabilities compiled by Mendoza (1983). This method has been applied to the four nebulae in which the 15.5 μm line has been measured; the results are shown in Table 4.

b) *Abundances*

Abundances determined from the infrared lines have only a weak dependence on T_e, and often on N_e as well, over a limited range of densities. The abundance of all the observed ions may therefore be calculated. Table 4 lists the resulting

[1]The *Infrared Astronomical Satellite* was developed and is operated by the Netherlands Agency for Aerospace Programs (NIVR), the US National Aeronautics and Space Administration (NASA), and the UK Science and Engineering Research Council (SERC).

ionic abundances and the implied lower limits to the element abundances. It is noteworthy that these values are several times higher than previous abundance estimates. Accepted abundances for average planetary nebulae are 3, 10, and 150×10^{-6} for Ar, S, and Ne.

We are greatly indebted to Klaas Lugtenborg of the Leiden University Observatory for producing the software necessary to process the spectrometer data. We also thank A. Priete-Martinez for his help in the abundance calculation.

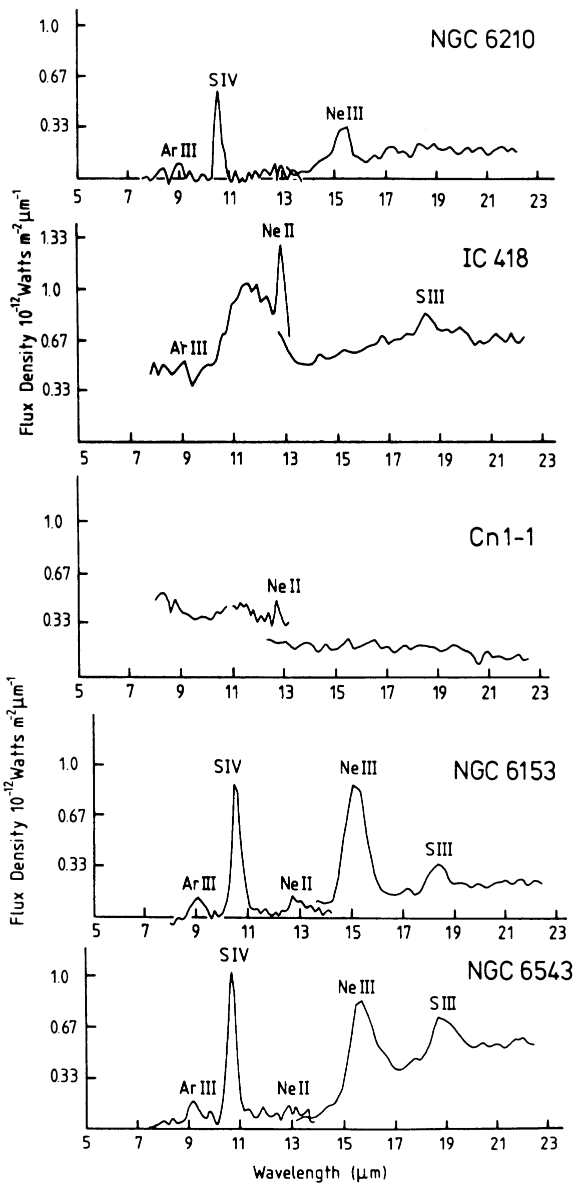

FIG. 1

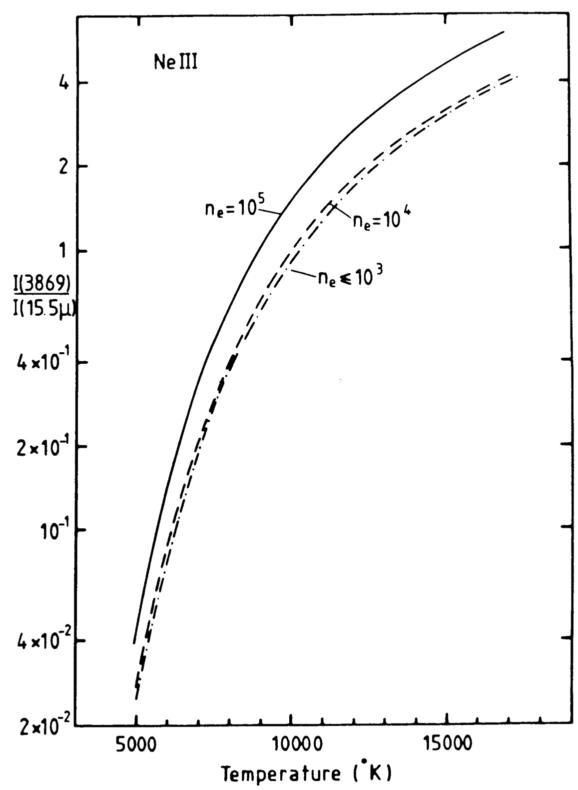

FIG. 2

FIG. 1.—Spectra of the five observed planetary nebulae. The two wavelength ranges of the spectrometer overlap near $\lambda = 13$ μm. All spectral lines are unresolved; their widths reflect the wavelength-dependent spectral resolution.

FIG. 2.—Intensity ratios of the [Ne III] lines at $\lambda = 0.3869$ μm and $\lambda = 15.5$ μm as a function of electron temperature and electron density

TABLE 1

INFRARED LINE INTENSITIES IN PLANETARY NEBULAE

(10^{-14} W m^{-2})

Wavelength (μm)	Ion	NGC 6153	NGC 6210	NGC 6543	IC 418	Cn 1-1
8.99	Ar III	7	4	7	3	...
10.52	S IV	40	20	40	...	...
11.3	...	...	...	...	170	14
12.82	Ne II	5	< 3	3:	22	4
15.5	Ne III	70	13	70	...	...
18.7	S III	15	< 7	25	7	...

TABLE 2

COMPARISON OF *IRAS* LINE INTENSITIES WITH OTHER OBSERVATIONS

(10^{-14} W m^{-2})

OBSERVER	DIAPHRAGM (arcsec)	NGC 6210			NGC 6543		IC 418	
		S IV	Ar III	Ne II	S IV	Ar III	Ar III	Ne II
Grasdalen (1979)	11	11.5	0.9	...	13.7	2.9	...	...
Dinerstein (1980)	10	8.4	...	...	10.4	...	...	...
		11.2[a]	...	...	33.34[a]	...	...	...
Beck et al. (1981)	6	16.3	0.8	≤ 0.1	...	...	≥ 1.0	26.4
Aitken, Roche, and Spenser (1979)	9	...	...	...	8.5	...	...	...
					26.6[a]	...	...	...
Willner *et al.* (1979)	22?	...	...	...	...	...	2.0	...
Roche, Aitken, and Whitmore (1983)	20	20	...	...	39	...	...	...
IRAS	...	20	4	≤ 3	40	7	3	22

[a]Values corrected for diaphragm size.

TABLE 3

CONTINUUM FLUX DENSITIES (Jy)

NEBULA	LOW-RESOLUTION SPECTROMETER				SURVEY	
	8 μm	12 μm	16 μm	20 μm	12 μm	25 μm
NGC 6543	...	...	28	67	8.1	118
NGC 6153	...	...	10	25	7.5	64
NGC 6210	...	...	9	20	2.4	30
CN 1-1	10	16	20	22	17.8	43.
IC 418	10	25	49	90	41.4	242

TABLE 4

DERIVED QUANTITIES[a]

PARAMETER	NEBULA			
	NGC 6543	NGC 6153	NGC 6210	IC 418
$I(\lambda 3868)/I(H\beta)$	0.47	0.9	0.8	...
$F(H\beta)$ (10^{-14} W s^{-1})	28	15	10	50
E_{B-V} (mag)	0.04	0.66	0.04	0.20
$I(\lambda 3868)/I(\lambda 15.5\ \mu m)$	0.20	0.20	0.60	...
T_e (K)	7200	7200	9000	...
Ar III	4	6	6	1
S III	15	15	≤ 20	25
S IV	7	11	8	...
Ne II	20	50	≤ 40	53
Ne III	250	570	150	...
Ar	> 4	> 6	> 6	> 1
S	> 21	> 26	> 21	> 25
Ne	> 270	> 620	> 190	> 53

[a]Abundance with respect to hydrogen in units of 10^{-6}.

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