ELECTRON DENSITIES FOR SIX PLANETARY NEBULAE AND HM SGE DERIVED FROM THE C III] λ1907/1909 RATIO

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ABSTRACT

Electron densities for IC 418, NGC 6572, IC 1297, NGC 3242, NGC 6818, NGC 3211, and HM Sge derived from high-dispersion IUE C III] spectrograms are consistently higher than those derived from either surface brightness measurements of forbidden line intensity ratios in the visible. The nebulae were selected for a range of excitation classes from 3 to 9. Line splitting due to expansion velocities is observed for three objects. The great width of the λ1909 C III] line in HM Sge suggests large expansion velocities.

The results described are part of an ongoing observational program of planetary nebulae in collaboration with A. Boggess, R. W. Hobbs, and C. W. McCracken.

INTRODUCTION

The usefulness of the C III] λ1907/λ1909 ratio as a diagnostic tool for determining electron densities in planetary nebulae has been recognized for some time (Osterbrock 1970; Loulergue and Nussbaumer 1976). Observations of 24 planetary nebulae by means of the International Ultraviolet Explorer (IUE) satellite have shown that in the low resolution (∿7Å) mode C III] λ1909 is usually the strongest emission feature (Boggess, Feibelman and McCracken 1980). The high-dispersion spectrographs of IUE easily resolve the pair of C III] lines. The instruments have been described in detail elsewhere (Boggess et al. 1978). We report results on six planetary nebulae and HM Sge observed in the high-resolution (0.1Å) mode to determine the λ1907/λ1909 ratios from them.

DATA AND DISCUSSION

Loulergue and Nussbaumer (1976) have pointed out that in the regime of $N_e < 10^6$ cm^{-3}, characteristic of planetary nebulae, the magnetic quadrupole transition $2s^2\ ^1S_0 - 2s\ 2p\ ^3P_2^0$ at λ1906.68 has an emissivity comparable to the intercombination transition $2s^2\ ^1S_0 - 2s\ 2p\ ^3P_1^0$ at λ1908.73. Subsequently, Nussbaumer and Schild (1979) published new curves for the relative emission strengths of the λ1906.68/λ1908.73 ratio, based on improved data for the collision strengths. These curves for the ratio of the C III] pair versus log N_e permit one to derive electron densities from the IUE high-resolution data.

The planetary nebulae IC 418, NGC 6572, IC 1297, NGC 3242, NGC 6818, NGC 3211, and HM Sge (which is suspected of being a proto-planetary in its early stages of development) have been observed in the high-resolution mode and the C III] λ1907/λ1909 ratios have been determined. Dates of observation and exposure times for the nebulae are summarized in Table 1. All spectrograms were obtained through the large aperture centered on the nuclei. The

results are shown in Table 2, where the electron densities derived from these ratios in conjunction with the curves of Nussbaumer and Schild (1979) are listed in the last column. Also shown in Table 2 are values of electron densities given by Aller (1965) based on Hβ surface brightness data, and densities derived by Aller and Walker (1970) from forbidden line intensity ratios. For all planetaries listed in Table 2, ranging in excitation class from 3 to 9, the lowest electron densities are the ones derived from the Hβ data, while the highest were obtained from the present IUE data based on the C III] ratios.

Relatively little is known about IC 1297 from ground-based observations. Its excitation class is estimated here to be in the range of 7 - 8, and the electron temperature is assumed to be 11,000K. Observations of IC 1297 are needed to verify these assumptions. The high-resolution spectrograms of NGC 3242, and a lesser degree those of NGC 3211 and NGC 6818, show splitting of the C III] lines due to Doppler velocities. The remainder of the planetaries do not show this effect. For NGC 3242 an expansion velocity of 39 km/sec is obtained, which is in very good agreement with the average value of 39.8 km/sec given by Wilson (1950). Examples of the split lines for NGC 3242 and the single lines for NGC 6572 are shown in Fig. 1 and Fig. 2.

Flower, Nussbaumer, and Schild (1979) obtained a value of 0.02 for the C III] λ1907/λ1909 ratio for HM Sge observed in 1978, implying log $N_e \geq 6$, corresponding to log $N_e \approx 6.5$ when derived from the updated curves by Nussbaumer and Schild (1979). On June 2, 1979, we obtained a 180 minute exposure of HM Sge which had a better S/N ratio than the relatively short (40 min) exposure by Flower et al. (1979). The weak λ1907 component is superimposed on the very extended blue wing of the strong, asymmetric λ1909 component, shown in Fig. 3, making a precise determination of the λ1907/λ1909 ratio difficult. An upper limit of the electron density can be set as log $N_e \approx 10^6$, derived from $R \approx 0.04$. The presence of a narrow spike in the λ1909 line profile suggests the possibility that the emission plasma consists of two separate components.

The great width of the λ1909 line in HM Sge yields a large expansion velocity. Flower et al. (1979) give a value of >118 km/sec, but the present data yield only ≈63 km/sec. The maximum velocity may be a more significant quantity to consider because of the asymmetry of the line profile. Wallerstein (1978) found v_{max} = 1700 km/sec for Hα + He II derived from the full width at the base of the line in HM Sge on September 2, 1977, but also listed on a wide range of lesser velocities for other ions. The present IUE data result in v_{max} = 353 km/sec and 375 km/sec derived from the C III] λ1909 and Mg II λ2798, λ2803 resonance lines, respectively.

CONCLUSIONS

Electron densities, based on the C III] λ1907/ λ1909 intensity ratios for six planetary nebulae are consistently higher than those derived from surface brightness or forbidden line intensity ratios in the visible. The nebular expansion velocity of 39 km/sec for NGC 3242 is in good agreement with ground-based observations by Wilson (1950). HM Sge has an expansion

velocity and electron density substantially greater than those of typical planetary nebulae, and the complex structure in the λ1909 line profile suggests the existence of more than one emission region in the line of sight. It remains to be determined whether these shells will evolve into a classical planetary nebula structure.

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TABLE I.- HIGH-DISPERSION OBSERVATIONS OF PLANETARY NEBULAE

Object	Date	IUE Image Number	Exposure (min)
IC 418	18 Dec 1978	LWR 3200	40
NGC 3211	18 Dec 1978	LWR 3204	90
NGC 3242	18 Dec 1978	LWR 3206	60
NGC 6818	7 April 1979	LWR 4211	150
IC 1297	7 April 1979	LWR 4212	120
NGC 6572	7 April 1979	LWR 4213	100
HM Sge	20 Dec 1978	LWR 3219	28
HM Sge	2 June 1979	SWP 5429	180

TABLE II.-ELECTRON DENSITIES FOR PLANETARY NEBULAE

Nebula	Excitation Class (Ref. a)	T_e (x10^{-4}) (Ref. a & c)	C III] λ1907/λ1909 Ratio	log N_e		
				Ref. a	Ref. b	This work
IC 418	3	0.91 (c)	0.93	4.27	4.22	4.4
NGC 6572	5	1.08 (a)	0.80	4.14	4.00	4.5
IC 1297	(7-8)	-	(1.0)	-	-	4.4*
NGC 3242	7	1.10 (a)	1.09	3.87	3.90	4.2
NGC 6818	9	1.80 (a)	1.19	3.75	3.84	4.1
NGC 3211	9	1.37 (c)	1.11	3.44	-	4.1
HM Sge	-	-	0.04	-	-	6.0#

Ref. a: Aller (1965; N_e derived from Hβ data.

Ref. b: Aller and Walker (1970); N_e derived from forbidden lines.

Ref. c: Torres-Peimbert and Peimbert (1977); N_e derived from [O III] data.

Notes:

Excitation class for IC 1297 not listed in Ref. a. The value shown is estimated.

* = assuming T_e = 11,000K. # = assuming T_e = 12,000K.

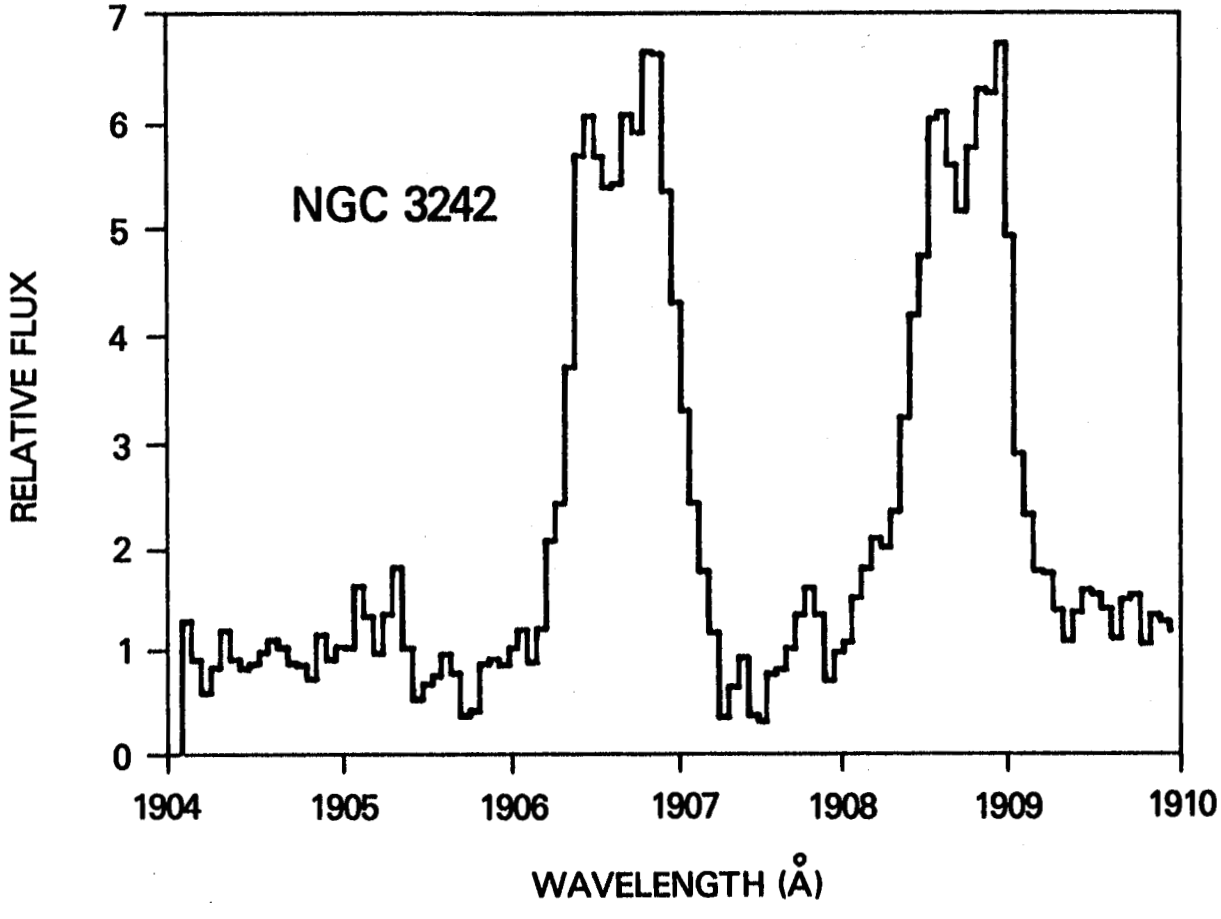

Fig. 1 - Section of IUE echelle spectrogram showing the C III] λ1906.68 and 1908.73 lines for NGC 3242.

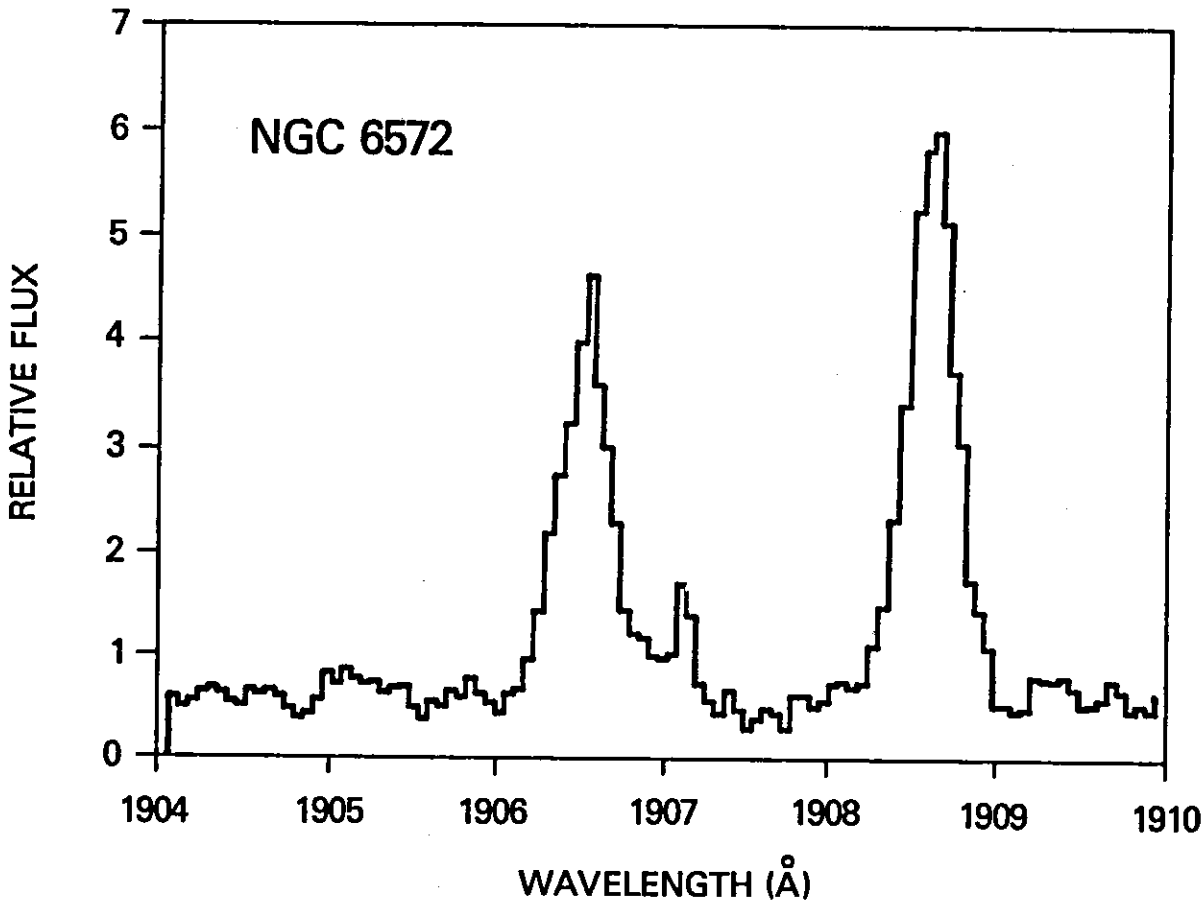

Fig. 2 - Same as Fig. 1, for NGC 6572

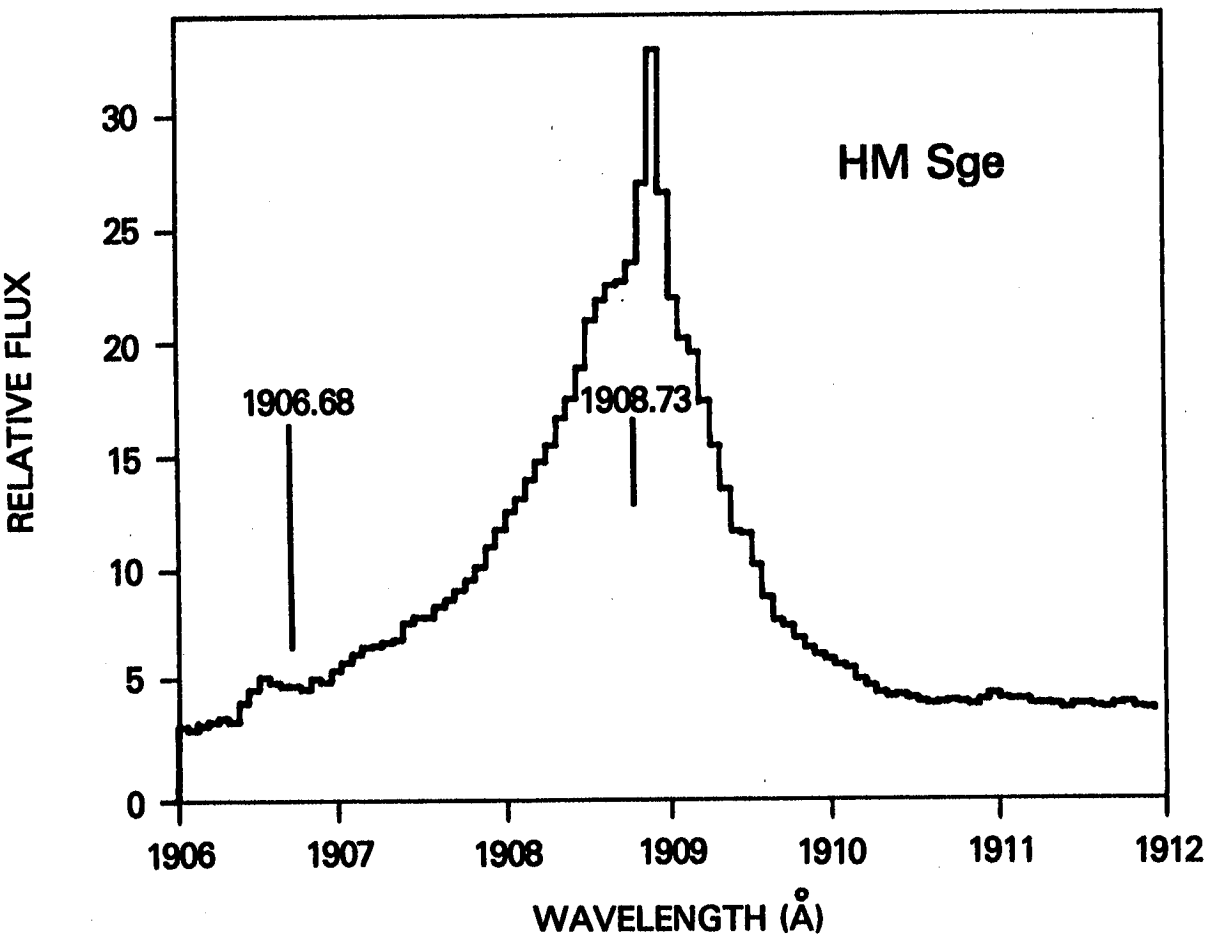

Fig. 3 - Same as Fig. 1, for HM Sge. The FWHM for the 1908.73 line is 0.8Å. The total width is ≈ 4.75Å.