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ULTRAVIOLET SPECTROSCOPY OF THE PLANETARY NEBULA IN THE FORNAX GALAXY

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ABSTRACT

The planetary nebula in the Fornax dwarf spheroidal galaxy is carbon rich, according to calculations based on measurements of the λ1909 emission line doublet of C III] obtained with the *International Ultraviolet Explorer*. The ratio $N(\mathrm{C})/N(\mathrm{O}) \approx 3.7$, comparable to the largest reliably determined carbon/oxygen ratios in high excitation planetaries of the Milky Way. The present result is based on four low-dispersion spectra with a combined exposure time of 27.2 hours; the Fornax planetary nebula is probably the most distant known planetary that can be observed with *IUE*. The *IUE* data were analyzed together with visible-wavelength emission-line fluxes reported by Danziger *et al.* to compute abundances for various elements. In terms of chemical composition, the Fornax nebula resembles planetary nebulae in the Magellanic Clouds more closely than it does typical or carbon-rich planetaries in the Galaxy.

Subject headings: galaxies: individual — nebulae: abundances — nebulae: planetary — ultraviolet: spectra

I. INTRODUCTION

The planetary nebula in the Fornax dwarf galaxy (Danziger *et al.* 1978) is, at an estimated distance of 158 kpc (Demers and Kunkel 1979), almost surely the most distant planetary that can be observed with the *IUE*. As such, it is also the only planetary in a dwarf spheroidal galaxy that is accessible to present techniques of ultraviolet spectroscopy. Accordingly, the Fornax planetary was added to our program of *IUE* observations of extragalactic planetaries (Maran *et al.* 1981; Stecher *et al.* 1982).

An accurate position for the Fornax planetary was required in order to track the nebula with *IUE*, since at about visual magnitude 17–18 it cannot be seen with the *IUE* Fine Error Sensor (slit jaw camera). Therefore, a CTIO 4 m telescope prime focus plate, kindly provided by Dr. J. Hesser, was measured with a PDS microdensitometer at NASA-GSFC; the resulting position (equinox 1950.0) is right ascension $02^{\mathrm{h}}37^{\mathrm{m}}44\overset{\mathrm{s}}{.}93$, declination $-34°45'37\overset{''}{.}8$, in excellent agreement with the position given by Danziger *et al.*, R.A. $02^{\mathrm{h}}37^{\mathrm{m}}45\overset{\mathrm{s}}{.}1 \pm 0\overset{\mathrm{s}}{.}7$, decl. $-34°45'38'' \pm 2''$ (1950).

II. OBSERVATIONS

Artifacts may occur in *IUE* spectra of faint sources as a result of overexposures on sources observed earlier or due to radiation (trapped or cosmic-ray particle) hits and defects in the camera (so-called hot pixels). Overexposures in fact occurred on the observing shifts immediately preceding those assigned to this program. Therefore, the *IUE* was pointed so as to image the faint Fornax planetary at a different location on the major axis of the 10 × 20 arcsec spectrograph entrance aperture on each of the four occasions when spectra were obtained. It was then possible to distinguish real features from the overexposure artifacts, and to eliminate the latter through data processing. The spectra are listed in Table 1. All observations were made with the short-wavelength spectrograph and low-dispersion camera and were obtained with the *IUE* pointing system tracking the 8th mag star SAO 193841, whose offset from the nebula was determined by PDS microdensitometer measurements on the CTIO 4 m plate mentioned above.

The spectra were co-added, using the *IUE* Regional Data Analysis Facility computer at NASA-GSFC, by a technique described by Davidson *et al.* (1982). The total exposure for the resultant spectrum (Fig. 1) is 27.2 hours, yet only the λ1909 emission line of C III] and a weak continuum were detected; the line can be seen in each of the individual spectra. The measured fluxes from the co-added spectra, corrected for the absolute sensitivity of the *IUE*, are listed in Table 2. We have not attempted a serious analysis of the continuum, because the statistics are very poor. Possible sources of the continuum are the nebula (the suggestion that we prefer), the central star, and perhaps one or more very faint, hot objects in the field.

III. ANALYSIS

We have analyzed the λ1909 C III] flux obtained with *IUE* along with the visible-wavelength lines reported by Danziger *et al.* (1978). The data were dereddened using a mean galactic extinction law (Seaton 1978) scaled to $c = 0.10$, the logarithmic extinction at Hβ that was determined by Danziger *et al.* We assumed that the Fornax galaxy does not contribute to the extinction since no interstellar dust nor gas has been found in that system (Hodge 1971).

The analysis followed the procedures described by Shields *et al.* (1981) and by Aller, Keyes, and Czyzak (1981). In this

TABLE 1

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Spectrogram No.	Date (1982)	Exposure Time (minutes)
SWP 16783	Apr 17	430
SWP 17128	Jun 5	350
SWP 17137	Jun 6	430
SWP 17142	Jun 7	420

[1] Guest Observer, *International Ultraviolet Explorer.*

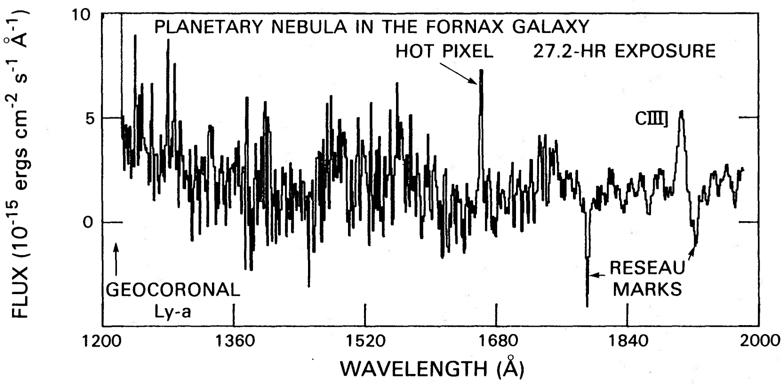

FIG. 1.—Co-added spectrum of the planetary nebula in the Fornax galaxy, prepared from four low-dispersion spectrograms with a total exposure time of 27.2 hours made with the *IUE* short-wavelength spectrograph. The only detected emission line is λ1909 C III].

method, a nebular model is developed to match both the usual diagnostic line ratios and the intensities of all observed lines as closely as possible. Then ionization correction factors are derived to account for the estimated effects of unobserved stages of ionization. These then enable one to calculate elemental abundances from the ionic concentrations indicated by the model.

For the visual data, the uncertainties in the line strengths range from 5% to 30% for the strongest and weakest lines, respectively, according to Danziger *et al.* The estimated uncertainty in the measurement of the λ1909 line is about 20%. The uncertainties arising from the model calculations, for example in the correction factors for unseen stages of ionization, amount to about 0.10 dex in the tabulated abundances. Our derived C abundance is thus 8.95 ± 0.1.

The analysis was carried out with the facilities of the computing center at UCLA. The results are shown in Table 3, where the elemental abundances in the Fornax planetary (col. [2]) are compared with those previously derived for (A) three high-excitation planetaries in the Magellanic Clouds (cols. [3], [4], and [5]; Maran *et al.* 1982), (B) a collection of 38 mostly bright galactic planetaries (col. [6]; Aller and Czyzak 1983), (C) 14 high-excitation, carbon-rich galactic planetaries (col. [7]; Aller and Czyzak 1981, 1983), (D) the galactic planetary nebula J900 (col. [8]; Aller and Czyzak 1983), and (E) an adopted solar composition (col. [9]; Aller 1980). The same set of atomic parameters was used in calculating all of the abundances in Table 3.

The relative abundances of He, N, and Ar in the Fornax planetary as shown in column (2) of Table 3 are in good agreement with those estimated by Danziger *et al.*, whereas we find a relative oxygen abundance that is 25% lower than their adopted result [but which is in agreement with *N*(O) that they calculated by a second approach, which resembles ours]. Danziger *et al.* did not observe emission from any state of carbon, and they reported only ionic abundances for neon and sulfur.

It is seen from Table 3 that although the Fornax planetary nebula has been described as being relatively high in oxygen (Ford 1983), it is less rich in O than typical galactic planetaries, and in fact it is most notable for a carbon-to-oxygen abundance ratio of 3.7, which is comparable to the highest well-established *N*(C)/*N*(O) values found in high-excitation galactic planetaries, e.g., *N*(C)/*N*(O) = 4.0 in J900 (Aller and Czyzak 1982). (This explains why J900 is listed separately in Table 3, although it is included in the sample of carbon-rich planetaries described by col. [7].)

Earlier studies (Aller, Keyes, and Czyzak 1981 and references therein; Maran *et al.* 1982) show that He is equally abundant in the planetary nebulae of the Magellanic Clouds and those of the Galaxy, while N, O, Ne, S, and Ar each are less abundant in the Magellanic planetaries than those of the Galaxy. N appears to be enhanced in the Magellanic

TABLE 2

MEASURED FLUXES IN THE ULTRAVIOLET SPECTRUM OF THE FORNAX PLANETARY NEBULA

Type	Line/Range (Å)	Value
Emission-Line	1909 C III]	3.3×10^{-14}[a]
Continuum	1798–1883	1.45×10^{-15}[b]
	1751–1836	6.4×10^{-16}[b]
	1345–1430	1.35×10^{-15}[b]
	1260–1329	2.45×10^{-15}[b]

[a] Units: ergs cm^{-2} s^{-1}.
[b] Units: ergs cm^{-2} s^{-1} Å^{-1}

TABLE 3

CHEMICAL COMPOSITION OF THE PLANETARY NEBULA IN THE FORNAX GALAXY

Element (1)	Fornax (2)	P40 (3)	N2 (4)	N5 (5)	38 PN (6)	C-Rich (7)	J900 (8)	Solar (9)
He	11.08	11.02	11.03	11.05	11.04	11.03	10.99	11.03
C	8.95	8.70	8.60	8.87	8.85	8.99	9.10	8.65
N	7.40	7.5:	7.42	7.60	8.11	8.15	7.70	7.96
O	8.38	8.33	8.30	8.36	8.62	8.69	8.50	8.87
Ne	7.57	7.62	7.53	7.79	8.02	8.05	7.91	8.05
S	6.7	6.42	6.26	...	6.99	7.09	6.38	7.23
Ar	5.90	6.19	6.04	6.02	6.40	6.46	6.07	6.57

planetaries with respect to its abundance in the present interstellar media of the Clouds, while O, Ne, S, and Ar, within the uncertainties involved, are present about equally in the planetaries and in the interstellar media of the Clouds, suggesting that the abundances of these elements reflect the initial composition of the respective progenitor stars of the nebulae. The interstellar media of the Clouds are deficient in these elements with respect to the Galaxy (Peimbert and Torres-Peimbert 1974; Dufour 1975; Aller, Czyzak, and Keyes 1977). The C content of planetary nebulae is dominated by the products of nucleosynthesis and convective dredgeup in the progenitors.

The above summary of the composition of planetaries in the Clouds appears to apply equally to the planetary nebula in the Fornax galaxy: He is present in about the same relative abundance as in the Magellanic and galactic planetaries, while N, O, Ne, S, and Ar are deficient with respect to the galactic planetaries but are present at about the same levels as in the three bright nebulae LMC P40, SMC N2, and SMC N5 discussed by Maran *et al.* (1982). It appears that the Fornax planetary nebula is chemically more like the planetaries in the Clouds than like those in the Galaxy.

IV. CONCLUSIONS

Ultraviolet spectroscopy at the limit of the *IUE*, combined with ground-based observations, indicates that the only known planetary nebula in the Fornax galaxy is notably richer in carbon than typical high-excitation planetaries in the Galaxy and the Magellanic Clouds; the measured carbon-to-oxygen abundance ratio is comparable to the highest well-determined values in high-excitation galactic planetaries.

The Fornax planetary nebula resembles the three planetaries of the LMC and SMC that were studied by Maran *et al.* (1982) in a clear deficiency of N, O, Ne, S, and Ar, but not C, with respect to planetaries in the Galaxy. O, Ne, S, and Ar, derived from the atmosphere of the progenitor star, may be relatively unaffected by stellar evolution. Thus, their abundances may reflect those which prevailed in the interstellar medium of the Fornax galaxy at the time when the progenitor of the nebula formed. If so, that medium must have been enriched by the nucleosynthetic products of an earlier generation of stars, in accord with the suggestion of Danziger *et al.* (1978). The low metallicity of the Fornax planetary is thus consistent with the results of studies of stars and clusters in the Fornax galaxy, which indicate that it is a low-metallicity system with at least one population component of metallicity comparable to that of the oldest clusters in the Clouds and the Galaxy (Danziger 1973; Zinn and Persson 1981) and that there have been several generations of stars (Aaronson and Mould 1980). Further investigation of this interesting nebula, at least in the ultraviolet, probably must await the advent of the Hubble Space Telescope.

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