ELEMENTAL ABUNDANCES IN HIGH-EXCITATION PLANETARY NEBULAE

P.A. Marionni*
Electro-Optics Branch, GSFC

J.P. Harrington
Astronomy Program, U. of Md.

ABSTRACT

The IUE satellite has been used to obtain low dispersion spectra of the high excitation planetary nebulae IC 351, IC 2003, NGC 2022, IC 2165, NGC 2440, Hu 1-2, and IC 5217. Numerical modeling has been undertaken to determine the chemical composition of these objects with particular emphasis on obtaining elemental carbon and nitrogen abundances. Preliminary results for several nebulae suggest large variations in the C/N ratio from object to object.

INTRODUCTION

Ultraviolet (UV) observations can aid in the assessment of elemental carbon and nitrogen abundances in planetary nebulae (cf. ref. 1). Presented here are low dispersion UV observations of seven high excitation nebulae. Three approaches of varying degrees of complexity are used to infer carbon to nitrogen abundances (C/N) for some of the objects observed.

OBSERVATIONS AND DATA REDUCTION

Our IUE observations were performed in 1979 August and November. Selection criteria for the objects studied were a) nebulae of high excitation; b) except for Hu 1-2, nebulae included in the study of Torres-Peimbert and Peimbert (ref. 2); and c) except for NGC 2440 and to some extent NGC 2022, nebulae with angular sizes comparable to or less than the large entrance aperture. All spectra presented here were taken with the large entrance aperture, low dispersion configuration, using both the long wavelength redundant (LWR) and short wavelength prime (SWP) cameras.

Data reduction consisted of examination and extraction of spectra from the 55-line spatially resolved files provided to guest IUE observers. Integration of emission line features over effective slit heights commensurate with the angular extents of individual nebulae somewhat enhanced our signal to noise ratio. A spurious feature ~7-10 Å longward (on lines 21 through 23-24) of the NIII] λ1751 Å emission line has been removed from our data. A median smoothing of the background was employed. Conversion to an absolute flux scale was accomplished via interpolation of a tabulated IUE standard calibration (ref. 3).

Our results are contained in Table I. For each object the observed emission line intensities, $F(\lambda)$, have been corrected for interstellar extinction to the dimensionless quantities $I_c(\lambda)$ using the expression $\log[I_c(\lambda)] = 2 + cf(\lambda) +$

*NRC/NAS Resident Research Associate

log (F(λ)/F(Hβ)]. Here c is the logarithmic extinction coefficient, f(λ) is based on the prescription of Seaton (ref. 4), and F(Hβ) is the observed HI flux at λ4861 Å taken from various sources. The use of the intensity ratio F(HeII λ4686 Å/F(HeII λ1640 Å) in deriving interstellar reddening depends upon the portion of a given nebula observed in both the optical and ultraviolet and the validity of the UV extinction law in the direction of that object. Because of uncertainties in these quantities, additional criteria (mainly available radio data, optical studies, the 2200 Å interstellar feature, and, where measurable, the UV continuum of the central source of excitation) have been used in the determination of extinction coefficients.

Except for IC 2003, where c = 0.37 ± 0.05, errors in c, if f(λ) is assumed correct, may be as large as 0.2, and these extinction estimates are presented only to facilitate further analysis. In the case of NGC 2440, 45% of the object is estimated to have been overlaid by the entrance aperture.

A better than 10% consistency error in the ratio of strong lines, and $\lesssim$25% repeatability error is estimated for our SWP data. For all weak lines, and for all LWR data excepting the [NeIV] λ2422 Å feature, our assessment of the continuum level was the limiting factor to our accuracy, with probable errors up to 50% for the weakest features.

ANALYSIS

The interpretations of UV spectra from high-excitation nebulae are characterized by several major difficulties, and are thus implicitly model-dependent. First, rates of collisional excitation of UV transitions are extremely sensitive to temperature variations which can exist in high-excitation nebulae. Second, charge transfer processes become more important in determining specific ionization structures, since the neutral fraction of hydrogen is correspondingly higher for the lower mean photoionization efficiencies from higher temperature excitation sources. Recent calculations of a charge transfer rate involving OIV + HI $\rightleftarrows$ OIII + HII (ref. 5) so change the structure of previously calculated models that, due to lack of time, we have employed a refined Landau-Zener approximation (ref. 6) to this rate. We thus do not attempt to derive oxygen abundances on the basis of UV lines, and our thermal structures may be in error. Finally, the ions CIII, CIV, NIII, and NIV can coexist both in high temperature regions where the thermal structure is dominated by their own cooling (HeIII zones) and regions of lower temperature dominated by [OIII] forbidden line cooling; thus UV emission lines predominantly represent those ions in regions of high temperature.

The following analysis depends upon many atomic rates, which we cannot reference due to space limitations. References to these and the specific computational methods used will appear elsewhere (ref. 7). It should be noted, however, that the electron collisional cross sections used in the analysis of the NIII] λ1751 Å and CIII] λ1909 Å lines are those of Jackson (ref. 8) and Dufton et al. (ref. 9).

Visual inspection of the dominant UV emission lines of carbon and nitrogen in Table I suggests large variations in C/N ratios, if the ionic distributions of CIII and NIII and/or CIV and NIV are similar. More quantitatively, Shields (ref.

10), in a discussion of quasar spectra, has pointed out that the emission line ratios I_c(CIII] λ1909 Å)/I_c(NIII] λ1751 Å) and to a lesser extent I_c(CIV λ1549 Å)/ I_c(NIV] λ1487 Å) are relatively insensitive to the details of specific ionizing distributions. Both from direct comparison of the collisional excitation rates involved, and the results of all our attempts to construct detailed numerical models for the objects in this study, the relationship C/N ~ .15 I(λ1909)/ I(λ1751) and C/N ~ .15 I(λ1549)/I(λ1487) should usually be accurate to within a factor of two over the range of effective stellar temperatures 90,000 K to 200,000 K, nebular electron densities 2 x 10^3 - 2 x 10^4, and C/N .5 to 5. Plane-parallel (ref.11) and extended (ref.12) model atmosphere flux distributions as well as blackbodies have been considered in the models used to test these relations. This relation will break down when a significant fraction of the observed nebular volume is in higher stages of ionization. The application of this "ratio" method to the observations is presented in Table II.

An alternative method of deriving C/N ratios is to treat the transitions responsible for the dominant UV emission lines CIII] λ1909 Å, CIV λ1549 Å, NIII] λ1487 Å and NV] λ1240 Å as simple two-level atomic systems, collisionally populated at specific electron temperatures. Computational models in conjunction with optical observations may be developed to derive an average electron temperature, t_{ion}, weighted by the ionic abundances of each ion and the electron density integrated over the nebular volume. This differs little from classical approaches to deriving elemental abundances from emission line intensities, but the constraint on thermal equilibrium is addressed. The t_{ion} may be applied in conjunction with observed UV line intensities to find the absolute ionic abundances directly. Examples of temperature distributions for NGC 2440 and NGC 2165 are presented elsewhere (ref. 13) and in Table III. Application of this method to our UV data toward deriving elemental C and N abundances is presented in Table II.

Finally, detailed computations for a given nebula may be undertaken. Models of NGC 2440 and NGC 2165 are given elsewhere in this volume (ref. 13). The results of a calculation for IC 2003 are displayed in Table III, and C/N abundance ratios and adopted abundances for all preliminary models are presented in Table II. Simple blackbodies and constant density distributions have limitations; but one is at least able to reach a terminal state. We find that under these limitations, further variations in relative C and N abundances unfavorably redistribute the emergent intensities in these lines and lead to less acceptable thermal structures. More realistic density variations could be addressed by radio synthesis via the VLA, or, for objects of greater angular extent, optical monochromatic images.

The three methods we have used to address the problem of C/N abundance variations, when applied to the same set of UV and optical observations and analyzed via the same atomic data, are seen to yield reasonably consistent results. While the absolute abundances derived from UV lines may be regarded with some reserve because of their extreme sensitivity to the assumed electron temperature, we would emphasize that the ratios of UV lines are much less sensitive. The difference between NGC 2440 and Hu 1-2 on the one hand, and IC 2003 and IC 2165 on the other, must surely reflect real composition variations.

REFERENCES

1. Peimbert, M.: New Insights Into the Physical State of Gaseous Nebulae. The Universe at Ultraviolet Wavelengths. The First Two Years of IUE. NASA CP-2171, 1980: this compilation.

2. Torres-Peimbert, S.; and Peimbert, M.: Photoelectric Photometry and Physical Conditions of Planetary Nebulae. Rev. Mexicana Astr. Astrofisica, Vol. 2, 1977, pp. 181-207.

3. Bohlin, R.C.; Holm, A.V.; Savage, B.D.; Snijders, M.A.J.; and Sparks, W.: Photometric Calibration of the International Ultraviolet Explorer. NASA X-681-79-19, 1979, pp. 1-27.

4. Seaton, M.J.: Interstellar Extinction in the UV. M.N.R.A.S., Vol. 187, 1979, pp. 73P-76P.

5. Butler, S.E.; Heil, T.G.; and Dalgarno, A.: Charge Transfer of Multiply-Charged Ions with Hydrogen and Helium: Quantal Calculations. Center for Astrophysics Preprint Series, no. 1281, 1980.

6. Butler, S.E.; and Dalgarno, A.: Charge Transfer of Multiply-Charged Ions with Hydrogen and Helium: Landau-Zener Calculations. Center for Astrophysics Preprint Series, no. 1281, 1980.

7. Harrington, J.P.; Lutz, J.H.; and Seaton, M.J.: Ultraviolet Spectra of Planetary Nebulae - II. NGC 7662. M.N.R.A.S., 1980, to be submitted.

8. Jackson, A.R.G.: Excitation of CII] λ 2326, OIII] λ1664 and Other Semi-Forbidden Lines in Quasars. M.N.R.A.S., Vol. 165, 1973, pp. 53-60.

9. Dufton, P.L.: Berrington, K.A.; Burke, P.G.; and Kingston, A.E.: The Interpretation of CIII and OV Emission Line Ratios in the Sun. Astr. Ap., 1978, Vol. 62, pp. 111-120.

10. Shields, G.A.: The Abundance of Nitrogen in QSOs. Ap.J., Vol. 204, 1976, pp. 330-336.

11. Hummer, D.G.; and Mihalas, D.: Model Atmospheres for the Central Stars of Planetary Nebulae. M.N.R.A.S., Vol. 147, 1970, pp. 339-354.

12. Cassinelli, J.P.: The Continuous Energy Distribution from Stars with Hot Extended Atmospheres. Ap. Letters, Vol. 8, 1971, pp. 105-109.

13. Harrington, J.P.; and Marionni, P.A.: Silicon and Magnesium Abundances in Planetary Nebulae. The Universe at Ultraviolet Wavelengths. The First Two Years of IUE. NASA CP-2171, 1980: this compilation.

14. Barker, T.: Spectrophotometry of Planetary Nebulae II. Chemical Abundances. Ap.J., Vol. 220, 1978, pp. 193-209.

15. Aller, L.H.; and Czyzak, S.J.: Spectrophotometric Studies of Gaseous Nebulae. XVI. The Moderately High Excitation Planetaries IC 2003, NGC 2022, and CD-23°12238, Ap.J., Vol. 160, 1970, pp. 929-938.

TABLE I. - OBSERVED UV EMISSION LINE INTENSITIES #
(corrected for interstellar extinction)

λ Å	Ion	f(λ)*	IC 351[a]	IC 2003[b]	NGC 2022[c,†]	IC 2165[d]	NGC 2440[e]	Hu 1-2[f]	IC 5217[g]
1240	NV	1.640	--	--	--	45.	100.	190.	38.:
1335	CII	1.417	--	--	--	--	8.4:	--	6.:
1400	OIV],SiIV	1.307	--	17.	110.:	39.	54.	52.	--
1487	NIV]	1.229	9.:	17.:	--	47.	220.	200.	14.:
1549	CIV	1.183	190.	320.	820.	970.	500.	540.	54.
1640	HeII	1.136	180.	330.	610.	260.	350.	460.	54.
1664	OIII]	1.128	--	20.	--	33.	42.	39.	26.
1751	NIII]	1.119	18.	16.	--	37.	170.	180.	9.5:
1909	CIII]	1.229	200.	320.	410.	850.	750.	398.	110.
1909	CIII]	1.229	--	350.	410.	830.	757.	560.:	140.:
2328	CII]	1.348	--	5.:	--	81.	97.	63.	40.:
2422	[NeIV]	1.120	--	45.	210.	110.	160.	150.	7.5:
2471	[OII]	1.023	--	--	--	--	17.	--	--
2512	HeII	0.954	--	--	--	12.	19.	--	--
2734	HeII	0.700	--	13.:	--	11.	17.	21.	4.1:
2784	[MgV]	0.659	--	--	--	5.2	8.3	17.	--
2800	MgII	0.646	--	--	--	6.4	3.9	--	1.7:
2837	OIII	0.619	--	9.:	--	9.1	7.5	6.7	2.7
3048	OIII	0.494	--	71.	30.:	8.5	13.7	30.	6.3
3204	HeII	0.424	--	--	17.:	79.	86.	37.	12.
C			0.35	0.37	0.60	0.64	0.4	0.70	0.55
F(Hβ) (10^{-12} ergs cm^{-2} s^{-1})			3.8	6.31	6.6	12.6	0.45 x 33.1	6.3	6.92

* ref. 4; † High Background; (:) uncertain; # Relative to $I_c(H\beta)$ = 100.
a) SWP 6264, 6259; b) SWP 7260, 7261, LWR 6255; c) SWP 6260, 6261, LWR 5431; d) SWP 7259, 6262, LWR 5432; e) SWP 7262, 7264, LWR 6256, 6258; f) SWP 7258, LWR 6254; g) SWP 6257, 7257, LWR 5429.

TABLE II. - ABSOLUTE AND RELATIVE ELEMENTAL ABUNDANCES

	Method	IC 351	IC 2003	IC 2165	NGC 2440	Hu 1-2
C/N	CIII]/NIII] Ratio	1.7	3.0	3.4	0.66	0.33
C/N	CIV/NIV] Ratio	3.2:	2.8:	3.1	0.34	0.41
C/N	t_{ion}	--	3.6	3.7	0.62	0.70
C/N	Model	--	4.0	4.0	0.60	--
C/H	t_{ion}	--	3.2(-4)	2.7(-4)	2.3(-4)	--
C/H	Model	--	4.0(-4)	2.7(-4)	2.9(-4)	--
N/H	t_{ion}	--	8.9(-5)	7.3(-5)	3.7(-4)	--
N/H	Model	--	1.0(-4)	6.7(-5)	4.8(-4)	--
O/H	Model	--	3.3(-4)	1.7(-4)	3.6(-4)	--

TABLE III. - OBSERVATIONAL FLUXES AND MODEL PREDICTIONS FOR IC 2003

λ Å	Ion	f(λ)*	t_{ion} (10^4 K)	$I_c(λ)$	Model Fluxes
1400	OIV]	1.307	1.36	17.[a]	11.4
	SiIV]		1.27		4.1
1487	NIV]	1.229	1.30	17.:[a]	19.
1549	CIV	1.183	1.40	310.[b]	443.
1640	HeII	1.136	1.34	330.[b]	344.
1664	OIII]	1.128	1.21	20[a],24[b]	24.
1751	NIII]	1.119	1.22	16[a],21[b]	19.
1909	CIII]	1.229	1.22	321.[b]	464.
1909	CIII]	1.229	1.22	350.[c]	464.
2328	CII]	1.348	1.19	5.[c]	16.
2424	[NeIV]	1.120	1.32	45.[c]	48.
2734	HeII	0.700	1.34	13.:[c]	11.
3726,29	[OII]	0.315	1.18	34.[d]	21.
3869	[NeIII]	0.270	1.20	91.[d]	74.
4267	CII	0.155	1.22	1.5[e]	0.25
4363	[OIII]	0.130	1.21	16.:[d]	17.
4471	HeI	0.105	1.20	3.9[d]	4.1
4686	HeII	0.045	1.34	53.[d]	50.
4861	HI	0.000	1.24	100.	100.
5007	[OIII]	-0.300	1.21	1083.[d]	1250.
5755	[NII]	-0.190	1.18	0.82[d]	0.55
5876	HeI	-0.210	1.20	10.6[d]	11.0
6306	[OI]	-0.285	1.16	3.6[d]	4.3
	[SIII]		1.21		
6583	[NII]	-0.340	1.18	17.[d]	17.
7325	[OII]	-0.435	1.18	3.6[d]	3.9

* refs. 4,2; (:) uncertain.
a) SWP 7261-90m; b) SWP 7260-30m; c) LWR 6255-45m; d) ref. 14; e) ref. 15.