THE HIGH-EXCITATION PLANETARY NEBULAE

NGC 3918 AND IC 2448

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ABSTRACT

We present IUE observations of NGC 3918 and IC 2448. Combining these observations with data in the optical range and computed model structures we derive the chemical composition for these objects. For NGC 3918 we obtain log C= -3.02, log N= -3.61 and log O= -3.22; while for IC 2448 we obtain log C= -3.44, log N= -3.81 and log O= -3.54.

INTRODUCTION

These planetary nebulae are ideally suited for observations with IUE since they have high surface brightness and small angular size.

They have been observed in the visual range by Torres-Peimbert and Peimbert (ref. 1). They derive for NGC 3918 N(He)/N(H)= .112, log N= -3.72, log O= -3.10 and log Ne= -3.84 and for IC 2448 N(He)/N(H)= .111, log N= -4.49, log O= -3.39 and log Ne= -4.08 under the assumption of t^2= 0.035.

OBSERVATIONS

For NGC 3918 we have the following large aperture exposures: SWP 1906 (7 min), SWP 3191 (20 min), SWP 3192 (10 min), LWR 1767 (12 min), LWR 2753 (20 min), LWR 2754 (10 min), LWR 2809 (6 min) and the following small aperture exposures: SWP 1906 (20 min), SWP 3216 (15 min), LWR 2809 (12 min). For IC 2448 we only have available the large aperture exposures: SWP 3194 (30 min) and LWR 2756 (30 min).

We have applied the mean calibration correction (ref. 2) to the observed fluxes to derive absolute fluxes. We present in Figure 1 composite large aperture spectra of these objects.

In Table II we present the derived intrinsic fluxes for all emission lines, I(λ), the observed fluxes F(1641) and F(Hβ) and the reddening correction at Hβ, C(Hβ). To obtain the intrinsic fluxes we have used the relation $\log I(\lambda)/I(H\beta)= \log F(\lambda)/F(H\beta)+C(H\beta)f(\lambda)$. We have derived the reddening correction by assuming that: 1) the fluxes relative to Hβ in the visual range are the same for the observed region as for the entire nebula, 2) the reddening law, f(λ), behaves as the expression given by Seaton (ref. 3) and 3) the intensity ratio of the HeII recombination lines I(1641)/I(4686) is 6.6 (ref. 4).

The internal errors in the measurements, as estimated from the different exposures, are ≤15% for NGC 3918, and presumably similar for IC 2448. For IC 2448 the listed flux for λ1549 is only an upper limit, since the line was saturated.

MODEL IONIZATION STRUCTURES

We have computed model ionization structures that will be described in detail elsewhere. The models predict line intensities for C, N, O, Ne, Mg, Si and S. For comparison we present a few representative models in Table III.

To try to fit NGC 3918 we computed models for an exciting star of $T_* =$ 150,000 (from ref. 5). We have tried unsuccessfully to adjust both I(5007) and I(1909) simultaneously by varying density distribution and chemical abundances. The resonant lines of CIV, NV and MgII appear systematically too bright in our models. This effect has been noted by other authors (refs. 6 and 7) who explain it by dust absorption. In order to adjust the lines of low ionization, it is necessary to assume that the nebula is density bounded.

For our models of IC 2448 we have adopted an exciting star of $T_* = 125{,}000$. We encounter the same problems in our attempt to adjust I(5007) and I(1909) and have found it necessary to assume a density bound nebula to improve the fit for ions of low stages of ionization. For this object we do not have observations of the faint lines and thus have less restrictions for our model.

IONIC ABUNDANCES

For NGC 3918 from the ratio I(1666)/I(5007) of O^{++} we obtain the same temperature as from I(4363)/I(5007). We also are able to derive a temperature of 13800 °K from the I(1602)/I(2423) ratio of Ne^{+3}; however none of our models predict the temperature of the highly ionized region to be drastically different for the O^{++} region.

To derive ionic abundances we adopted an empirical scheme of dividing the nebulae in three regions: those of low, medium and high stages of ionization. For elements in low stages of ionization we have assumed the observed T(NII) to be applicable. Our models do not predict such a sharp decrease in temperature in the outer shells and thus the derived abundances are probably overestimated, but these ions are not dominant in either nebula. For the elements in the intermediate stages we have used T(OIII) as derived from observations (ref. 1); and for the higher stages of ionization we have used temperatures 600 K higher than T(OIII), since our models predict this temperature variation. We have assumed $t^2 = 0.0$ for our derivation of the ionic abundances. The results are listed in Table II. For both objects, the O^{++} abundances derived from λ5007 and λ1666 are in excellent agreement and give us confidence in the adopted reddening.

All ionic abundances derived from ultraviolet lines are highly dependent on temperatures, and we typically expect errors of ±0.10 dex in the ionic determinations for errors of ±300 °K.

DISCUSSION

We have derived total abundances from the ionic ones. In the case of NGC 3918, for oxygen and nitrogen we have added all the ionic abundances in a straightforward way. For carbon we have taken into account only I(1909) and from comparison with our models we have adopted a ratio of relative volumes of carbon to oxygen $x(C^{++})/x(O^{++}) = 0.74$. In the case of IC 2448 we have added O^{+} and O^{++}, and have corrected by a factor $i_{cf} = He/(He^{+})$, which is in agreement with our models. For nitrogen we have adopted an intermediate value between those derived from the comparison of our models and N^{+2} and N^{+4}. For carbon we have assumed that the resonance line I(1549) has been depleted by a factor of 2 due to dust and have added all other ions. Comparison with our models shows that the carbon abundance is probably underestimated. The total abundances relative to hydrogen in NGC 3918 are log O= -3.22, log N= -3.61 and log C= -3.02; in IC 2448 are log O= -3.54, log N= -3.81 and log C= -3.44.

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TABLE I .- UNREDDENED FLUXES RELATIVE TO Hβ a)

λ	Ion	I(λ)/I(Hβ)	
		NGC 3918	IC 2448
1215	HI	<-0.51	-0.41
1240	NV	-0.54	-0.25
1401	OIV] +SIV+SiIV	-0.46	....
1488	NIV]	-0.43	≤1.00
1549	CIV	+0.64	+0.37
1575	[NeV]	....	-1.01
1602	[NeIV]	-1.17	....
1641	HeII	+0.43	+0.40
1666	OIII]	-0.55	-0.63
1749	NIII]	-0.63	≤-0.82
1909	CIII]	+0.69	≥+0.58
2298	....	....	-0.75
2326	CII] + [OIII]	-0.38	-0.99
2386	NeII	-1.57	....
2423	[NeIV]	+0.11	-0.63
2471	[OII]	-0.98	....
2512	HeII	-1.33	....
2734	HeII	-1.03	-1.12
2800	MgII	<-1.34	<-1.10
2837	OIII	-0.98	-1.17
3023+47	OIII	-0.73	-1.06
3133	OIII	-0.04	-0.26
3204	HeII	-0.66	-0.83
log F(1641)	....	-10.05	-10.69
log F(Hβ)	....	-10.03	-10.84
C(Hβ)	....	+ 0.40	+ 0.22

a) Log I(λ)/I(Hβ).

TABLE II.- TEMPERATURE, DENSITY AND IONIC ABUNDANCES a)

		NGC 3918	IC 2448
T(NII)		8900	9400 b)
T(OIII)		12100	12500
T(NeIV)		13800	13100 b)
N_e(SII)		9000	12000
N_e(rms)		4600	1700
C^{+}	2326	-3.84	-4.62
C^{++}	1909	-3.52	≥-3.72
C^{+3}	1549	-3.82	-4.20
N^{+}	6584	-4.68	-6.17
N^{++}	1749	-4.11	≤4.40
N^{+3}	1488	-4.00	≤4.71
N^{+4}	1240	-4.21	-4.05
O^{+}	3727	-4.06	-5.08
O^{++}	5007	-3.54	-3.71
O^{++}	1666	-3.55	-3.72
O^{+3}	1401	-3.46:	....
Ne^{++}	3869	-4.28	-4.38
Ne^{+3}	2423	-4.09	-4.90
S^{+}	6717+31	-6.30	-7.51:
S^{++}	6311	-4.99	....
S^{+3}	1393	-4.50:	....
Ar^{++}	7136	-5.97	-6.51:

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a) Given in log $N(X^{+m})/N(H^{+})$.

b) Adopted.

TABLE III.- COMPARISON OF MODELS WITH OBSERVATIONS.
LINE INTENSITIES, TEMPERATURES AND RELATIVE VOLUMES. a)

		NGC 3918				IC 2448		
		Obs.	N1	N2	N3	Obs.	I1	I2
HeI	4471	3.8	3.1	3.0	3.1	4.0	3.3	3.0
HeII	4686	44.0	41.8	44.0	43.1	38.0	34.7	41.2
CII]	2326	41.0	122.0	34.7	133.0	10.0	9.1	12.0
CIII]	1909	490.0	1070.0	567.0	1170.0	$\geq$380.0	411.0	460.0
CIV	1549	450.0	2540.0	1950.0	1970.0	230.0	1010.0	885.0
[NI]	5200	0.5	0.0	0.0	0.1	.....	0.0	0.0
[NII]	6584	66.0	45.0	24.9	60.7	2.5	10.5	14.2
NIII]	1749	23.0	56.6	60.1	59.4	$\leq$ 15.0	51.5	57.3
NIV]	1488	37.0	71.0	112.0	54.0	.....	65.7	55.2
NV	1240	29.0	174.0	296.0	104.0	56.0	8.3	6.1
[OI]	6300	3.8	13.0	4.7	15.2	.....	0.0	0.1
[OII]	3727	61.0	277.0	222.0	349.0	6.3	28.3	39.9
[OIII]	5007	1570.0	1590.0	2210.0	1630.0	1060.0	1400.0	1290.0
OIV]	1401	<35.0	18.8	39.9	16.4	.....	40.5	14.2
$T(C^+)$		....	12600	12830	11890	....	13240	13260
$T(C^{++})$		....	12680	12940	12050	....	13340	13330
$T(C^{+3})$		....	13530	14180	12930	....	13540	13480
$T(N^+)$		8900	12590	12820	11900	....	13250	13270
$T(O^+)$		....	12620	12830	11840	....	13110	13130
$T(O^{++})$		12100	12700	12970	12100	12500	13250	13260
$x(C^+)$		....	0.035	0.017	0.041	....	0.008	0.010
$x(C^{++})$		....	0.363	0.329	0.441	....	0.383	0.432
$x(C^{+3})$		....	0.386	0.415	0.340	....	0.574	0.525
$x(N^+)$		....	0.015	0.008	0.018	....	0.005	0.007
$x(N^{++})$		....	0.438	0.395	0.520	....	0.481	0.541
$x(N^{+3})$		....	0.295	0.318	0.255	....	0.477	0.420
$x(O^+)$		.155	0.111	0.066	0.137	.030	0.018	0.020
$x(O^{++})$		.513	0.447	0.461	0.421	.676	0.653	0.602
$x(O^{+3})$		....	0.195	0.213	0.228	....	0.300	0.349
N_H (cm^{-3})		4600	5000	5000	5000	1700	4000	2000
ε b)		.26	1.0	1.0	0.5	.02	1.0	1.0
log O/H		-3.22	-3.30	-3.20	-3.20	-3.54	-3.54	-3.54
log C/O		+0.20	+0.40	0.00	+0.40	+0.10	+0.10	+0.10
log N/O		-0.39	-0.20	-0.30	-0.20	-0.27	-0.16	-0.16
R_i (pc) c)		....	.001	.001	.001	....	.001	.107
$R_{\odot}$ (pc)		.05	.068	.067	.084	.13	.074	.116
R_* ($R_{\odot}$) d)		....	0.10	0.10	0.10	....	0.10	0.10
T_* (10^3°K)		....	150	150	150	....	125	125

a) Relative to Hβ, where I(Hβ)= 100 ,
$T(X^{+m}) \equiv \int N_e N(X^{+m})dV / \int N_e N(X)dV$.
$x(X^{+m}) \equiv \int N_e N(X^{+m})dV / \int N_e N(X)dV$.

b) ε is the filling factor.

c) R_i, R_o are inner and outer radii.

d) R_*, T_* are central stars parameters.