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The Ionization Structure of Planetary Nebulae

IV. NGC 6853

TIMOTHY BARKER[1,2]

Department of Physics and Astronomy

Wheaton College

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[1]Visiting Astronomer, Kitt Peak National Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract to the National Science Foundation.

[2]Guest observer with the International Ultraviolet Explorer satellite, NASA grant NSG 5376 (Supplement No. 2).

ABSTRACT

Spectrophotometric observations of emission line intensities have been made in seven positions in the planetary nebula NGC 6853; for five of the positions, coverage is across the entire spectral range 1400Å to 9600Å. Standard equations used to correct for the existence of elements in other than the optically-observable ionization stages give results over a wide range of ionization that are generally consistent and in agreement with abundances calculated using ultraviolet lines. As in the previous studies in this series, the λ4267 CII line implies a C^{2+} abundance that is higher than that determined from UV lines. Although this effect is much smaller than in NGC 6720 and NGC 7009, it is again largest nearest the central star, giving more evidence that the excitation mechanism for the λ4267 line is not understood. The logarithmic abundances (relative to H=12.00) are: He=11.04, O=8.92, N=8.48, Ne=8.43, C=8.88, Ar=6.52, and S=6.77. The abundances of the elements other than He average nearly 50% higher than those measured by Pottasch, Gilra, and Wesselius (1982), primarily because of a difference in measured electron temperatures. There is excellent agreement with the abundances determined by Hawley and Miller (1978), except that the S abundance is about a sixth theirs. This low (~1/3 solar) S abundance is quite surprising and should be investigated further. As in NGC 6720, the lighter elements have abundances that are significantly greater than solar, implying that there may have been mixing of processed material in the progenitors of both nebulae.

I. INTRODUCTION

In the three previous papers in this series (Barker 1980, Barker 1982, and Barker 1983; hereafter, Papers I, II, and III, respectively), optical and ultraviolet observations of different positions in the planetary nebulae NGC 6720 and NGC 7009 were discussed. The idea behind these studies is to measure optical and UV emission line intensities in the same nebular positions using similar entrance apertures. Since the ionization frequently changes dramatically with position in an extended nebula, this procedure is almost essential in order to make a meaningful comparison between UV and optical measurements. The ultimate goals are: 1) to observe elements in more stages of ionization than is possible from optical spectra alone; this provides a check on optical ionization correction procedures, which are still useful for nebulae that are too faint to be observed with the International Ultraviolet Explorer (IUE) Satellite, 2) by averaging measurements made in different parts of the nebula, to get particularly accurate total abundances so that small differences between nebulae will become apparent; such differences can be sensitive tests of theoretical predictions regarding CNO processing and mixing in the progenitors of planetary nebulae, and 3) to further investigate the discrepancies found in Papers II and III between optical and UV measurements of C abundances in nebulae; these discrepancies need to be understood before we can have confidence in optical measurements of that important element.

I chose NGC 6853 as the next planetary in this series primarily because the extensive optical study by Hawley and Miller (1978; hereafter HM) showed that it has a wide range of ionization. In addition, its large angular size and high declination mean that observational difficulties such as atmospheric refraction and errors in telescope pointing are relatively minor. HM found a rather high N abundance in NGC 6853, suggesting that there was substantial mixing in the planetary progenitor, and I thought that it would therefore be interesting to measure the C abundance in the nebula. Finally, although some UV measurements of NGC 6853 have been made by Pottasch, Gilra, and Wesselius (1982; hereafter PGW), the authors point out that the observations were not made in the same positions as optical ones; because of the wide variation in ionization in NGC 6853, I felt that it was important to do this.

II. OBSERVATIONS

a) Optical Observations

Preliminary measurements were made with the Intensified Reticon Scanner (IRS) on the No. 1 90 cm telescope at Kitt Peak National Observatory in 1981 July. The two entrance apertures were 13.5" in diameter, (the closest size to the IUE aperture available) separated by 61", and oriented east-west. Since this separation is only about a sixth of the diameter of the nebula, it was necessary to use the "nebular" mode in which the nebula is observed through both apertures simultaneously. Within these restrictions, positions 2-6 were selected as giving as wide a range of ionization as possible. The offsets for these positions are given in Table 1; increasing position number corresponds to increasing angular distance from the central star. Although the offsets are given with respect to the central star, for convenience the actual offsetting was done with respect to a much brighter star measured to be 155" west and 21" south of it. (Positions 1, 6, and 7 correspond approximately to HM's Positions 2, 6, and 5, respectively, although an exact comparison is impossible because they used different entrance apertures and did not list precise offsets.) Further observations were made with the same equipment in 1982 July and 1983 June; spectra were obtained with three grating settings which covered the range 3700-7200Å. Unfortunately, these observations were affected significantly by scattered light within the IRS, an effect which amounts to about 10% between the two channels. (This effect is not immediately apparent because emission lines in the scattered light are smeared out to about ten times their normal width and merge with the continuum.) The scattering is not serious when objects are observed in the normal beam switching mode, since the signal from the scattered light is removed when sky subtraction is performed. It can be a significant source of error for objects like NGC 6853, however, when positions with widely different surface brightnesses and emission line intensities are observed simultaneously.

Because of this problem, I decided to make further observations in 1983 July, this time using the 2.1 m telescope and the Intensified Image Dissector Scanner (IIDS), where the percentage of scattered light is acceptably low (less than 1%). Unless otherwise noted, all the optical observations discussed here were made with this equipment. Since UV and near infrared observations (see below) of Positions 2-6 had already been made, the same positions were observed with the IIDS, but an additional position close to the central star was added. Since the separation between the IIDS apertures (99") is larger than for the IRS, but still much smaller than the nebula, it was again necessary to observe each position in the nebular mode, but with one aperture on a position (deliberately chosen to be faint to cut down on scattered light) that was not analyzed further. The apertures used were 7.6" X 13.1" rectangles (the largest available), oriented east-west. Spectra were obtained with three grating settings covering the range 3700-7200Å, 3300-5500Å, and 5200-7200Å, with a spectral resolution as good as about 10Å (FWHM) for the latter two settings. Finally, intensities of the near infrared λ9069 and λ9532 [S III] lines relative to H_α were measured in 1982 July using the Harvard sequential scanner (see Paper I) using a 15.5" diameter entrance aperture.

b) Correction for Interstellar Reddening

The amount of interstellar reddening can be estimated by comparing the observed and theoretical intensities of the Balmer recombination lines. This technique is especially sensitive to the measured intensity of H_α, however, and the average measured H_α/H_β intensity ratio for the seven positions, 3.53, is significantly higher than the value of 3.35 measured by HM, who remarked that even this value is higher than the ratio 2.90 determined from photoelectric scanner observations by Miller (1973). Further evidence for a systematic error in this ratio is that three planetaries observed on the same night as NGC 6853 had H_α/H_β ratios averaging 13% higher than found by Barker (1978). In the end, this 13% correction was applied to H_α intensities measured in all seven positions; the average H_α/H_β ratio is then 3.07. The resulting intensities of H_α, H_β, H_γ, and H_δ are then consistent with there being a small but approximately constant amount of interstellar reddening at all seven positions. A reddening parameter, c, of 0.17 was adopted, and the intensities listed in Table 2 have all been calculated by multiplying the observed intensities by $10^{cf(\lambda)}$; the values of $f(\lambda)$ are also listed in Table 2. The average of the intensities of each of the six observed Balmer lines agrees with the theoretical (Brocklehurst, 1971) intensities to within about 5%, so the adopted value of c cannot be greatly in error. It is also close to the value of 0.14 estimated by PGW.

c) Ultraviolet Observations

Ultraviolet observations were made of Positions 2, 3, 4, 6, and 7 with the 21" X 9" oval entrance of the IUE satellite in 1982 July and December. The aperture position angle was approximately 82°, close to the east-west orientation used in the IIDS observations. Although the IUE aperture has about twice the area of the IIDS one, both are very small compared to the size of the nebula, and the difference in sizes is not likely to cause any large (> 10%) systematic errors in the relative line intensities. The IUE positions are judged to be within 2-3" of the optical ones. The IUE exposure numbers (all were at low dispersion) and exposure times are listed in Table 1. The data were reduced in 1983 January at the IUE Regional Data Analysis Facility at Goddard Spaceflight Center using the 1980 May calibration (the same calibration used in Papers II and III).

Since no emission lines could be observed in common, some other method must be used to put the UV and optical observations on the same intensity scale. One method is to compare absolute fluxes. Unfortunately, the IIDS observations were not made under sufficiently photometric conditions, so it was necessary to use the fluxes measured with the 13.5" entrance on the IRS, which did agree quite well (~10% or better) on three different nights. The measured H_β fluxes are listed in Table 1. A check on this method is that I(λ1640) should equal 6.25 I(λ4686) (Seaton 1978); the predicted and observed <u>fluxes</u> (uncorrected for interstellar reddening) are compared in Table 1. These values do agree remarkably well, considering the different apertures used and the uncertainties in their sizes and in the value of the reddening parameter, c. For Positions 2, 3, and 4, the UV intensities were put on the same scale as the optical ones by requiring that I(λ1640)=6.25 I(λ4686), although using absolute fluxes would have given a similar result. The validity of this method is also supported by the generally good agreement between the UV- and optically-measured O^{2+} abundances (see § IV). Unfortunately, neither UV O III] nor any He II emission was observed in Positions 6 and 7. Optical and UV intensities could therefore be combined only by using absolute fluxes. Although this method is apparently reliable for the inner positions, it is less so for positions near the edge of the nebula; the different aperture sizes and possible errors in offsetting are far more critical here. As a result, the UV intensities relative to the optical ones could be systematically in error by as much as a factor of two for Positions 6 and 7.

d) Observational Errors

Aside from possible systematic errors discussed above, the ultraviolet intensities are judged to be accurate to within a factor of two for the faintest lines (less than 20% of H_β), to ~40% for those of intermediate intensity (between 20% and 80% of H_β) and to ~20% for the strongest lines. While these errors may seem high, errors in electron temperatures generally have a greater effect on the accuracy of the abundances (discussed in § III) than do those in line intensities.

Based on a comparison between the IRS and IIDS results, and between IIDS measurements made on different nights, the intensities of the strongest optical lines are judged to be accurate to ~10%, those weaker than half of H_β to be accurate to ~20%, and even the faintest lines to be accurate to ~30%. The near infrared [S III] intensities, however, which were measured with a sequential scanner, are good to only ~50%. In addition, the intensity of the λ9532 line was affected by terrestrial H_2O absorption as discussed in Paper III and so was not used further here. Finally, intensities in Table II labeled with colons are uncertain by approximately a factor of two.

III. TEMPERATURES, DENSITIES, AND IONIC ABUNDANCES

Calculations of the electron temperature (T_e), electron density (N_e), and ionic abundances in the different positions were made using the same methods and atomic constants as in Paper III. The results for N_e and T_e for different positions is not much larger than would be expected from observational errors, and so the average value given in Table 3 was adopted. It is somewhat lower than found by HM because more recent collision strengths for S^+ were used, but agrees well with the value of 200 cm^{-3} used by PGW. The uncertainty in N_e is large, but calculated abundances are very insensitive to N_e at such densities.

There are much larger variations in T_e. Note first of all the increase in the calculated value of T_e (S^+) with decreasing position number. As discussed in Paper I, this is probably at least partly due to the presence of several faint blended lines near 4072Å. For low position numbers, which correspond to higher ionization positions nearer the central star, S^+ emission is weaker and so contamination from these lines is relatively more important and leads to an overestimate of T_e; only the values of $T_e(S^+)$ for Positions 4-7 are therefore judged to be useable. Note second of all that T_e measured from the singly-ionized species S^+ and N^+ in most positions is lower than T_e measured from the doubly-ionized species S^{2+} and O^{2+}. Because this appears to be a systematic difference that is significantly larger than can be explained by observational errors, a two-temperature scheme was used for the abundance calculations: T_e (low ion.) was used for He^+, O^+, N^+, C^+, S^+, and T_e (high ion.) was used for the other (more highly-ionized) species. (HM found a similar effect and used a similar method, but PGW adopted a constant value of 12,000 K for T_e; the latter procedure is not supported by the evidence listed in Table 3.)

The ionic abundances calculated using the values of T_e and N_e given at the bottom of Table 3 are listed in Table 4. It should be emphasized that these temperatures may not be suitable for elements in the highest ionization stages, such as O^{3+}, N^{3+}, Ne^{3+}, C^{3+}, and Ar^{3+}. As discussed in Papers II and III, there is evidence in other planetaries that these ions exist in regions of higher T_e than do the others. (Unfortunately, the optical [Ne IV] lines were too faint to detect, so it was not possible to estimate T_e for Ne^{+3}.) The abundances calculated for these ions should therefore be regarded as upper limits.

IV. TOTAL ABUNDANCES

Total abundances may be found by simply adding together all the ionic abundances or by using only optically-measured ionic abundances and correcting for the presence of elements in optically-unobservable stages of ionization. The former procedure would appear to be the more reliable, but it is subject to the uncertainties in electron temperatures described above. In addition, even if T_e can be measured in high-ionization regions, relatively small errors in it will result in very large errors in abundances determined from UV lines. At the very least, however, this method serves as a valuable check on the second procedure, which is often the only one possible when no UV data are available. Both methods were used whenever possible, and the results are summarized in Table 4. The abundances labeled "Optical" have been calculated by multiplying the optically-measured ionic abundanes by the listed values of i_{cf}, the ionization correction factor; the equations used to calculate i_{cf} values are given in Paper III. The abundances labeled "UV + Optical" are simple sums of all the ionic abundances.

Except for He, the errors assigned to the abundances are based on the errors estimated for T_e, N_e, and the line intensities. In most cases, the errors in T_e dominate over other sources.

a) Helium

The average He^+/H^+ abundance for each position given in Table 4 is based on a 1:3:1 weighting of I(λ4471), I(λ5876), and I(λ6678), respectively; the total He abundance is the simple sum of the He^+ and He^{++} abundances. Note that the calculated He abundance is essentially constant, suggesting that little if any He^0 exists in the low ionization regions. Using Equation (1b) from Paper III would have lead to a much (factor of 2-3) higher calculated He abundance in the outer positions than the inner ones; as discussed in Paper III, the applicability of this equation is highly suspect.

b) Oxygen

The UV and optical measurements of the O^{2+} abundance are in reasonable agreement, considering the uncertainties discussed above. The optically-measured O abundance is even more constant than found by HM, and over a wider range of values of i_{cf}. Similarly, the Optical and UV + Optical measurements agree quite well, although, as discussed in Papers II and III, the O^{3+} abundance may be overestimated because the electron temperature for this region is likely to be higher than the value assumed in the abundance calculation. In summary, the standard procedure (Equation 2 in Paper III) for calculating O abundances from optical measurements seems to work very well for NGC 6853.

c) Nitrogen

The above statement is also true for N; the optically-determined N abundances are very constant over a wide range of ionization, again even more constant than found by HM. Similarly, the optical and UV measurements agree extremely (perhaps fortuitously) well, except for Position 6. The discrepancy for this position could be explained in part by errors in T_e and I(λ1747), but probably the most important factor is the uncertainty associated with combining UV and optical data for this position (see § IIc). It is possible that the UV intensities relative to H_β have been overestimated by a factor of two or even three in this position.

d) Neon

The Ne abundance has been calculated using the Ne^{2+} abundance only. It is in reasonable agreement with that implied by the Ne^{3+} and Ne^{4+} abundances in Position 2, the one position where they were all measured. The abundances for Positions 6 and 7 are clearly overestimated because the different efficiencies of the O and Ne charge transfer reactions were not allowed for (see Paper I and references therein); HM found a similar result, although the theoretical explanation was not known at that time.

e) Carbon

A major motivation for this study was to further investigate the discrepancies found in Papers II and III between optical and UV measurements of the C^{2+} abundance. Note that there is a systematic discrepancy in NGC 6853 as well; in position 2, the C^{2+} abundance measured from the optical λ4267 line is about a factor of three higher than that found from the UV λ1906,1909 lines. The discrepancy is smaller than that found in NGC 6720 and NGC 7009, but it is still significantly larger than can be explained on the basis of errors in T_e or in line intensities. (Note that the C^{2+} abundances calculated from the UV lines would be even lower, and the discrepancy with the optical measurments even greater, if PWG's value of T_e = 12000K had been used for each position.) The abundances agree reasonably well for Positions 3, 4, 6, and 7, although a meaningful comparison is difficult in the latter two positions because of the difficulty of combining UV and optical observations there. It is unfortunate that no UV measurements were made in Position 1. Even so, the general trend (discrepancy decreasing with increasing distance from the central star) is consistent with that found in NGC 6720 and NGC 7009. The reason for this effect is unclear at the present time, although a number of possible explanations were discussed in Paper II. Because the problem probably lies in the interpretation of the intensity of the optical λ4267 line, only the UV lines were used to determine the total C abundance in each position.

Note that the calculated C abundance increases with increasing distance from the central star. Positions 6 and 7 should probably be disregarded because of the problem of combining UV and optical data for them. Even in Positions 2-4, however, there is some evidence for a systematic effect. It is possible that this is a result of absorption of the C IV λ1548,1550 resonance lines by dust, which is more serious in the inner part of the nebula where more of the C is in this stage of ionization. A similar effect was observed in NGC 6720.

Marionni and Harrington (1981) have suggested that the C/N abundance ratio may be estimated from UV observations alone using the formula $C/N \sim 0.15$ I(λ1906,1909)/I(λ1747). This expression gives C/N ratios of 4.2, 2.7, 3.3, 1.2, and 4.8 for Positions 2, 3, 4, 6, and 7, respectively, values which are reasonably consistent with the average values of 2.5 found for NGC 6853 (see Table 5).

f) Argon

The total Ar abundances are reasonably consistent, but the high abundance found in Position 7 is cause for some concern as it may be due to the inapplicability of the ionization correction procedure in regions of low ionization. The procedure advocated by French (1981) gives a similar result for this position, however.

It was shown in Papers I and II that the equation $Ar/H=1.5\ Ar^{2+}/H^{+}$ can give an approximate total Ar abundance; in faint planetaries where only the [Ar III] λ7135 line is observable, this equation can be quite useful. The equation gives Ar/H ratios of (1.8, 2.1, 2.3, 3.2, 3.3, 2.6, and 3.0) X 10^{-6} for Positions 1-7, respectively, in reasonable agreement with the average value of 3.3 X 10^{-6} given in Table 5.

g) Sulfur

The trend of decreasing calculated S abundance nearer the central star suggests that the total S abundance is underestimated in these regions of higher ionization. This trend is not apparent in NGC 6720 or NGC 7009, however. Using the ionization correction formula of Natta et al. (1980) would give an even greater systematic effect. It would clearly be very valuable to have infrared observations of the 10.5μm [S IV] line, especially in the inner regions.

DISCUSSION

The total abundances in the first row of Table 5 are weighted averages of measurements made in the different positions. Except for C, only optical measurements were used because they are less sensitive to errors in T_e. For the reasons discussed in § IV, only Positions 2-4 were used for C and only Positions 1-5 were used for Ne. Note that the errors listed in Table 5 come from comparisons between the different positions and do not allow for systematic errors such as those introduced by uncertainties in the atomic constants.

In general, the abundances are in reasonable agreement with previous determinations, but there are several important differences. First, the abundances of the elements other than He average nearly 50% higher than those found by PGW, despite the fact that the same atomic constants were used and that there was good agreement between their UV line intensities (which were averages of several positions, mostly near the center of the nebula) and those measured in Position 2. The discrepancy is apparently due to the different T_e's used; PGW assumed a mean value of 12,000 K, somewhat higher than the values used here.

This leads to a lower calculated total abundance. The exception is the N abundance, where PGW's value is 10% higher. This difference can be traced back to their λ1750 N III] line intensity, which is three times higher than that given here for Position 2. The abundances given in this paper should be more accurate than PGW's, however, because they are based on optical and UV observations made in the same nebular positions and because more information on T_e was available (see Table 3).

The agreement with HM's abundances is excellent. The one exception is S, which is six times lower than their measurement. Much of this discrepancy is a result of the different ionization correction procedure that they used, which has subsequently been shown to give S abundances that are systematically too high (see Paper I and references therein). Even so, the measured S abundance is rather low, especially in comparison to the other objects listed in Table 5. It is improbable that S or Ar are affected by nuclear processing in the relatively low-mass progenitors of planetary nebulae, and so it is hard to see how NGC 6853 could be so deficient in S, especially considering its normal Ar abundance. On the other hand, there is no obvious error in the S abundance determination. The λ9069 Å [S III] line intensities are rather uncertain (see § IId), but since the values of T_e determined by comparing them to the λ6312 Å line intensities are quite reasonable (see Table 3), they cannot be greatly in error. As discussed in § IVg, the correction for unobserved ionization stages is particularly uncertain for S. A check on this procedure can be made, however, by looking at the S^+/N^+ ratio which, because of the similarities of the ionization potentials of S and N, should be a good indication of the total S/N ratio. The S^+/N^+ ratios average 0.018±0.002 for the seven positions, very close to the S/N ratio of 0.020 from Table 5. In summary, it appears possible that S is somewhat underabundant in NGC 6853, although it is clearly important to make measurements of the S^{3+} abundance before deciding definitely.

It is interesting to compare the abundances in NGC 6853 with those found in other planetaries using the same techiques and with those in H II regions and the sun. Note that NGC 7009, H II regions, and the sun have very similar abundances, especially considering the differences in the measurement techniques. The He, Ar, and S abundances are also similar for all the objects listed in Table 5. The O, N, Ne, and C abundances, however, which might be expected to be enhanced by reactions in some pre-planetary progenitors, are significantly higher in both NGC 6853 and NGC 6720 than in the others. The possibility that NGC 6720 is slightly enriched was discussed in Paper III; the fact that NGC 6853 shows similar, but slightly greater, light element enhancements gives more support to this result.

VI. CONCLUSIONS

In summary, NGC 6853 is another planetary nebula for which total abundances can apparently be estimated from optical data alone. The one element for which this is not true is C; the λ4267 line again gives a higher abundance than the UV lines. Although this discrepancy is not as great as in NGC 6720 and NGC 7009, it again is greatest nearest the central star, implying that the λ4267 line may be excited by processes other than pure recombination. The abundances listed in the first row of Table 5 are believed to be improvements on earlier studies of NGC 6853, although the low observed S abundance should be further investigated. NGC 6853, like NGC 6720, shows significant enhancements of the lighter elements O, N, Ne, and C, implying that some mixing of processed material into the envelope of the pre-planetary progenitor occurred in both.

I hope to continue this series of studies by concentrating on high-excitation planetaries which have some He II emission in even the lowest excitation regions so that optical and UV data may be more reliably combined for all positions. UV observations have already been made of NGC 3242 and NGC 7662, and the optical measurements should be completed shortly.

I am grateful to the staffs of the Kitt Peak National Observatory for their assistance in obtaining the observations and for their development of excellent data reduction facilities.

TABLE 1

PARAMETERS OF OBSERVED POSITIONS

	POSITION						
PARAMETER	1	2	3	4	5	6	7
Offset (arcsec)	10E,2S	12E,27S	49W,27S	66W,70S	73E,79N	127W,70S	134E,79N
SWP number	--	17421	17420	18739	--	18737	17426
Exposure (min)	--	100	100	120	--	240	120
LWR number	--	13677	13676	13682	--	14790	13681
Exposure (min)	--	140	120	50	--	180	100
$F(H_\beta)$[a], 13.5" ent.	--	0.72	1.56	1.12	0.60	0.32	0.24
$F(\lambda 1640)$[a] predicted	--	3.09	3.33	1.06	0.49	<0.06	0.0
$F(\lambda 1640)$[a] observed	--	3.68	3.70	1.08	--	0.09	0.0

[a]Units of 10^{-12} ergs $cm^{-2} sec^{-1}$.

TABLE 2

LINE INTENSITIES

λ(Å)	ID	f (λ)	I (λ) Pos. 1	Pos. 2	Pos. 3	Pos. 4	Pos. 5	Pos. 6	Pos. 7
1403,1409	O IV]	1.32	--	20.0	4.1	--	--	--	--
1487	N IV]	1.23	--	16.6	6.0	--	--	--	--
1548,1550	C IV	1.18	--	211.3	77.3	16.4	--	--	--
1640	He II	1.14	--	469.	239.	104.	--	21.:	--
1661,1666	O III]	1.13	--	13.9	11.1	16.0	--	--	--
1747	N III]	1.12	--	13.1	15.6	13.8	--	27.1	4.5
1906,1909	C III]	1.23	--	369.	283.	303.	--	219.	145.
2326,2328	C II]	1.35	--	47.3	128.	105.	--	318.	625.
2422	[Ne IV]	1.12	--	77.4	22.0	--	--	--	--
2470	[O II]	1.10	--	--	11.6	--	--	--	--
2512	He II	0.95	--	--	7.0	--	--	--	--
2734	He II	0.72	--	1.1	5.9	--	--	--	--
2800	Mg I	0.66	--	12.5	8.4	27.5	--	21.1	18.8
3133	O III	0.45	--	4.4	7.4	--	--	--	--
3204	He II	0.42	--	--	12.8	--	--	--	--
3426	[Ne V],O III	0.38	27.9	16.0	--	--	--	--	--
3444	O III	0.37	--	4.9	2.3	--	--	--	--
3727	[O II]	0.29	243.	158.	636.	612.	518.	1233.	1407.
3798	H 10	0.27	5.7	4.2	5.8	4.4	4.5	--	4.7
3835	H 9	0.26	7.0	7.3	6.7	4.5	5.9	7.2	6.7
3869	[Ne III]	0.25	112.	115.	138.	152.	132.	111.	126.
4069,4076	[S II]	0.21	3.4	1.9	6.2	3.7	4.2	15.0	16.0
4102	H_δ	0.20	27.1	25.4	25.7	25.1	25.3	26.0	26.4

TABLE 2 continued

4267	C II	0.17	0.8:	1.1	0.41	0.91	<0.7	<0.9	0.8:
4340	H_γ	0.15	42.6	45.4	43.4	43.7	42.3	47.6	43.5
4363	[O III]	0.15	12.9	11.6	8.6	8.0	8.0	2.6:	1.2:
4471	He I	0.11	3.2	2.7	3.5	4.93	5.3	6.8	6.2
4686	He II	0.05	62.1	74.8	38.1	16.6	14.3	<3	--
4711	[Ar IV]	0.04	3.6	7.4	2.6	--	--	--	--
4740	[Ar IV]	0.03	2.0	5.1	1.5	--	--	--	--
4861	H_β	0.00	100.	100.	100.	100.	100.	100.	100.
4959	[O III]	-0.03	387.	399.	336.	418.	404.	71.4	88.6
5007	[O III]	-0.04	1231.	1264.	1048.	1305.	1285.	226.	282.
5200	[N I]	-0.08	1.4	--	7.9	4.1	5.9	27.6	35.3
5412	He II	-0.13	3.3	4.5	2.7	1.5	2.1	--	--
5755	[N II]	-0.20	2.1	1.9	7.4	6.7	6.8	13.0	23.0
5876	He I	-0.22	8.7	5.9	11.8	12.3	12.4	17.0	17.4
6300	[O I]	-0.29	--	--	25.8	17.2	16.3	78.4	103.
6312	[S III]	-0.29	4.2	1.7	1.3	1.8	3.3	1.8	--
6360	[O I]	-0.30	--	--	7.9	5.7	5.4	26.2	35.0
6548	[N II]	-0.33	65.3	40.0	172.	159.	139.	339.	421.
6563	H_α	-0.33	268.	277.	261.	283.	243.	287.	300.
6583	[N II]	-0.34	197.	115.	518.	477.	414.	1014.	1260.
6678	He I	-0.35	2.0	1.8	3.0	3.5	2.7	3.7	--
6717	[S II]	-0.36	16.3	13.0	44.5	27.0	32.7	142.	143.
6731	[S II]	-0.36	11.8	8.5	30.7	22.7	20.6	102.	116.
7065	He I	-0.40	4.7	--	3.6	3.1	3.6	--	5.6
7135	[Ar III]	-0.41	19.2	20.5	19.4	24.1	27.3	15.9	20.3
9069	[S III]	-0.50	--	15.6	19.3	22.3	13.3	0.8:	11.3
9532	[S III]	-0.63	--	28.2[a]	21.8[a]	24.7[a]	16.6[a]	2.2[a]:	14.2[a]

[a]Affected by terrestrial H_2O absorption; see text.

TABLE 3

ELECTRON TEMPERATURES AND DENSITIES

QUANTITY	ION	RATIO	POSITION 1	2	3	4	5	6	7
N_e (cm^{-3})	S^+	$\frac{I(6731)}{I(6717)}$	100	<100	<100	500	<100	100	400
T_e (K)	N^+	$\frac{I(6583)}{I(5755)}$	8600	10,000	9600	9500	10,100	9200	10,600
T_e (K)	S^+	$\frac{I(6724)}{I(4072}$	13,000	10,000	9500	8500	9000	7600	7700
T_e (K)	S^{2+}	$\frac{I(9069)}{I(6312)}$	--	11,000	9600	10,500	--	--	--
T_e (K)	O^{2+}	$\frac{I(5007)}{I(4363)}$	11,600	11,100	10,700	9700	9800	12,000:	8800:
N_e (adopted)			300	300	300	300	300	300	300
Error			±200	±200	±200	±200	±200	±200	±200
T_e (low ion; adopted)			8600	10,000	9600	9200	9700	8700	9600
Error			±1000	±800	±500	±500	±500	±800	±1000
T_e (high ion; adopted)			11,600	11,100	10,400	9900	10,100	9000	9400
Error			±500	±500	±500	±500	±500	±1500	±1000

TABLE 4

IONIC AND TOTAL ABUNDANCES

λ(Å)	ABUNDANCE	POSITION 1	2	3	4	5	6	7
4471	He^+/H^+	0.064	0.055	0.071	0.100	0.108	0.136	0.126
5876	He^+/H^+	0.062	0.044	0.086	0.089	0.091	0.121	0.127
6678	He^+/H^+	0.054	0.048	0.085	0.090	0.082	0.093	--
Average	He^+/H^+	0.061±0.002	0.047±0.003	0.081±0.005	0.091±0.003	0.094±0.008	0.188±0.010	0.127±0.001
4686	He^{2+}/H^+	0.053	0.064	0.032	0.012	0.012	--	--
	He/H	0.114±0.003	0.111±0.004	0.113±0.005	0.130±0.004	0.106±0.008	0.118±0.010	0.127±0.010
3726,3729	$10^4 XO^+/H^+$	1.9	0.62	3.0	3.5	2.3	9.1	6.6
5007	$10^4 XO^{2+}/H^+$	2.6	3.0	3.1	4.5	4.2	2.2	1.8
1661,1666	$10^4 XO^{2+}/H^+$	--	2.6	3.6	8.0	--	--	--
1403,1409	$10^4 XO^{3+}/H^+$	--	8.5	3.5	--	--	--	--
	i_{cf}	1.87	2.36	1.39	1.13	1.13	1.00	1.00
Optical	$10^4 XO/H$	8.4±2.1	8.5±2.1	8.5±2.1	9.1±2.3	7.3±1.8	11.±7.	8.4±6.
UV + Optical	$10^4 XO/H$	--	12.±5.	10.±4	12.±5.	--	--	--
6583	$10^4 XN^+/H^+$	0.56	0.21	1.1	1.1	0.84	2.8	2.6
1747	$10^4 XN^{2+}/H^+$	--	0.62	1.7	2.2	--	10.	1.1
1487	$10^4 XN^{3+}/H^+$	--	1.4	0.92	--	--	--	--
	i_{cf}	4.42	13.7	2.83	2.60	3.17	1.24	1.27
Optical	$10^4 XN/H$	2.5±1.2	2.9±0.8	3.1±0.4	2.9±0.4	2.7±0.4	3.5±0.8	3.3±0.8
UV + Optical	$10^4 XN/H$	--	2.4±1.3	3.7±1.9	3.3±1.9	--	13.±7.	3.7±1.0

TABLE 4 Cont.

3869	$10^4 X Ne^{2+}/H^+$	0.67	0.81	1.3	1.7	1.3	1.9	1.7
2422	$10^4 X Ne^{3+}/H^+$	--	1.6	0.67	--	--	--	--
3426	$10^4 /Ne^{4+}/H^+$	0.16	0.11	--	--	--	--	--
	i_{cf}	3.23	2.83	2.74	2.02	1.74	5.14	4.67
	$10^4 X Ne/H$	2.2±0.4	2.3±0.4	3.6±0.7	3.4±0.7	2.3±0.4	9.8±5.8	7.9±3.2
2326,2328	$10^4 X C^+/H^+$	--	0.72	2.6	2.8	--	13.	13.
1906,1909	$10^4 X C^{2+}/H^+$	--	4.1	5.1	8.0	--	13.	5.9
4267	$10^4 X C^{3+}/H^+$	8.9:	12.	4.5	9.9	<7.	<9.	8.6:
1548,1550	$10^4 X C^{3+}/H$	--	2.2	1.4	0.5	--	--	--
UV	$10^4 X C/H$	--	7.0±2.0	9.1±2.8	11.±4.		26.±18.	19.±8.
7135	$10^6 X Ar^{2+}/H^+$	1.2	1.4	1.5	2.1	2.2	1.7	2.0
4740	$10^6 X Ar^{3+}/H^+$	0.49	1.4	0.5	--	--	--	--
	i_{cf}	--	1.19	1.50	1.30	1.48	--	3.40
	$10^6 X Ar/H$	--	3.3±0.4	3.0±0.3	2.7±0.4	3.3±0.4	--	6.8±1.7
6717,6731	$10^6 X S^+/H^+$	0.88	0.45	1.7	1.3	1.2	7.4	6.0
9069	$10^6 X S^{2+}/H^+$	--	2.4	3.4	4.4	2.5	0.2:	2.5
	i_{cf}	1.23	1.70	1.11	1.10	1.14	1.00	1.00
	$10^6 X S/H$	--	4.9±1.2	5.7±1.4	6.2±1.6	4.2±1.1	7.6±2.5	8.5±3.0

TABLE 5

COMPARISON OF ABUNDANCES

Object	He/H	$10^4 \times O/H$	$10^4 \times N/H$	$10^4 \times Ne/H$	$10^4 \times C/H$	$10^6 \times Ar/H$	$10^6 \times S/H$	Reference
NGC 6853	0.110 ± 0.002	8.4 ± 0.3	3.0 ± 0.1	2.7 ± 0.3	7.6 ± 0.8	3.3 ± 0.4	5.9 ± 0.6	1
NGC 6853	---	5.6	3.3	1.7	4.1	---	---	2
NGC 6853	0.110	9.3	2.9	2.8	---	---	35.	3
NGC 6720	0.110	6.2	2.2	1.6	3.9	3.7	10.	4,5
NGC 7009	0.117	4.8	1.3	1.5	1.5	2.3	13.	6
H II regions	0.117	4.0	0.4	1.3	---	---	18.	7
Sun	0.100	7.4	0.9	1.1	4.5	3.7	17.	8,9

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Timothy Barker

Department of Physics and Astronomy

Wheaton College

Norton, Massachusetts 02766