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TWO CONTRASTING ABELL PLANETARY NEBULAE

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ABSTRACT

We present line fluxes, radial velocities, and analyses of two large Abell-type planetaries that show marked contrasts. Abell 43 is a high-excitation galactic-disk, or Population I, nebula that is optically thin in the hydrogen Lyman continum. Abell 50 in a medium-excitation, optically thick, Population II (high velocity) object. Although the two nebulae are of similar size (radius>0.2 pc), which in a simple theory might imply a similar evolutionary state, the central star of A43 appears to be much more luminous than that of A50. The set of large nebulae does not constitute a homogeneous evolutionary class in which the stars can be linked by a monotonic evolutionary track. The comparisons between these two objects illustrate and perhaps epitomize very large differences among large planetaries which probably involve differences in population type, and in stellar and nebular masses.

Subject headings: nebulae: planetary — stars: Population II

I. INTRODUCTION

The origin of the differences between planetary nebulae of vastly different sizes has never been clearly understood. Usually, the largest nebulae are considered to be in an advanced state of evolution: given a uniform rate of expansion, large planetaries should be older than small ones. In a different view, Renzini's (1979) hypothesis infers that the large nebulae are produced by high mass stars; the differences in nebular diameters and in observed central star characteristics depend upon the time-scales of the evolution of different mass stars. The true explanation must be complex, and will have to include variations in stellar masses, stellar evolution rates, nebular masses, expansion rates, the production of multiple shells, fragmentation of the gas, and certainly a variety of other factors.

Although the set of large nebulae is sometimes thought of as being homogeneous, it clearly is not. As an example, compare NGC 246 with NGC 3587 (the Owl Nebula). These objects are similar in size, and both central stars are above 10^5 K, but the former object is of much higher excitation (see Kaler 1976). Pottasch *et al.* (1978) (see also Pottasch 1980) suggest that NGC 246 is optically thin in the hydrogen Lyman continuum, and that NGC 3587 is thick. The range and distribution of the differences among the large nebulae (defined here by radii greater than 0.2 pc) is poorly known. Because of their low surface brightnesses, these objects have not been widely examined. Only a few nebulae, such as NGC 3587 (Torres-Peimbert and Peimbert 1977) mentioned above, and some others, have been extensively observed.

This paper is the first in a series in which the class of large nebulae will be extensively and systematically examined. Here we discuss two objects from Abell's (1966) list, A43 and A50, that further illustrate the large differences that can exist among this interesting group of objects.

II. THE OBSERVATIONS

We observed both A43 (PK 36+17°1) and A50 (PK 78+18°1) with the intensified image dissector scanner, or IIDS, at the 2.1 m telescope at Kitt Peak, and with a single channel photometer, equipped with an array of interference filters, at the 1 m telescope of the University of Illinois's Prairie Observatory. The IIDS data were obtained on 1980 April 26 and 27 and the Illinois data in May and June of 1980.

With the IIDS we observed A43 and A50 with a 4″ aperture 10″ north and 10″ southeast of their central stars respectively, in the wavelength region 4000–4700 Å. The data were calibrated with a variety of Kitt Peak photometric standards, and with IAU radial velocity standards and other stars chosen from Abt and Biggs (1972). Reductions were made using the standard IIDS

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1981ApJ...249..602K

programs. Line fluxes were derived by fitting Gaussian profiles.

At Prairie Observatory we measured total fluxes, with 55 Cyg as the standard star. Details of the observation and reduction of the interference filter data are given by Kaler (1976, 1980*a*). In addition the results from the three blue filters here also include correction for air temperature. A50 was observed with a 40″ aperture that encompassed the entire nebula. We observed A43 twice. With a 4′ aperture we measured the absolute Hα flux, and with a 40″ aperture centered on the object we determined absolute surface brightnesses of Hα and a number of other lines. The absolute Hβ flux was found from the 4′ data by using the theoretical $F(\mathrm{H}\alpha)/F(\mathrm{H}\beta)$ ratio of 2.86 (Brocklehurst 1971) and the interstellar extinction constant found from the 40″ data. The 40″ data provided a second value of $F(\mathrm{H}\beta)$, found by multiplying the Hβ surface brightness by the ratio of the nebular area to the aperture area. The two values agree within 15%, and the final value is an average of the two.

We present the data in Table 1, where the observed lines are identified in column (1). Relative line fluxes on the scale $I(\mathrm{H}\beta)=100$ are given first, followed by the log of the absolute Hβ flux. The interstellar extinction constant, c, found from the comparison of the observed and theoretical Hα/Hβ ratio, is given below the Hβ flux. We use the Whitford (1958) reddening function throughout this paper.

Three sets of data are included for each nebula. Columns (2) and (3) give relative line intensities of A43 from the IIDS and from the Prairie (PO) observations, not corrected for interstellar extinction. The combined and averaged A43 data corrected for extinction are given in column (4). Columns (5)–(7) give the analogous data for A50.

The IIDS and Prairie data cannot be straightforwardly combined because the former do not extend to Hβ. There is only one overlapping line between the two sets of data, λ4686 He II, which should not be used for scaling because of possible stratification effects between restricted and wide aperture observations. Scaling was done through the theoretical Balmer decrement (Brocklehurst 1971). We scaled the IIDS data in columns (2) and (5) to the theoretical Hγ and Hδ intensities, which were first reddened for A43. The scale factor for A50 was found from both Hγ and Hδ, and that for A43 from the more reliable Hγ. We then combined the corrected IIDS and PO data to produce the final corrected data in columns (4) and (7).

The PO fluxes were measured by a beam-switching technique and are the averages of several on-off pairs. Simple statistics were then used to produce the errors. Because of uncertainties in the temperature and velocity corrections for the red filters, an additional error of ±10% was added to the intensities of Hα and [N II]; see Kaler (1981) for further discussion. The errors in the IIDS data are more difficult to assess. For A50, we estimated them from the comparison between the observed and theoretical Hγ and Hδ intensities, and for weak lines also from the rms variation of the continuum. Errors are not assigned to the A43 IIDS data. Hγ is pinned to the theoretical value, and Hδ is a factor of 1.5 weaker than expected, well outside the anticipated error. The cause of the discrepancy is not known, but it can probably be dismissed because of the weakness of the observed line. A colon indicates at least a factor of 2

TABLE 1

LINE FLUXES AND RADIAL VELOCITIES FOR ABELL 43 AND ABELL 50

	ABELL 43			ABELL 50		
λ ID (1)	I_0 (IIDS) (2)	I_0 (PO) (3)	I_c (4)	I_0 (IIDS) (5)	I_0 (PO) (6)	I_c (7)
3727 [O II]	...	...	...	...	105±16	105±19
4068 [S II]	...	...	...	2.6:	...	2.6:
4101 Hδ	13.8	...	16.4	27.2±1.6	...	27.2±1.6
4340 Hγ	41.7	...	46.9	45.1±2.5	...	45.1±2.5
4363 [O III]	13:[a]	...	14:[a]	11±2	...	11±2
4471 He I	...	...	...	2.9±1.3	...	2.9±1.3
4686 He II	84	94±17	93±5	36±2	32±1	34±2
4861 Hβ	...	100	100	...	100	100
4959 [O III]	...	277±56	272±55	...	420±10	420±10
6563 Hα	...	382±65	285±48	...	266±28	266±28
6584 [N II]	...	52±16	39±12	...	74±11	74±11
log $F(\mathrm{H}\beta)$ (ergs cm^{-2} s^{-1}) ...	...	−12.40±0.07	...	...	−12.02±02	...
$c(\mathrm{H}\alpha/\mathrm{H}\beta)$	...	0.38±0.22	...	...	0±.04	...
v_r (km s^{-1})	−42±6	...	...	−159±10	...	...

[a]Marginal detection.

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1981ApJ...249..602K

uncertainty. Note the excellent agreement between the λ4686 intensities derived for each nebula from the two techniques. Our intensities for A43 also agree well with those measured by Kondratyeva (1979), who found $I(\lambda4686)=105$ and $I(\lambda4959)=247$.

The last row in Table 1 gives heliocentric radial velocities found from the IIDS data. We used all the lines but λ4471 in A50 and λ4363 in A43. Laboratory data are from the Revised Multiplet Table (Moore 1945) and from Bowen (1960). These results are significant because of the high velocity obtained for A50 and because of the general lack of measured velocities for large objects: they are known for only six other Abell nebulae (Bohuski and Smith 1974).

III. RESULTS

a) *Analysis of the Data*

In Table 2 we present the results of a variety of calculations based on the observational data of Table 1. First, we discuss parameters relating to distance. Rows (1) through (4) show the mean angular radii, ∅, taken from Abell (1966), the distances in parsecs calculated from the premises adopted by Cahn and Kaler (1971) and from the observed Hβ fluxes and extinctions in Table 1, the resulting physical radii, and the distances from the galactic plane.

In rows (5) and (6) we give the physical properties of the plasma. We calculated rms electron densities, N_e, from the distances in row (2), the corrected Hβ fluxes, and a filling factor of 0.65. Electron temperatures, T_e, were calculated from the $I(\lambda4959)/I(\lambda4363)$ ratios, Seaton's (1975) target areas, and Nussbaumer's (1971) transition probabilities. The temperature of A43 is very approximate because λ4363 is a marginal detection, only 1 σ above the noise. The only conclusion we can draw is that T_e seems to be somewhat high, consistent with the high excitation. For both nebulae, but particularly for the accurate value given for A50, stratification is a potential complication, since λ4363 was observed with a restricted aperture and λ4959 relates to total nebular flux. This does not seem to be a serious problem, however, because the λ4686 He II flux, which is a sensitive indicator of stratification, is nearly the same for both apertures.

TABLE 2

ANALYSIS OF ABELL 43 AND ABELL 50

Parameter	Abell 43	Abell 50
1) ∅	40″	13.″5
2) D	2100 pc	4000 pc
3) r	0.41 pc	0.27 pc
4) Z	0.63 kpc	− 1.2 kpc
5) N_e	30 cm^{-3}	90 cm^{-3}
6) T_e	14,000 K:	10,600 ± 700 K
7) He^+/H^+	...	0.060 ± 0.027
8) $He^{2+}H^+$	0.081 ± 0.005	0.029 ± 0.001
9) He/H	...	0.089 ± 0.027
10) $10^4\ O^+/H^+$	...	0.28 ± 0.07
11) $10^4\ O^{2+}/H^+$ ...	1.0 ± 0.4	3.1 ± 0.6
12) 10^4 O/H	3.7 ± 1.8[a]	5.0 ± 1.1
13) 10^4 N/H	0.034 ± .012	0.12 ± 0.02
14) N/O	...	0.44 ± 0.10
15) m_B, m_v..........	14.53, 14.71	19.40, ...
16) T_*(H)	24,000 K	104,000 K
17) L_*(H)	73 $L_\odot$	55 $L_\odot$
18) T_*(He II)	68,000 K	125,000 K
19) L_*(He II)	1020 $L_\odot$	91 $L_\odot$

[a]Assuming $O^+/H^+=7N^+/H^+$ and He/H = 0.12 ± 0.02.

In rows (7) to (14) we present the results of a straightforward abundance analysis: see Kaler (1978, 1980*a*) for procedures and atomic parameters. For A43, all that can be determined directly from the observations is He^{2+}/H^+ and O^{2+}/H^+, which by themselves are not very significant, except to indicate further the high excitation of the nebula since a large amount of helium is in the doubly ionized state. Only a crude estimate can be made for the O/H ratio. The [N II] line is weak, and O^+/H^+ is probably no greater than $7\ N^+/H^+$, or 0.2×10^{-4}. The abundances of the states above O^{2+} are calculated as usual from He^{2+}/He^+ (Seaton 1968). A43 has $|Z|$ and v_r characteristic of a Population I, or disk, planetary. From Kaler (1978), a typical value of He/H might be 0.12 ± 0.02 and thus $He^{2+}/He^+=2.1\pm1.1$, and $O/H=3.1\times(O^++O^{2+})/H^+=3.7\pm1.8\times10^{-4}$, which is at least a reasonable value.

For A50, there are sufficient data to make a proper and complete analysis for helium, oxygen, and nitrogen. As usual, N/O is set equal to N^+/O^+; the excitation of A50 is within the range for which this procedure yields correct nitrogen abundances (Kaler 1979). Also within this excitation range, the [O III] electron temperature should be appropriate to the O^+ and N^+ excitation.

In order to determine the errors on the abundances, we propagated the errors on the line intensities, the errors on the electron temperatures, and those on the He^+/H^+, and He^{2+}/H^+ ratios through the calculations. For A43 the errors on T_e and He/H are rather arbitrarily assumed to be ±2000 K and ±0.02, respectively.

Properties of the central stars are given in rows (15)–(19). We take the blue and visual apparent magnitudes (row 15) from Abell (1966). The T_*(H) and T_*(He II) are hydrogen and He II Zanstra temperatures calculated from Harman and Seaton's (1966) formulation, with the fractional solid angle subtended by the nebula at the

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1981ApJ...249..602K

star, ξ, set equal to 1. The L_* are bolometric luminosities in solar units.

b) *Discussion*

The analysis in Table 2 presents us with two broad areas of discussion: (1) the relationships between the physical and kinematical properties of the objects, and (2) the properties of the central stars and their interaction with the surrounding nebulae. Within area (1) only a few minor comments are applicable since we are dealing with just two objects. A50 has a high radial velocity characteristic of Population II, whereas A43 would fall into a disk population. The He/H ratio for A50 is low and consistent with Kaler's (1978) analysis of Population II objects. The O/H for A50 is at the upper limit for Population II, when compared with the results from Kaler's (1980*a*) oxygen study, but it is still in reasonable accord. Nitrogen may show some enrichment relative to oxygen; the N/O ratio is near the upper limit for the majority of Population II planetaries (Kaler 1979).

The high excitation of A43 is consistent with a Population I object (Kaler 1980*b*); that of A50 is somewhat high for Population II. From Kaler (1980*b*), nebulae with $V_r > 80$ km s^{-1} have Ex$=$He^{2+}/He<0.2. A50, however, has Ex$=0.33\pm0.10$, and although the error brings this object close to the above limit, that limit may have to be revised upward. The conclusions drawn by Kaler (1980*b*) do not change, however; a maximum stellar temperature of 125,000 K (see Table 2) in the galactic halo implies a maximum core mass of 0.58 $M_\odot$, only 0.08 $M_\odot$ above that found earlier. Clearly more observations are needed for high velocity nebulae in order to establish the limit firmly.

In this paper, the second of the above two areas of discussion is the more important. If T_*(H)$=T_*$(He II) we may assume that a nebula is optically thick in the entire Lyman continuum (see Harman and Seaton 1966). This is approximately the case for A50, where both values exceed 10^5 K. For A43, however, T_*(H) is much less than T_*(He II) implying either that the nebula is dusty (Helfer *et al.* 1981) or it is thin in the hydrogen Lyman continuum. The color excess for the central star is consistent with the measured interstellar extinction, and Kaler (1981) indicates that this type of object is probably mass bounded. For a Population I planetary, He/H should be >0.10; that He^{2+}/H$^+$ is <0.10 for A43 implies that the object may be thick in the He$^+$ Lyman continuum, and that T_*(He II) and L_*(He II) are reasonably accurate evaluations. The He^{2+}/H$^+$ ratio is high enough, however, to indicate that there may be some leakage of He$^+$ Lyman radiation, and that T_*(He II) and L_*(He II) may in fact be higher than presented.

The luminosities can be similarly discussed. Those for A50 are within a factor of 2 of one another, but for A43 the two values differ by a factor of over 13. The high luminosity for A43 is qualitatively consistent with that found by Greenstein and Minkowski (1964) from the stellar spectrum.

The contrast between the two nebulae is dramatic. A50 is a medium excitation optically thick nebula with a high temperature central star. A43 is a much higher excitation, partially optically thin object, with a cooler and much more luminous nucleus. The difference between the stars is so great that even with the uncertainties involved in this kind of analysis, it seems clear that we are dealing with two very different kinds of objects. These differences are parallel to those between NGC 3587 and NGC 246 discussed in § I (see Pottasch *et al.* 1978; Pottasch 1980).

Now compare the temperatures and luminosities with the relative radii of the nebulae. The true relative radii are difficult to evaluate; those given in Table 2 rest on an assumption of similar ionized masses. The evidence still supports A43 being the larger of the two. Since the radial velocities imply that A43 is Population I and A50 is Population II, we might expect the former nebula to have a higher mass, as it is more likely (although not provable) that it was produced by a higher mass progenitor (see Kaler 1980*b*). Furthermore, from the discussion above, A50 is radiation bounded, whereas A43 appears mass bounded. These arguments combined imply that if anything the ionized mass of A43 is greater than that of A50. The calculated distance and radius are proportional to the 0.4 power of the assumed ionized mass. Consequently, we would expect the ratio of the radius of A43 to that of A50 to be even larger than that calculated from Table 2. We thus come to the interesting result that the central star of the larger of the two nebulae, which from a simple theoretical picture we might expect to be farther along in its course of evolution, and which, as would be expected, is the cooler (see Paczyński 1971), is by far the more luminous. A50 is optically thick, or nearly so, in the hydrogen Lyman continuum because of the low luminosity of its central star, a condition predicted for large nebulae by Seaton (1966); A43 has not yet reached this state. The stars clearly do not fall on a monotonic evolutionary sequence.

We are looking here at two different kinds of nebulae. They may represent discrete subgroups of planetaries perhaps related to population types, or they may be extreme examples along a continuum which depends on stellar and nebular mass. The observations of A43 and A50 show that there are real differences between large nebulae. A full comprehension of the differences will require a large statistical sample.

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1981ApJ...249..602K

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REFERENCES

Abell, G. O. 1966, *Ap. J.*, **144**, 259.
Abt, H. A., and Biggs, E. S. 1972, *Bibliography of Stellar Radial Velocities* (New York: Latham Press Corp.).
Bohuski, T. J., and Smith, M. G. 1974, *Ap. J.*, **193**, 197.
Bowen, I. S. 1960, *Ap. J.*, **132**, 1.
Brockelhurst, M. 1971, *M.N.R.A.S.*, **153**, 471.
Cahn, J. H., and Kaler, J. B. 1971, *Ap. J. Suppl.*, **22**, 319.
Greenstein, J. L., and Minkowski, C. 1964, *Ap. J.*, **140**, 1601.
Harman, R. J., and Seaton, M. J. 1966, *M.N.R.A.S.*, **132**, 15.
Helfer, H. L., Herter, T., Lacasse, M. G., Savedoff, M. P., and van Horn, H. M. 1981, *Astr. Ap.*, **94**, 109.
Kaler, J. B. 1976, *Ap. J.*, **210**, 113.
______. 1978, *Ap. J.*, **226**, 947.
______. 1979, *Ap. J.*, **228**, 163.
______. 1980*a*, *Ap. J.*, **239**, 78.
______. 1980*b*, *Ap. J.*, **237**, 491.
______. 1981, in preparation.
Kondratyeva, L. N. 1979, *Trudy Astroph. Inst. Kazahkstan*, **34**, 53.
Moore, C. 1945, *A Multiplet Table of Astrophysical Interest*, (N.B.S. Tech. Note, No. 36).
Nussbaumer, H. 1971, *Ap. J.*, **166**, 411.
Paczyński, B. 1971, *Acta Astr.*, **21**, 417.
Pottasch, S. R. 1980, *Astr. Ap.*, **89**, 336.
Pottasch, S. R., Wesselius, P. R., Wu, C.-C., Fieten, H., and van Duinen, R. J. 1978, *Astr. Ap.*, **62**, 95.
Renzini, A. 1979, *Stars and Star Systems*, *Proc. of IAU Regional Mtg. in Astr.*, *Ap. Space. Sci. Lib.*, **75**, ed. B. Westerlund (Dordrecht: Reidel).
Seaton, M. 1966, *M.N.R.A.S.*, **132**, 113.
______. 1968, *M.N.R.A.S.*, **139**, 129.
______. 1975, *M.N.R.A.S.*, **170**, 475.
Torres-Peimbert, S., and Peimbert, M. 1977, *Rev. Mexicana Astr.*, **2**, 181.
Whitford, A. E. 1958, *A.J.*, **63**, 201.

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