The Astrophysical Journal, Vol. 153, July 1968

SPECTROPHOTOMETRIC STUDIES OF GASEOUS NEBULAE. X. THE SMALL, HIGH-EXCITATION PLANETARY NEBULA IC 2165

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Received November 18, 1967

ABSTRACT

We have measured emission-line intensities in IC 2165 between λλ3122 and 5007 Å to a minimum intensity of 7×10^{-4} $I(\mathrm{H}\beta)$ at peak instrumental sensitivity by a combination of photographic and photoelectric photometry. The nebula shows a wide range of excitation, from [Mg I] to [Ne V].

I. INTRODUCTION

IC 2165 (221—12°1 in Perek and Kohoutek's [1967] catalog) is a small, high-excitation planetary nebula in Canis Major, whose spectrum somewhat resembles that of NGC 2440. The slitless spectrograms of Wilson (1950) show that it has a ring structure vaguely similar to NGC 6720, with two bright lobes, and a diameter of about 5″. Also, like NGC 2440, no central star is visible under conditions of even the best seeing, implying a very high central-star temperature. From an analysis of the best available data (including preliminary results of this study), Kaler (1966) determined an electron temperature of 12200° K and an electron density of 1.8×10^3 cm^{-3}.

The nebula has previously been studied spectroscopically by Wyse (1942), who made eye estimates of line intensities between λλ3705 and 6755, and Aller (1951), who made quantitative measurements in the region λλ3130–5007. Minkowski and Aller (1956) extended this work to λ6730. The most recent work has been done by Liller and Aller (1963), who studied the spectrum photoelectrically.

II. THE OBSERVATIONS

The procedure for observation and reduction for this nebula is quite similar to that used for NGC 2440 (Aller, Czyzak, and Kaler 1968) in Paper VIII of this series.

We have observed the bright lines photoelectrically, using the same procedure as that used for Paper VIII.

The data on the fainter lines are derived from photographic observations. We used seven plates in this investigation, which were taken with three different telescopes. The observations are given in Table 1.

Photographic density calibrations were provided by the prime-focus step wedge for ES 622 and ES 731, by the coudé step-slit device for ES 1200 and ES 1201, and by a V-slit device for the Mount Wilson plates. All the photographic observations except ES 622 were corrected to outside the atmosphere by observations of standard stars, which are listed in the last column of Table 1. The data from ES 622 were corrected to outside the atmosphere with the averaged intensities of the other three Lick plates. For the Lick plates we used the mean extinction coefficients determined by Popper (1937). We reduced the Mount Wilson and Lick plates independently, and the photoelectric data were used to scale the Mount Wilson observations to the strong lines. Since the Lick data record the fainter lines, the Mount Wilson observations were subsequently used to scale the Lick data to $I(H\beta) = 100$. We measured the wavelengths of the fainter lines on ES 1200 to 0.1 Å, where the strong lines served as wavelength standards.

We present the results in Table 2. The first column gives the measured wavelength and the second column the identification. In the case of permitted lines, the third and fourth columns give the Revised Multiplet Table (Moore 1945) multiplet number and wavelength, respectively (we have deleted the first two digits of the wavelength), whereas, in the case of forbidden lines, the fourth column gives the wavelength measured by Bowen (1960). The fifth column gives the adopted photographic intensity and the sixth column the photoelectric intensities.

Continuous energy distributions for the standard stars were taken from the work of Code (1960); Oke (1964); and Aller, Faulkner, and Norton (1964). A continuous spectrum appropriate to a blackbody at 50000° K was assumed for the central star of NGC 4361.

TABLE 1

THE OBSERVATIONS

Plate	Date	Telescope	Exposure (min)	Dispersion (Å mm^{-1})	Standard Star
B 2433........	3/13/64	60-inch, Mt. Wilson	150	80	α Leo
B 2589........	10/30/64	60-inch, Mt. Wilson	301	80	ξ^2 Cet
Ce 16759......	11/30/63	100-inch, Mt. Wilson	305	20	ξ^2 Cet
ES 622...... ..	10/24/63	120-inch, Lick	93	60	None
ES 731.......	2/ 4/64	120-inch, Lick	180	60	ε Ori
ES 1200.. ...	1/15/66	120-inch, Lick	90	120	θ Crt Central star NGC 4361
ES 1201.......	1/15/66	120-inch, Lick	30	120	

III. DISCUSSION

We have observed lines of the following spectra: H, He I, He II, C II, C III, C IV, N III, O II, O III, O IV, S III, Mg I, [O II], [O III], [F IV], [Ne III], [Ne IV], [Ne V], [Mg I], [S II], [S III], [A IV], [K V], [Fe III], and [Fe V]. The Bowen flourescent mechanism is strongly present in the O III and N III lines.

The sources of error for this type of work are extensively discussed in Papers VII (Aller, Kaler, and Bowen 1966) and VIII (Aller, Czyzak, and Kaler 1968) of this series and need not be repeated here. As usual, care must be taken to allow for overlapping orders. The order of accuracy is about the same as that in Paper VIII.

The agreement between the Mount Wilson and Lick observations is quite good. There appears to be a small systematic effect with wavelength, with an amplitude of about 14 per cent of the intensities, for which we cannot account. The final averaged intensities are probably good to better than 10 per cent.

We express our gratitude to Director Horace W. Babcock of Mount Wilson and Palomar Observatories for giving us the opportunity to work on this problem with the 60- and 100-inch telescopes. This study was partially supported by Air Force Office of Scientific Research grant 83-65 to the University of California, Los Angeles; trips to Lick Observatory to secure observations were financed by NASA grant NsG 237-62.

1968ApJ...153...43K

TABLE 2

The Spectrum of IC 2165

λ	ID	Mult	λ_R	*I*	*I*_PEP
5007	[O III]	...	...	...	1180
4959	[O III]	...	...	...	395
4930 1	[O III]	...	31 0	0 33	...
4922 3	He I	48	22 0	0 66	...
4861 3*	Hβ	...	...	...	100
4816 3	...	...	...	0 11	...
4741 3	[A IV]	...	40 2	5 89	7 5
4725	[Ne IV]	...	25 6	0 48	...
4724	[Ne IV]	...	24 2 24 15	0 67	...
4711 5	He I A IV	12 ...	13 1 11 3	7.63	6 8
4685.7*	He II	...	...	...	41 0
4658 8	[Fe III] C IV	... 8	58 1 58 6	0.58	...
4649.2	C III O II	1 1	51 4 50 2 49.1	0 75	5 1
4640 2	N III	2	40 6 41 9	3 46	
4634 1	N III	2	34 2	1 65	
4608.8	O II [Fe III]	93 ...	09 4 07 1	0 29	...
4575 0	...	...	...	0 18	...
4570 8	[Mg I]	1	71 1	0 58	...
4563 4	...	...	...	0 08	...
4541 6*	He II	2	...	2 56	...
4471 5	He I	14	71 7	4.70	5 9
4452 9	O II	5	52 4	0 07	...
4448.1	O II	35	48 2	0 06	...
4396.5	O II	26	96 0	0.14	...
4387 5	He I C III	51 14	87 9 88 2	0.75	...
4379.7	Mg I C III	12 14	80 4 80 0	0.12	...
4369	...	...	...	0.10	...
4363	[O III]	...	63 2	22 8	51 6
4340.5*	Hν	...	...	...	
4314 3	C II	28	13 5	0 06	...
4267.4	C II	6	67 2	0 46	...
4227.8	[Fe V]	...	27.5	0 26	...
4200*	He II	...	...	1 22	...
4187.2	C III	18	87 1	0 36	...
4169 6	O II He I	19 52	69 2 69 0	0 07	...
4163 3	[K V]	...	63.3	0 10	...
4156 0	O II C III	19 21	56 5 56 5	0 08	...
4143.9	He I	53	43 8	0 45	...
4129 3	O II	19	29 3	0 09	...
4122 1	He I	16	20 8	0 27†	
4120 4	O II	20	20.6	0.13	...
4103	N III	1	03 4	0 43	24 2
4101*	Hδ	...	...	23 8†	
4097	N III	1	97 3	1 51	
4085 9	...	...	...	0 12	...

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* Line used as wavelength standard.

† The intensities within the brace were found by using the peak intensities to interpolate from a blend. The sum of the intensities is considerably more accurate than the ratio.

TABLE 2—*Continued*

λ	ID	Mult	λ_R	I	I_{PEP}
4077.2	[S II] O II C II	... 10 36	76.3 75.9 75.6 76.0 74.9	0.80	...
4070	O II C III	10 16	72.2 69.9 69.6 70.3	2.26	...
4068	[S II] C III	... 16	68.3 67.9 69.0		
4051.2	...	...	...	0.12	
4046.0	...	...	...	0.11	
4026*	He I	18	26.2	2.74	
4010.4	He I	55	09.3	0.19	
3996.2	O IV [F IV]	10 ...	95.2 97.4	0.15	
3970	H7	...	70.1	18.1†	36.6
3967	[Ne III]	...	67.5	18.3	
3964	He I	5	64.7	0.47	
3957.3	O IV	10	56.8	...	...
3951.7	...	...	...	0.04	
3945.4	O II	6	45.1	0.06	
3938.4	...	...	...	0.07	
3923.9	He II		24.2	0.57	
3908.4	...	...	...	0.06	
3905.2	Si I	3	05.3	0.07	
3889*	H8 He I		89.1 88.6	15.7	8.8
3887	He II		87.4		
3868	[Ne III]		...	79.6	78.5
3858.6	He II		58.1	0.32	...
3835	H9		35.4	6.67	8.0
3833	He II		33.8	0.38	..
3827.8	...	...	...	0.10	
3820.1	He I [Fe V]	22 ...	19.6 19.8	1.07	
3814.1	He II	...	13.5	0.25	
3797	H10	...	97.9	4.97	
3791.4	O III	2	...	0.19	
3782.4	[Fe V] He II	... ...	83.6 81.7	0.20	
3774	O III	2	74.0	0.23	
3771	H11	...	70.6	3.66	
3759.9	O III	2	59.9	3.89†	
3757	O III	2	57.2	0.29	
3754.8	O III	2	54.7	1.06	
3750*	H12		50.2	3.03	
3734	H13		34.4	2.53	
3729	[O II]		28.8	14.0‡	36.9
3726	[O II]		26.1	22.9	
3722	H14 [S III]		21.9 21.7	2.81	
3712	H15		12.6	1.80	
3705	He I		05.0	1.27†	
3703	H16		03.9	1.20	
3697	H17		97.2	1.46	
3691*	H18		91.6	1.14	
3686	H19	...	86.8	0.99	

‡ The photographic peak intensities were used to interpolate from the blended photoelectric intensity.

TABLE 2—*Continued*

λ	ID	Mult	λ_R	*I*	I_{PEP}
3682......	H20		82 8	0 86	..
3679....	H21	..	79 4	0 80	..
3676....	H22	.	76 4	0 74	
3674....	H23		73 8		
3671....	H24	....	71 5	...	
3634 6....	He I	28	34 4	0 47	
3587 3....	He I	31	87.3	0 25	
3560 1....	O IV	12	60 4	0 40	
3554 4....	He I	34	54 4	0 40	
3448.4....	He I	7	47 6	0 44	
3444*....	O III	15	44 1	16 3	
3429 3....	O III	15	28 7	3 7 †	43 9
3426 2....	[Ne V]	....	25 9	35 2	
3416....	O III	15	15 3	1 80	
3407....	O III	15	08 1 05 7	0 65	
3385 4....	O IV	3	85 6	0 27	
3369 2....	......	....	....	0 56	
3346.1....	[Ne V]	......	45.8	17 9	
3340....	O III	3	40 7	8 87	
3323 8....	S III	2	24 9 24 0	0.28	
3312*....	O III	3	12 3	6 91	
3299 7....	O III	3	99 4	3 18	
3294 1....	...	....	.....	0 19	
3266 6....	O III	8	65 5 67 3	0 71	
3256 6....	......	.....	....	0 44	
3241 7....	[Na IV]	....	..	0 32	
3234 0....	S III	3	34 2 33 2	0 62	
3203....	He II	.....	03 1	14 2	
3187....	He I	3	87 7	5 04	
3132....	O III	12	32 9	98 8	
3122 1....	O III	12	21 7	11 3	

We would also like to express our appreciation to the National Science Foundation for partial support of this work under NSF grants GP 6559 to the Ohio State University and GP 4928 and GP 7816 to the University of Illinois. We have also used the facilities of the General Physics Laboratory, Aerospace Research Laboratory at Wright-Patterson Air Force Base, Ohio. We are grateful to Mrs. Frances Murray and Mrs. Rhonda Duvall of that office for their help in reducing some of the data.

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