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SPECTROPHOTOMETRIC STUDIES OF GASEOUS NEBULAE
XI. THE PLANETARY NGC 6543

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ABSTRACT

By means of photographic and photoelectric techniques, we have measured the emission-line intensities in the spectrum between λλ3187 and 5175 of the planetary NGC 6543, which is an irregular object of excitation class 5. This object shows a range of excitation from Mg I to N III as well as a number of forbidden transitions involving ions from [O II] to [K IV]. The determination of the electron density and temperature by methods involving forbidden lines yields $T_\epsilon \sim 8200°$ K and $N_\epsilon \sim 5.6 \times 10^3$ electrons cm^{-3}. The latter value is also confirmed by surface-brightness measurements.

I. INTRODUCTION

The planetary NGC 6543 ($\alpha = 17^h58^m34^s$, $\delta = 66°38'$ [1966]) lies in the constellation Draco near the north ecliptic pole. The central star (m_{pg} 11.2; Berman 1937), is surrounded by an intricate inner helical structure of integrated magnitude 8.8 (Liller 1955) and an outer ring. The outer ring is considerably fainter than the inner ring and shows a knot about 105″ due west of the central star (see Fig. 1 [Pl. 4]). This planetary was the very first to be observed spectroscopically. Huggins (1864) discovered Hβ and the green nebular lines of [O III] which were identified by Bowen sixty-three years later.

Long exposures with large reflectors, particularly the Palomar 48-inch Schmidt (Fig. 1 [Pl. 4]), show that the faint outer envelope has a sharp limit. This sharp limit has been attributed either to a shock-wave front or just to the limit of the nebular matter. The outer edges of the luminous rings have been interpreted as the ends of the Strömgren ionization zones.

Many years ago Green (1917) attempted to measure the internal motions and construct a model of rotating shells; Koslov (1935) also tried to deduce the internal motions. Berman (1930) attempted to measure isophotal contours but noted that because of its intricate helical structure and lack of symmetry, a determination of the true structure of this object would be difficult. Münch (1968) used a multislit with 40 slits and a 1″ separation to measure the velocities at 200 points in images of [O II], [O III], and [Ne III]. He suggests a model with two helices, each moving away from the central star with a velocity of 12 km sec^{-1} along an axis tilted at an angle of 30°. The angular expansion rate of about 0″.5 per century would imply an age of about 1000 years.

The earliest photographic spectrophotometry of this nebula was undertaken by Berman (1930). Further spectrophotometric studies were made in 1938 by Aller (1941) 1956), Page (1942), and Andrillat (1950, 1952), while Liller and Aller (1954, 1963) and O'Dell (1963) investigated this object photoelectrically. In this paper we present data in which the primary emphasis was on the weaker permitted and forbidden lines. These

PLATE 4

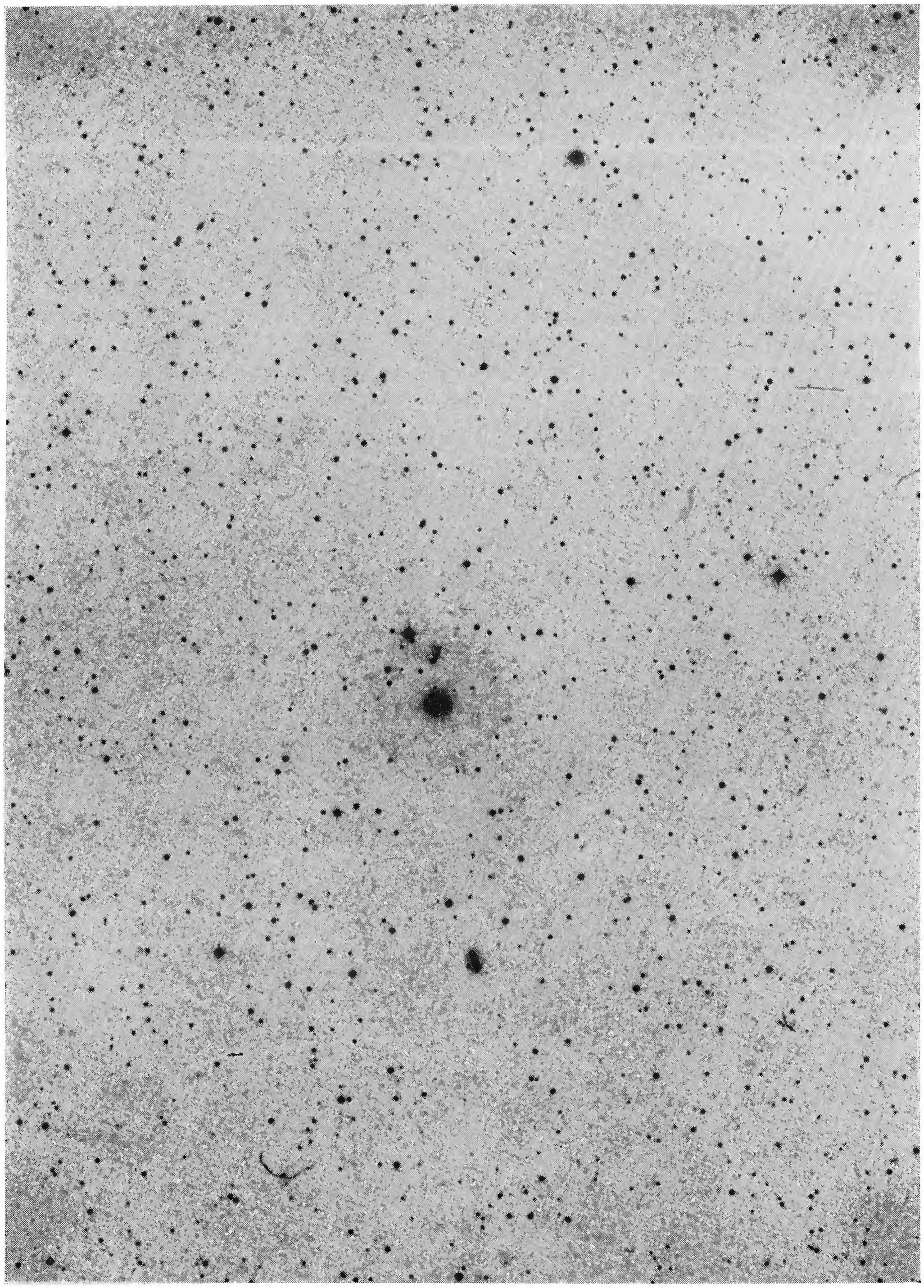

FIG. 1.—NGC 6543. Reproduction courtesy of *National Geographic Society–Palomar Observatory Sky Survey* plate 550. Copyright held by National Geographic Society. (North is at top and west is right.)

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were used to determine the electron temperature and density by using the latest collision cross-sections obtained by Saraph, Seaton, and Shemming (1966, 1968) and by Czyzak and Krueger (1967).

II. PRESENT SERIES OF OBSERVATIONS

In the present series of observations we secured eighteen plates of NGC 6543. Except for the coudé plates taken especially for the spectrum of the central star, we placed the slit approximately midway between the central star and the nebular edge.

We used the following instruments and IIaO baked plates to obtain the necessary data: (1) at Mount Wilson Observatory the X- and B-spectrographs with the 8-inch and 3-inch cameras, respectively (five plates), at the 60-inch telescope; (2) at Lick Observatory the coudé and prime-focus spectrographs (nine plates) at the 120-inch telescope; (3) at Kitt Peak Observatory with the 36-inch Meimel Cassegrain spectrograph (two plates) and with the 84-inch Cassegrain spectrograph (two plates). Table 1 lists the observations. Along with these eighteen nebular spectrograms, we secured spectrograms of appropriate standard stars with a wide slit to determine the combined effects of plate sensitivity, reflectivity of optics, etc.

The nebular spectrograph at the Lick 120-inch telescope has no device for impressing photometric calibrations; therefore, it was necessary to use the coudé spectrograph to calibrate strips of film which were developed subsequently with the nebular spectrograms. For spectrograms secured at Mount Wilson and Palomar Observatories, we exposed standard plates in a specially provided calibration wedge spectrograph. The Kitt Peak plates were calibrated with a collimated spot sensitometer and a series of appropriate filters. All standard plates were developed simultaneously with the plates of the planetary and comparison star.

Our main task was to secure reliable intensities for lines of low and intermediate intensities. Therefore, we took a series of plates of different exposures so as to be able to tie together into one system both the lines observed photographically and those observed with photoelectric spectrum scanners by Liller and Aller (1963) and by O'Dell (1963). To allow for atmospheric extinction, we employed Oke's (1964) determinations for Mount Wilson and Popper's (1937) and Hayes's (1966) mean extinction coefficients for Mount Hamilton. For the atmospheric extinction for Kitt Peak the results of Schulte and Crawford (1961) were used. Comparison-star observations yielded data for plate sensitivity, optics transmission, etc. In a separate reduction we temporarily ignored the standard stars and compared the photographically established intensities with the photoelectric intensities to allow for wavelength-dependent factors. The two sets of reductions gave intensities that were in good agreement.

Our general procedure was as follows: First we corrected the data from our plates to outside the Earth's atmosphere and allowed for other wavelength-dependent factors by using the appropriate atmospheric extinction coefficients and observations of the appropriate comparison star as shown in Table 1. From those data we obtained the corrected mean line intensities, which were then normalized to $I(H\beta) = 100$. The agreement between the photoelectric and photographic data, for those lines for which comparisons could be made, were good (see Fig. 2.) The results for the eighteen plates are shown in Table 2. In this table we give the laboratory wavelengths as found in Moore's *Revised Multiplet Table* (1945). We also give the adopted intensity for the lines corrected to outside the Earth's atmosphere.

The over-all accuracy of the line-intensity measurements for the stronger lines is within 20 per cent; of course, lines near the limit of detection can easily have errors of 50–100 per cent. Lines in the far-ultraviolet may be affected by systematic errors that are difficult to evaluate. It is important to distinguish between random or systematic errors in the photometry and variations produced by actual fluctuations in the intensity

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from point to point in the nebula. At the prime or Newtonian focus one tends to smooth over a strip that may be several seconds of arc wide; at the coudé focus (where an image rotator is used), one can distinguish between condensations and filaments only a few seconds of arc apart. Table 3 reproduces a small section of the worksheets to illustrate the agreement (or lack of it) between results from different plates. Because of the great range of intensities involved and different dispersions, not all lines appear on all plates. The stronger lines are overexposed (OE) on the longer exposures.

TABLE 1

LIST OF OBSERVATIONS

Plate No	Date of Observation	Telescope and Spectrograph	Exposure Time for Nebula (min)	Comparison Star	Exposure Time for Comp. Star (min)
X 7511	March 4–5, 1963	60-inch (Mount Wilson), X-spectrograph, 8-inch camera, dispersion 40 Å mm^{-1}	113	α Leonis	20
X 7516	March 6–7, 1963	60-inch (Mount Wilson), X-spectrograph, 8-inch camera, dispersion 40 Å mm^{-1}	120	α Leonis	20
X 7519	March 7–8, 1963	60-inch (Mount Wilson), X-spectrograph, 8-inch camera, dispersion 40 Å mm^{-1}	170	α Leonis	20
B 2471	May 11–17, 1964	60-inch (Mount Wilson), B-spectrograph, 3-inch camera, Newtonian focus, dispersion 80 Å mm^{-1}	226	α Lyra	1
B 2474	May 12–13, 1964	60-inch (Mount Wilson), B-spectrograph, 3-inch camera, Newtonian focus, dispersion 80 Å mm^{-1}	180	α Lyra	1
Ec 4278	May 18–19, 1965	120-inch (Lick), coudé, 20-inch camera, dispersion 16 Å mm^{-1}	120	Central star	. .
Ec 4325	June 16–17, 1965	120-inch (Lick), coudé, 20-inch camera, dispersion 16 Å mm^{-1}	200	Central star	.
Ec 4329	June 17–18, 1965	120-inch (Lick), coudé, 20-inch camera, dispersion 16 Å mm^{-1}	144	Central star	.. ..
Es 840	June 15–16, 1964	120-inch (Lick), prime focus, dispersion 50 Å mm^{-1}	76	BD+28°4211	8
Es 841	June 15–16, 1964	120-inch (Lick), prime focus, dispersion 50 Å mm^{-1}	76	BD+28°4211	8
Es 846	June 18, 1964	120-inch (Lick), prime focus dispersion 50 Å mm^{-1}	.	BD+28°4211	8
Es 1096	September 19, 1965	120-inch (Lick), prime focus, dispersion 105 Å mm^{-1}	60	BD+28°4211	3
Es 1104	September 20, 1965	120-inch (Lick), prime focus, dispersion 105 Å mm^{-1}	10	BD+28°4211	3
Es 1105	September 20, 1965	120-inch (Lick), prime focus, dispersion 105 Å mm^{-1}	20	BD+28°4211	3
A 1662a	October 11–12, 1965	36-inch (Kitt Peak), Cassegrain, dispersion 63 Å mm^{-1}	270	..	......
A 1664a	October 12–13, 1965	36-inch (Kitt Peak), Cassegrain, dispersion 63 Å mm^{-1}	270	..	... ...
C 44	May 10–11, 1966	84-inch (Kitt Peak), Cassegrain, dispersion 39 Å mm^{-1}	339	55 Cygni	1
C 47a	May 11–12, 1966	84-inch (Kitt Peak), Cassegrain, dispersion 39 Å mm^{-1}	420	δ Crateris 55 Cygni	1 1

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III. ELECTRON TEMPERATURE AND DENSITY

Theoretical interpretation of the spectrum of NGC 6543 will be deferred to a later paper when calculation of certain necessary parameters are complete (Czyzak and Krueger 1963, 1967; Czyzak *et al.*, 1968).

We adopt an angular radius of 10″ for NGC 6543 (Curtis 1918). Liller and Aller (1954) and Liller (1955) give log $F(\mathrm{N1} + \mathrm{N2}) = 0.00$, where $F(\mathrm{N1} + \mathrm{N2})$ is the flux in ergs $\mathrm{cm}^{-2}\ \mathrm{sec}^{-1}$ at the outer boundary of the nebula in the light of the green nebular [O III] lines. Adopting $I(\mathrm{N1} + \mathrm{N2})/I(\lambda 4363) = 390$ after correction for space absorption (O'Dell 1962, 1963), we obtain the T_ϵ and N_δ from the following (respective) expressions

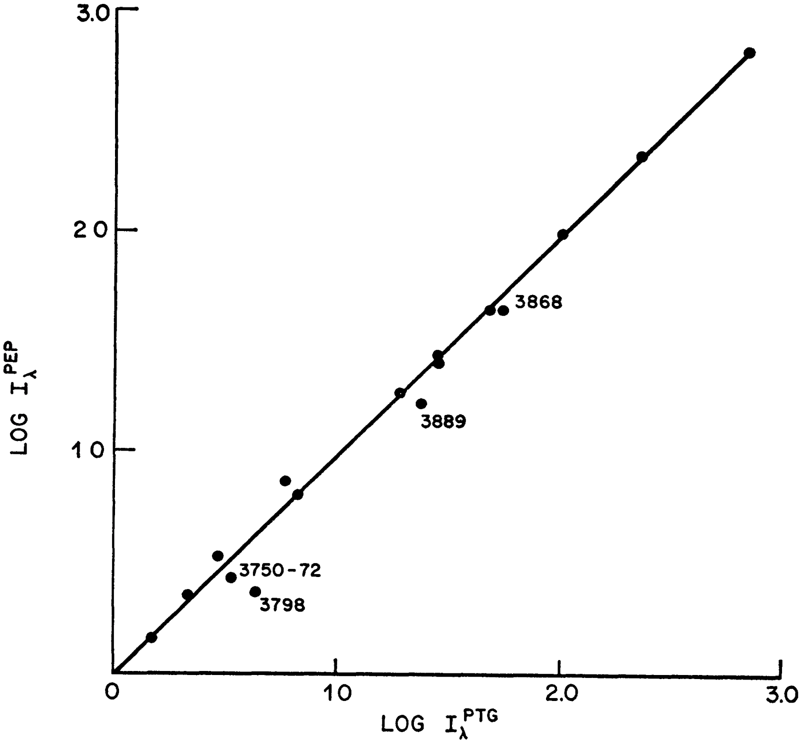

FIG. 2.—Comparison of certain spectral-line intensities obtained by photoelectric (I_λ^{pep}) and photographic (I_λ^{ptg}) methods.

$$\frac{I(\mathrm{N1} + \mathrm{N2})}{I(\lambda 4363)} = 7.0 \times 10^{14300/T_\epsilon}\,, \qquad N_\epsilon^2 = 3.52\,\frac{F(\mathrm{H}\beta) \times 10^{25}}{D E_{4\,2}{}^{0}}\,, \tag{1}$$

where

$$D \equiv 3d\left(1 - \frac{d}{A} + \frac{d^2}{3A^2}\right) \quad \text{and} \quad E_{4\,2}{}^{0}(T_\epsilon) = \frac{E(\mathrm{H}\beta)}{N_i N_\epsilon} \times 10^{25}\,. \tag{2}$$

From the $(\mathrm{N1} + \mathrm{N2})/\lambda 4363$ ratio = 390 we find $T_\epsilon = 8200°$ K. Then $E_{4,2}{}^{0}$ (8200° K) = 1.633 (Clarke 1965; Aller and Liller 1968). The outer radius of the nebula in centimeters is $A = 1.494 \times 10^{13}\, rA''$, where A'' is its angular radius. Adopting $d/A = 0.2$, r = distance of nebula = 1080 pc, and $F(\mathrm{H}\beta) = 0.112$ erg $\mathrm{cm}^{-2}\ \mathrm{sec}^{-1}$, we find $D = 7.88 \times 10^{16}$ cm, $N_\epsilon = 5.5 \times 10^{3}$ electrons cm^{-3}. If we use O'Dell's (1962, 1963) values, $d = 996$ pc and $F(\mathrm{H}\beta) = 0.121$ ergs $\mathrm{cm}^{-2}\ \mathrm{sec}^{-1}$, we get $N_\epsilon = 6 \times 10^{3}$ electrons cm^{-3}. Both estimates

TABLE 2*

NGC 6543

λ (Å)	Ident.	Mult	I_{pep}	I_{ptg}
3187.6	He I, Ne II	...	...	3.45
3211.2	...		...	0.48
3218.2	O II		...	0.30
3334.28	...	...	...	1.26
3348.72	He I			0.18
3354.55	He I	...		0.45
3403.71	...	...	...	0.45
3413.01	...	...		1.17
3447.91	O II, He I	27	...	0.22
3450.3	He I	...		0.37
3479.08	He I	43		0.37
3498.65	He I	40		0.13
3512.51	He I	...		0.50
3530.49	He I			0.38
3532.2	He I			0.30
3554.49	He I			0.41
3581	...			0.36
3587.32	He I			0.52
3594	...			0.30
3599	...			0.39
3613.94	He I			0.60
3634.37	He I			0.65
3656.6	H37			0.07
3657.9	H35			0.22
3658.5	H34			0.36
3660.3	H32			0.30
3661.2	H31			0.23
3662.26	H30			0.29
3663.65	H29			0.42
3664.89	H28			0.37
3666.18	H27			0.40
3667.72	H26			0.36
3669.49	H25			0.37
3671.68	H24			0.50
3673.82	H23			0.58
3676.28	H22			0.68
3679.44	H21			0.72
3682.91	H20			0.81
3686.73	H19	...		1.00
3691.56	H18	...		1.26
3694.10	Ne II	1		0.16
3697.15	H17	...		1.33
3702.84	O III	14		0.10
3703.92	H16	...		1.66
3704.89	He I	25		1.30
3707.05	O III	14		0.38
3711.93	H15	...		2.30
3713.72	O III	14		0.15
3715.08	O III	14		0.20
3721.94	H14, [S III]	...	...	3.09
3726.05	[O II]		19.1	12.9
3728.80	[O II]			6.97
3734.37	H13			3.00
3740.3	O II	...	...	0.17
3750.15	H12	...	2.63	3.46
3754.90	O III	2	...	0.41
3756.29	He I	66		0.15
3757.30	O III	2		0.26
3759.96	O III	2	...	0.35
3762.70	O II	31		0.11
3770.63	H11	...	...	3.84

* The numeral after H (as in H37) denotes the number of the Balmer line

TABLE 2—*Continued*

λ (Å)	Ident.	Mult.	I_{pep}	I_{ptg}
3774.22	O III	2	...	0.14
3777.13	Ne II	1	...	0.12
3785.37	O II	95	...	0.16
3791.32	O III	2	...	0.12
3794.91	S III	10	...	...
3797.90	H10	...	2.40	4.71
3805.84	He I	63	...	0.14
3819.7	He I	...	...	1.97
3828.30	...	...	...	0.03
3833.78	He I	62	...	0.17
3835.39	H9	...	6.31	6.46
3838.23	He I	61	...	0.06
3847.5	O II	...	...	0.10
3851.17	O II	12	...	0.11
3856.30	Si II, O II	1, 12	...	0.17
3862.76	Si	1	...	0.26
3868.76	[Ne III]	...	44.7	41.1
3871.73	C II	18	...	0.15
3876.8	...	...	...	0.13
3882.09	O II	12	...	0.14
3889.05	H8	...	16.3	21.5
3891.3	...	...	...	0.25
3919.37	C II	4	...	0.09
3920.98	C II	4	...	0.27
3926.60	He I	58	...	0.26
3927.86	...	...	...	0.08
3954.4	O II	...	...	0.10
3964.73	He I	...	...	1.14
3967–70	[Ne III], H7		27.5	23.0
3978.6	...	...	...	0.12
3984.5	...	...	...	0.06
3994.63	N II	12	...	0.08
4009.27	He I	...	...	0.46
4016.7	...	...	...	0.09
4026.2	He I	...	...	3.21
4041.05	O II, N II	39	...	0.13
4048	O II	50	...	0.40
4057.68	...	...	...	0.21
4068.75	[S II]	...	...	0.77
4069.85	O II, C III	10, 16	...	0.63
4071.86	O II	...	2.24	0.35
4076.05	[S II], O II	10	...	0.68
4078.95	O II	10	...	0.06
4083.62	O II	49	...	0.09
4084.76	O II	21	...	0.11
4086.95	O II	48	...	0.06
4089.11	O II	48	...	0.26
4092.62	O II	10	...	...
4097.31	N III, O II	...	...	0.97
4101.74	Hδ	...	...	...
4103.35	N III, O II	20	...	...
4105.00	O II	20		0.06
4110.81	O II	20	...	0.24
4119.36	O II	20		0.62
4120.96	He I	...		...
4128.36	...	...		0.08
4132.79	O II	19		0.27
4143.76	He I	...	...	0.64
4145.87	O II, N II	106, 65	...	0.09
4148.63	S III	...	...	...
4153.21	O III	19	...	0.27
4156.39	O II, C III	21	...	0.17
4162.54	C III	21	...	0.05

TABLE 2—*Continued*

λ (Å)	Ident.	Mult.	I_{pep}	I_{ptg}
4168.96	O II, He I	19, 52	...	0.25
4175.08	N II	42	...	0.10
4185.72	O II	36		0.13
4190.07	O II	36		0.14
4195.77	N III	6		0.09
4220	Ne II	52		0.13
4236.9	N II	48	...	0.09
4241.93	N II	47, 48		0.12
4245.8	...	...		0.06
4253.88	S III, O II	4, 4		0.12
4257.74	...	...		0.05
4260.18	...	...		0.12
4267.15	C II	6		0.95
4275.65	O II	67		0.28
4282.53	O II	54		0.08
4285.3	S III, O II	4, 78		0.14
4288.22	N III	...	...	0.32
4292.09	C II, O II	41, 78		0.14
4294.81	O II	54		0.09
4298.3	...	...		0.05
4303.81	O II	54		0.22
4317.12	O II	2		0.43
4319.83	O II	2		0.17
4325.83	C III, O II	7, 2	...	0.11
4331.77	O II	41	...	0.11
4340.47	Hγ	...	45.7	43.9
4345.23	O II	2	...	0.24
4347.8	O II	...		0.56
4349.30	O II	2		0.43
4353.54	O II	6		0.30
4356.45	...	...		0.08
4363.21	[O III]	...		2.26
4367.08	O II	2	...	0.27
4370.2	Ne II	...		0.11
4379.20	N III	17		0.17
4384.05	Ne II, Ne III	56		0.05
4387.93	He I	...		1.03
4391.87	Ne II	...		0.10
4398	Ne II	...	...	0.07
4409.21	Ne II	...	...	0.15
4414.90	O II	5	...	0.15
4417.24	O II	5	...	0.26
4433.7	...	...	...	0.15
4437.54	He I	50	...	0.20
4448.2	O II, N III	...	...	0.05
4456.9	Ne II	...	...	0.05
4465.2	O II	...	...	0.13
4471.48	He I	...	7.4	6.05
4481.3	Mg II		...	0.12
4492.0	O II	...	...	0.10
4500	...	...	...	0.05
4510.8	[K IV]	...		0.15
4516.9	C III	...	...	0.09
4523.6	N III	...		0.08
4527.8	N III	...	...	0.09
4537.6	...	...	...	0.04
4552	N II, Si III	...	...	0.10
4571.0	Mg I	...	...	0.14
4590.79	O II	15	...	0.15
4595.99	O II	15	...	0.10
4605.85	...	...	...	0.12
4609.48	O II	93	...	0.10
4611.2	...	...	...	0.20

TABLE 2—*Continued*

λ (Å)	Ident.	Mult.	$I_{\rm pep}$	$I_{\rm ptg}$
4615.1	...	...	...	0.06
4620.68	O II	92	...	0.09
4624.47	...	...	...	0.03
4629.99	...	...	...	0.17
4633.74	N III	2		0.67
4638.36	O II	1		0.69
4640.64	N III	2		1.56
4641.72	N III, O II	1	...	...
4647.66	C III	1	...	...
4649.23	O II	1	...	...
4650.20	C III	1	...	0.84
4650.90	O II	1	...	...
4651.46	C III	1	...	...
4653.51	...	...	...	0.09
4657.1	...	...	...	0.08
4657.89	...		...	0.21
4660.24	...	...	...	...
4661.17	O II	1	...	0.29
4673.15	...	...	...	...
4676.05	O II	1		0.23
4677.6	...	...	...	0.26
4689.5	...	...		0.09
4699.2	O II	...		0.13
4702.22	O II, [Fe III]	58	...	0.20
4711.27	[Ar IV]	...	...	...
4713.14	He I	...	1.4	1.42
4725.5	[Ne IV]		...	0.10
4739.99	[Ar IV]		1.1	0.93
4756.7	...		...	0.21
4789.2*	[F II]		...	0.05
4797.80				0.11
4805.8				0.08
4815.4			...	0.09
4825.			...	0.11
4846.9	...	...	...	0.08
4861.3	Hβ		100.0	100.0
4903.63	...	...	...	0.09
4906.63	O II	28		0.09
4921.93	He I	48		1.33
4931.81	[O III]	...	...	0.25
4942.0	...		...	0.09
4945.6	...		...	0.23
4958.9	[O III]	...	229.0	227
5006.8	[O III]	...	671.0	665
5016.83	He I	4	...	2.17
5032.97	C II	17	...	0.49
5081.2	...	...	...	0.60
5175.44	...		...	0.48

* Predicted by Bowen (1960).

assume no space absorption. Adopting $T_\epsilon = 8200°$ K and $N_\epsilon = 5600$ electrons cm^{-3}, we now predict the intensity ratio

$$r = \frac{I(\lambda 3729)}{I(\lambda 3727)} = 1.5\left[\frac{1 + 0.13\epsilon + 2.30x(1 + 0.55\epsilon + 0.06\epsilon^2)}{1 + 0.16\epsilon + 9.85x(1 + 0.61\epsilon + 0.07\epsilon^2)}\right] \tag{3}$$

(Seaton and Osterbrock 1957), wherein

$$\epsilon = e^{-1.96/t} \qquad x = 10^{-4}\frac{N_\epsilon}{\sqrt{t}}, \qquad \text{and} \qquad t = 10^{-3}T_\epsilon .$$

Table 3

NGC 6543

Plate Numbers

λ	Ident.	ES 1096	ES 1104	ES 1105	EC 4278	EC 4325	EC 4329	X 7511	X 7516	X 7519	B 2471	B 2474	ES 846	ES 840	ES 841	C 44	A 1662	A 1664	Adopted I_{PTG}	I_{PEP}
3721.94	H_{14}	2.88	2.78	3.40	3.06	3.63	3.28	-	2.11	2.37	-	-	3.43	3.21	4.00	4.26	2.74	2.12	3.45	
3726.05	[O II]	OE	10.19	7 83	15.88	13.98	12.12	OE	12.04	12.98	14.92	40.65	8.32	10.77	12.63	6.69	6.80	5.40	12.9	19.1
3728.80	[O II]	OE	6.55	6.77	7.57	7 32	5.75	OE	5.66	4.50	12.35	12.78	7.14	6.81	8.70	5.39	3.40	2.70	6.97	
3734.37	H_{13}	3.10	2.61	2.83	2.84	3.51	2.63	1.20	3.01	2.17	3.59	5.96	3.06	2.76	3.11	4.26	2.55	1.82	3.00	
3740.30	O II	0.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.17	
3750.15	H_{12}	3.22	3.13	3.38	3.86	3.90	3.44	1.71	2.80	3.43	3.33	6.24	3.64	3.50	3.32	4.56	2.85	2.44	3.46	2.63
3754.90	O III	0.66	0.35	0.38	-	-	0.39	-	-	-	-	-	-	-	-	0.29	-	-	0.41	
3756.29	He I	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.15	-	-	0.15	
3757.30	O III	-	-	-	-	-	0.37	-	-	-	-	-	-	-	-	0.15	-	-	0.26	
3759.96	O III	0.48	0.27	0.24	-	-	0.46	-	-	-	-	-	-	-	-	0.33	-	-	0.35	
3770.63	H_{11}	3.55	3.77	3.56	3.81	4.23	4.45	1.89	3.57	4.39	3.87	5.73	3.90	4.14	3.32	-	3.75	3.48	3.84	
3774.32	O III	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.16	0.11	0.14	
3777.13	Ne III	0.18	0.10	0.09	-	-	-	-	-	-	-	-	-	-	-	0.12	-	-	0.12	
3785.37	O II	0.19	0.09	0.08	-	-	-	-	-	-	0.34	-	-	-	-	0.09	-	-	0.16	
3791.32	O III	0.15	0.16	0.09	-	-	-	-	-	-	-	-	-	-	-	0.08	-	-	0.12	
3797.90	H_{10}	3.47	4.35	3.69	5.53	5.85	6.53	3.20	4.86	5.87	4.43	6.77	4.58	5.16	3.27	-	4.60	3.12	4.71	2.40
3805.84	He I	0.22	0.09	0.14	-	-	-	-	-	-	-	-	-	-	-	0.09	-	-	0.14	
3819.7	He I	2.15	1.86	1.91	1.89	1.71	1.69	1.21	2.11	2.20	1.76	2.26	2.21	2.01	1.74	2.40	1.97	2.43	1.97	
3828.30		-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	-	-	0.03	
3833.78	He I	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	0.09	-	-	0.17	
3835.4	H_9	-	6.31	4.40	7.13	7 29	9.22	6.84	8.39	9.41	6.22	9.49	5.29	6.25	3.38	4.47	5.63	3.69	6.46	6.31

The new cross-sections do not give a significantly different formula. The predicted value is $r = 0.508$, while the observed value is $r = 0.532$. This agreement suggests that the density in the regions radiating the [O II] lines is close to the density estimated from the surface brightness.

O'Dell has suggested an absorption correction amounting to

$$C = \log \frac{I(\mathrm{H}\beta)}{I_0(\mathrm{H}\beta)} = 0.30 .$$

Then $F(\mathrm{H}\beta) = 0.224$ erg cm^{-2} sec^{-1}, $N_\epsilon = 7.9 \times 10^3$ electrons cm^{-3}, and T_ϵ becomes 8400° K. Independent estimates of the electron temperature are available also from forbidden lines of [S III] and [Ar III].

The strong infrared nebular lines of [S III] λλ9532 and 9069 may be compared with the transauroral line λ3722, which, however, is blended with H14. In practice λ9532 is blended with a Paschen line, so that it is better to use λ9069 alone. At the range of densities encountered in NGC 6543, we have (Aller and Czyzak 1968)

$$\frac{I(\lambda 9069)}{I(\lambda 3722)} = 2.86 \times 10^{-9800/T} .$$

With $I(\lambda 9069) = 25.7$ (O'Dell 1963) and $I(\lambda 3722) = 0.5$ (after correction for the contribution of H14 and for the effects of space absorption as proposed by O'Dell), we obtain $\mathrm{T} = 7900°$ K for [S III].

The nebular transitions of [Ar III], λλ7136, 7151 have an intensity 21.1 (O'Dell 1963). The auroral line λ5191 shows an intensity that fluctuates by a factor approximately 2 from point to point in the nebula (Walker and Aller 1968). Choosing $I = 0.10$ as a rough average value and employing the equation

$$\frac{I(\lambda 5191)}{I(\lambda 7136) + I(\lambda 7151)} \cong 0.091 \times 10^{-12000/T} ,$$

we obtain $T \sim 9200°$ K, which is also a very uncertain value because of the inaccuracy of the intensity of the auroral lines. Nevertheless, the [Ar III] and [S III] data tend to be in harmony with the low electron temperature found from the [O III] lines, viz., 8400° K, which places NGC 6543 among the coolest of planetary nebulae. Recent radio data (Thompson 1968) indicate that other planetaries of low to moderate excitation also may have low electron temperatures.

Why should this particular nebula show an electron temperature so very much lower than that found for other nebulae of a similar excitation class? Considerations of thermal balance (Menzel and Aller 1941; Aller 1953) might lead us to expect a slightly higher temperature unless excitation of neglected low metastable terms is more efficient than supposed. Another possibility is that the ultraviolet-energy emission of the central star deviates severely from that of a black body. This would not be surprising, since the central star shows Of characteristics with possibly incipient P Cygni–type emission. In Figure 3 we compare the observed Balmer decrement with the theoretical decrement. This nebula shows excellent agreement with theory, a phenomenon not often observed (Kaler 1966).

IV. THE OUTER ENVELOPE

Minkowski (as reported in Aller 1956) first noted that NGC 6543 was surrounded by a large outer halo, about 5′ in diameter, which is readily apparent on the *Palomar Sky Survey* prints (Fig. 1 [Pl. 4]). The Kitt Peak observations were made with the longest possible slit set in an east-west direction, and record the spectrum of a bright knot of material 105″ due west of the central star. The intensities of the observed lines are given in Tables 4 and 5, together with the estimated upper limit of Hβ, which is not observed. The intensities are on the scale $I(\mathrm{H}\beta)$ of the central region = 100.

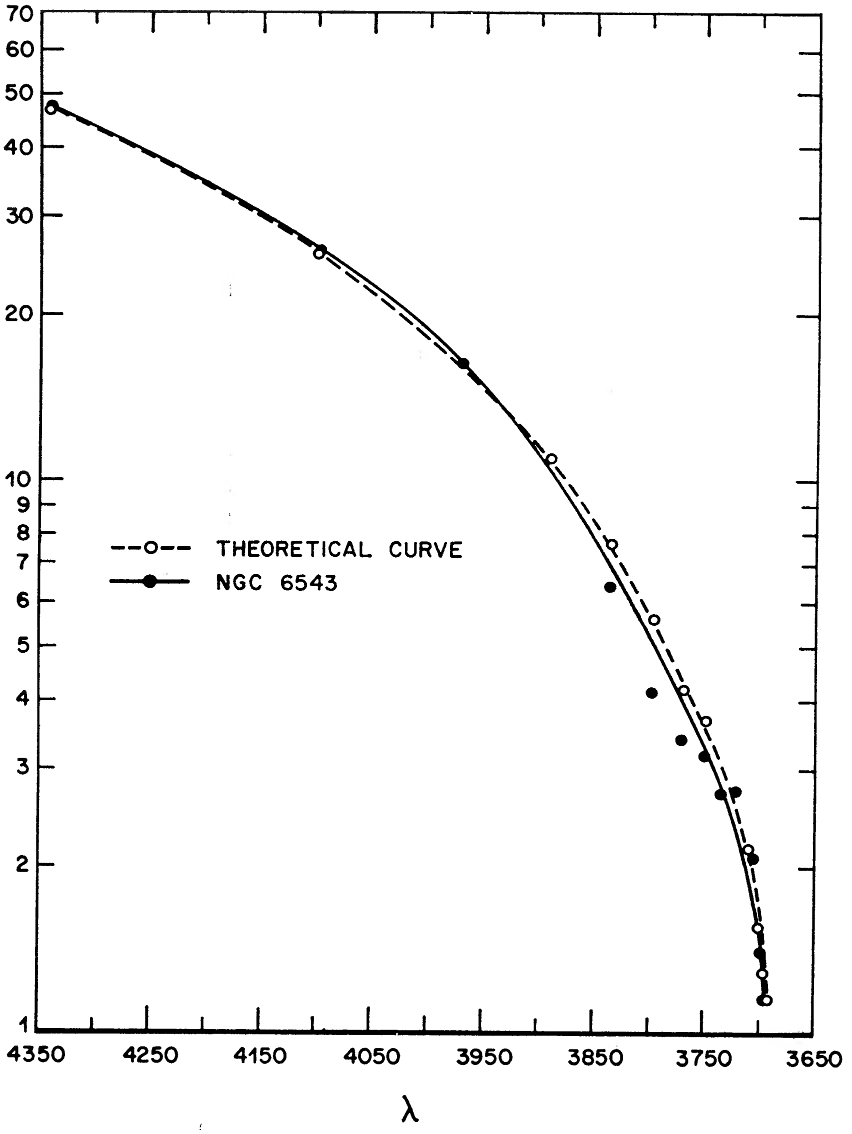

FIG. 3.—Comparison of observed Balmer decrement with the theoretical decrement

TABLE 4

INTENSITIES OF OBSERVED LINES: WEST KNOT, OUTER SHELL (FIG. 1 [PL. 4])*

λ (Å)	Ident.	I_{ptg}
5007	[O III]	0.69
4959	[O III]	.13
4861	Hβ	< 10
3868	[Ne III]	08
3729	[O II]	17
3727	[O II]	0 17

* Knot is approximately 120″ due west of main body of nebula and is part of the surrounding shell.

If we use the formula of Seaton and Osterbrock (1957) for the ratio of the forbidden lines $I(\lambda 3729)/I(\lambda 3726)$, we derive an electron density of 470 cm^{-3} for an assumed electron temperature of 8200° K. Unfortunately, we cannot measure the electron temperature of the knot itself.

TABLE 5

INTENSITIES OF OBSERVED LINES EXTENDING INTO SHELL FROM MAIN BODY OF NEBULA

λ (Å)	Ident.	Position	I_{ptg}
5007....	[O III]	45″ E. 30″ E. 38″ W.	0.18 .36 .27
3868.....	[Ne III]	26″ E. 29″ W.	08 0 06

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