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SHARPLESS 216: A CURIOUS EMISSION-LINE NEBULA

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ABSTRACT

Spectrophotometry is presented for the large and very faint emission nebula known as Sharpless 216. Although classified as an H II region, our observations show it has stronger lines of [S II] $\lambda\lambda$6717,6731 and [N II] $\lambda\lambda$6583,6548 relative to Hα than are seen in the spectra of H II regions. While the spectrum of S216 is similar to that observed for supernova remnants, the nebula does not show any filamentary structure on either direct narrow passband imagery or on the Palomar Sky Survey, and it is not coincident with any known extended nonthermal radio source. S216's spectral properties are also similar to those of a few peculiar planetary nebula, and it does exhibit a pronounced ionization structure in which the [O III] emission is stronger toward the interior. We discuss the possibility that this object is an H II region, a planetary nebula, or a supernova remnant.

Subject headings: nebulae: individual — nebulae: planetary — nebulae: supernova remnants

I. INTRODUCTION

In a recent survey of the galactic plane using interference filter photographs (Parker, Gull, and Kirshner 1979, hereafter PGK), a large faint diffuse nebula at $\alpha = 4^h37^m.3$, $\delta = +46°35'$ (1950) known as Sharpless 216 (Sharpless 1959; also YM 22, Johnson 1954) was found to have strong [S II] $\lambda\lambda$6717,6731 emission relative to Hα + [N II]. A follow-up [O I] λ6300 photograph also showed that the object has stronger [O I] emission relative to Hα + [N II] than is usually seen in H II regions. The object appears on the Palomar Sky Survey as a faint 80′ long crescent-shaped nebula, showing no resolved filamentary structure. However, the deeper Hα + [N II] photographs of PGK and Meaburn (1971) show that the object is distinctly circular having an apparent diameter of 100′, and whose center lies almost exactly on the galactic plane ($l = 158.°3$, $b = +0.°1$).

Strong [S II] $\lambda\lambda$6717,6731 emission relative to Hα has been a successful criterion in searches for galactic and extragalactic supernova remnants (SNRs) (Mathewson and Clarke 1973; van den Bergh 1978; D'Odorico, Dopita, and Benvenuti 1980; Blair, Kirshner, and Chevalier 1981). This is because the passage of a supernova's blast wave compresses and heats the encountered interstellar medium which then cools slowly, creating a stratified ionization structure behind the shock front. The presence of electrons at a temperature near 10,000 K in the zone where S^+ is the dominant ionization species of sulfur, together with the large collisional cross sections of the $^2D_{3/2,5/2}$–$^4S_{3/2}$ transitions, tend to produce much stronger [S II] $\lambda\lambda$6717,6731 emission relative to Hα than is usually seen in H II regions.

Despite its relatively strong [S II] emission, S216 is not a previously known or suspected optical SNR (van den Bergh 1978). This may be due to its very low surface brightness and diffuse appearance. Moreover, its position is not coincident with any known nonthermal radio source (Milne 1970; Downes 1971; Ilovaisky and Lequeux 1972; Clark and Caswell 1976). The nearest nonthermal radio source is the once suspected SNR radio source CTB 13 (Milne 1970; Downes 1971; Haslam and Salter 1971), whose outermost radio contours overlap the southern part of S216, but which is centered $\sim 2°$ to the southwest. Although S216 has been classified as an H II region (Marsalkova 1974), it was not detected by Felli *et al.* (1976) in a search for extended radio sources near the galactic plane. Also, no exciting star for the nebula is known (Johnson 1954; Georgelin and Georgelin 1973).

While strong [S II] $\lambda\lambda$6717,6731 emission relative to Hα is characteristic of the spectra of SNRs, some other types of nebulae also exhibit strong [S II] emission in their spectra. These include Herbig-Haro objects, which have spectra very similar to SNRs but are thought to be stellar wind driven shocks around young stars (Dopita 1978; Schwarz 1978) and a few low excitation planetary nebulae such as S188 and S274 (Leibowitz 1975; Kwitter 1979). Although S216 could be related to these few peculiar planetary nebulae, its large, diffuse, and fairly uniform structure makes it very unlikely that it is a Herbig-Haro object. After presenting our observations in § II, followed by a brief analysis in § III, we will discuss various interpretations of S216 and suggest some possible future observations that would be helpful toward understanding this object.

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TABLE 1

LOG OF OBSERVATIONS

UT Date	Integration Time (s)	Position	Slit Orientation	Slit Coordinates	
				$\alpha(1950)$	$\delta(1950)$
1980 Jan 16	5000	B	E–W	$04^h41^m38^s$	+46°45′47″
1980 Jan 21	2700	C	E–W	04 41 06	+46 41 03
1980 Jan 21	600	A	E–W	04 42 00	+46 43 38
1980 Mar 17	2400	A	N–S	04 42 00	+46 43 38

II. OBSERVATIONS

In Figure 1 (Plate 1) we reproduce the Hα + [N II], [O III], and [SII] interference filter photographs of S216 from PGK (S216 was fortuitously centered in the $l = 158°$, $b = 0°$ field in PGK's survey) and also an [O I] λ6300 photograph obtained with the same equipment. A description of the instrumentation and the characteristics of the filters is given by PGK. The [O I] filter used has a passband of 12 Å (FWHM) centered at 6299 Å. The original plates covered a 7°.1 circular field at 12′ mm^{-1} and had an effective resolution of 30″–40″ limited by the linear resolution of the image intensifier.

We have obtained spectrophotometry at three positions in the brighter eastern portion of the nebula using the 2000 channel intensified Reticon spectrometer on the 1.3 m telescope of the McGraw-Hill Observatory. The spectrometer employs six stages of image intensification, a self-scanned diode array, and pulse centroid-finding electronics. Because of the large angular size of S216, the telescope was moved to a position well outside the nebula for sky measurements every 10 minutes. The slit size used for all the observations was 4″ × 40″. Accurate slit positioning and guiding was made possible by an intensified television guiding system. The log of observations is given in Table 1 with the slit positions indicated in Figure 2.

Data reduction consisted of subtracting the sky scans, placing the data on a linear wavelength scale by using

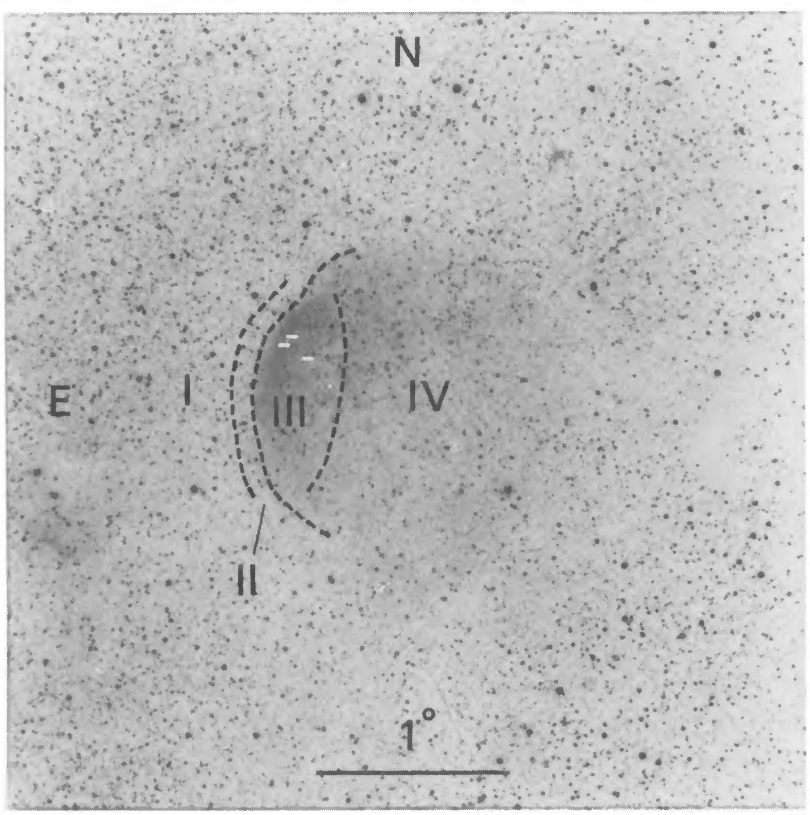

FIG. 2.—An Hα + [N II] interference filter photograph of S216 and vicinity with areas having differing amounts of obscuration indicated as Regions I–IV. The small white rectangles indicate the three slit positions, but are not drawn to scale.

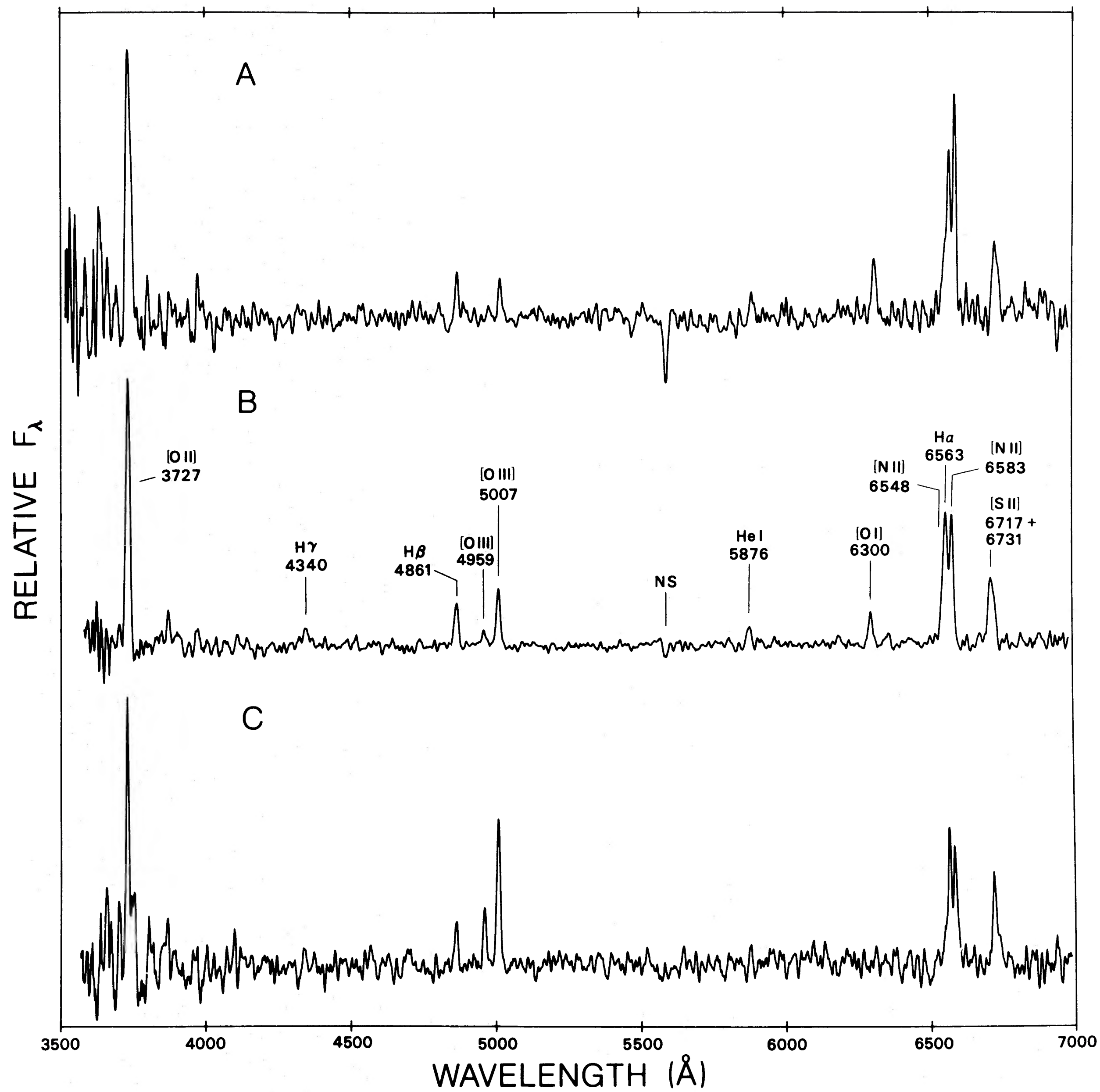

FIG. 3.—Spectra of S216 at three locations in the nebula's eastern sector. Relative flux per unit wavelength is plotted vs. the observed wavelength. The resolution of the data as shown here is about 15 Å. The dip at 5577 Å is due to imperfect sky subtraction of the [O I] airglow emission.

observations of comparison lamps, and correcting for atmospheric extinction using mean extinction values for Kitt Peak (Strom and Barnes 1977). The instrumental response was determined from observations of white dwarfs whose absolute fluxes for given wavelength intervals are known (Oke 1974). The spectral coverage of each scan was 3600–7000 Å with a resolution of about 10 Å. The reduced spectra are shown in Figure 3, with the observed line intensities, $F(\lambda)$, on a scale where $F(\mathrm{H}\beta) \equiv 100$, given in Table 2. The error estimate for a relative line measurement is $\pm 25\%$ for the strongest lines, with larger errors for weaker lines, the [O II] λ3727 line, and the [O I] λ6300 line as a result of sky subtraction uncertainties.

III. ANALYSIS

Inspection of the region near S216 on the Palomar Sky Survey (PSS), the Lick Observatory Sky Atlas, and PGK's interference filter photographs (see Fig. 1) shows the absorption to be very patchy. This has been confirmed by star counts on the blue PSS print in the four regions shown schematically in Figure 2. Region I appears to be an area of relatively low absorption, and there appears to

TABLE 2

OBSERVED RELATIVE LINE INTENSITIES ($F_{H\beta} = 100$)

λ(Å)	ID	Position A	Position B	Position C
3727	[O II]	904	622	564
3868	[Ne III]	...	(80)	...
4340	Hγ	...	43	...
4861	Hβ	100	100	100
4959	[O III]	...	34	133
5007	[O III]	86	131	347
5876	He I	65	43	(50)
6300	[O I]	142	74	<75
6364	[O I]	...	26	...
6548	[N II]	142	86	67
6563	Hα	354	299	306
6583	[N II]	493	294	267
6717	[S II]	133	144	245
6731	[S II]	100	105	

be a narrow band of higher extinction (Region II) just east of the brightest section of S216. Region III contains the brightest area of the nebula, and the star counts here indicate that the absorption in this direction is almost the same as in Region I. An extended area of heavier obscuration is seen in Region IV. It is tempting to physically associate the nebula with the dust lane of Region II since the brightest part of the nebula seems to be bounded by it. It is also possible that the western portions of the nebula appear fainter because of heavier obscuration, but no direct observations to confirm this are available.

The observed Hα/Hβ ratios for our three positions in S216's eastern sector are all close to 3.0 (see Table 2). This suggests a small amount of reddening ($E(B-V) \lesssim 0.25$ mag) to this portion of the nebula, regardless of whether the gas is photoionized or collisionally ionized (Brockelhurst 1971; Raymond 1979). Considering possible errors in our measured line intensities, we can place an upper limit on the color excess of about 0.5 mag.

Studies by FitzGerald (1968) and Lucke (1978) show the extinction to be very low within about 250 pc of the Sun for galactic longitudes near 160° and it increases rapidly thereafter. Their studies when combined with our observed upper limit to the reddening of 0.5 mag suggest a distance to S216 of less than 1 kpc. However, it is not certain that these surveys of the general obscuration can yield strict distance limits over small angular regions, especially in the light of the patchy extinction in the direction to S216. If the object is nearby, it would be in our local spiral arm while distances of 1–2 kpc would place it in the Perseus arm.

An examination of our interference filter photographs reveals the presence of a resolved ionization structure in the nebula's eastern sector (see Fig. 1). Comparison of S216's [O III] image with its [O I], [S II] and Hα + [N II] images shows clearly that the [O III] emission is concentrated toward the optical center of the object, while the others are conspicuously brighter along the eastern rim. This spatial difference amounts to several arc minutes and suggests a systematic decrease in ionization from the nebula's center outward. This ionization structure is also evident in the spectroscopic data shown in Figure 3 where the strength of the [O III] lines decreases as the [O I] and [N II] lines increase moving from position C (closest to center) to position A (closest to edge).

As a result of S216's low surface brightness, we were unable to measure the line strength of either [O III] λ4363 or [N II] λ5755 and thereby obtain an estimate for the nebula's electron temperature. However, we are able to estimate S216's electron number density. Using Pradhan's (1978) collisional cross-section values, the observed [S II] λλ6717,6731 ratio suggests values $\lesssim 100$ cm^{-3}. Although this ratio is not well determined from our data, we believe the data does constrain the electron density at these locations in the nebula to values less than 1000 cm^{-3}. A relatively low electron density is also supported by the observed Hβ flux from S216. The observed flux in Hβ can be expressed

$$F(\mathrm{H}\beta) = \frac{N_p N_e E(\mathrm{H}\beta) V}{4\pi d^2}, \quad (1)$$

where N_p and N_e are the number densities of protons and electrons, $E(\mathrm{H}\beta)$ is the emissivity of Hβ in units of ergs cm^3 s^{-1}, V is the volume of the gas being observed, and d is the distance to the object in parsecs. Replacing V by $l\Theta_x \Theta_y d^2$, where Θ_x and Θ_y are the angular dimensions of the slit in radians, and l is the path length in the emitting gas, we have

$$l(\mathrm{cm}) = \frac{4\pi I(\mathrm{H}\beta)}{N_e^2 E(\mathrm{H}\beta)\Theta_x \Theta_y}. \quad (2)$$

Assuming a 10% mixture of helium by number, choosing $E(\mathrm{H}\beta)$ for 10,000 K, and using our observed Hβ flux of $\sim 10^{-14}$ ergs cm^{-2} s^{-1}, we find the path length in parsecs to be equal to

$$l(\mathrm{pc}) \approx \frac{117}{N_e^2}. \quad (3)$$

This expression is independent of the distance or the source of ionization. Electron densities greater than 100 cm^{-3} lead to very small path lengths (i.e., ≤ 0.01 pc) which requires either an implausibly small size for the nebula or a very thin shell of emission—a situation unlikely in view of its resolved ionization structure. Therefore, we conclude that the [S II] line ratio as well as the observed Hβ flux indicate a low electron density for the nebula.

IV. DISCUSSION

Although catalogued as an H II region, S216 exhibits properties unlike those of normal H II regions. There are no obvious exciting OB stars within the nebula, and it has an unusually diffuse and symmetrical appearance. Also relative to H II regions, our spectra of S216 reveal it to have much stronger [O I], [N II], and [S II] emission (cf. Kaler 1976). The unusual strength of the [N II] and [S II] lines can be clearly seen by comparing S216's line intensities with the line ratio diagrams of Sabbadin, Minello, and Bianchini (1977) and D'Odorico (1978) in which the Hα, [N II], and [S II] line intensities are used to distinguish between H II regions, SNRs, and planetary nebulae.

S216 is seen to have a much smaller Hα/[S II] ratio (1.2–1.5) and a much larger [N II]/Hα ratio (1.1–1.8) than H II regions. However, its line intensities are compatible with those of SNRs and a few peculiar low excitation planetary nebulae. We will discuss these two possible interpretations below.

a) *Supernova Remnant?*

The absence of any obvious source of photoionization and the similarity between its spectral properties and those of SNRs suggests a possible interpretation of S216 as a large and probably old SNR. In Table 3 we compare our observations for S216 position B with observations of two SNRs, the Cygnus Loop (Miller 1974) and IC 443 (Fesen and Kirshner 1980), and also with selected shock wave models from Raymond (1979) and Shull and McKee (1979). While these SNRs have higher surface brightnesses than S216 and show a characteristic filamentary structure, there are significant similarities in the relative line intensities of these remnants and S216. Likewise, a reasonable agreement exists between our observations and theoretical shock wave models having velocities of 70–100 km s^{-1}.

Although virtually every optical SNR exhibits nonthermal radio emission, the lack of any detected nonthermal radio emission from S216 is not necessarily a strong argument against its identification as a SNR. Nonthermal radio emission from the SNR G65.2 + 5.7 was only recognized after its optical detection (Gull, Kirshner, and Parker 1977; Reich, Berkhuijsen, and Sofue 1979), and no known radio source is associated with the remnant G343.2 − 5.6 (Meaburn and Rovithis 1977). This last remnant might be an example of an SNR which has escaped radio detection because its surface brightness is near or below that of the adjacent nonthermal galactic disk background emission. Because of S216's large angular size ($\sim 100'$) and its position in the galactic plane where confusion with the general galactic background can occur, it is plausible that S216 might also have been missed. Assuming a surface brightness limit of $\Sigma(408\ \mathrm{MHz}) \approx 3 \times 10^{-21}$ W m^{-2} Hz^{-1} sr^{-1} (Clark and Caswell 1976) and the Σ-diameter relation given by Caswell and Lerche (1979), we find that S216 must have a diameter larger than about 40 pc to have escaped detection. This would indicate a distance to S216 of larger than 1.3 kpc, which is in conflict with the low reddening our observations imply for its eastern sector.

If we assume that S216 is a SNR which is still in the adiabatic phase of its evolution, then we can roughly estimate the initial energy injected by the supernova explosion and then compare it to the values derived for other SNRs. First, we calculate the preshock density using Dopita's (1978) formula,

$$N[\mathrm{S\ II}] = 45N_c\left(\frac{V_s}{100\ \mathrm{km\ s^{-1}}}\right)^2\ \mathrm{cm^{-3}}\ , \qquad (4)$$

where N[S II] is the observed electron density from the [S II] lines, N_c is the preshock electron density, and V_s is the shock velocity. Letting $V_s \sim 70$–100 km s^{-1} and $N[\mathrm{S\ II}] \lesssim 100\ \mathrm{cm^{-3}}$, we obtain $N_c \lesssim 2$–5 $\mathrm{cm^{-3}}$. The initial energy can then be estimated using the formula of McKee and Cowie (1975),

$$E_0 = 2 \times 10^{46}\beta'^{-1}N_c\left(\frac{V_s}{100\ \mathrm{km\ s^{-1}}}\right)^2 R^3\ \mathrm{ergs}\ , \qquad (5)$$

where β' describes the ratio of the pressure in a cloud and intercloud medium and is near unity, and R is the radius of the SNR in parsecs. If we adopt $R \approx 25$ pc (from the above radio considerations) and N_c and V_s from equation (4), we find $E_0 \lesssim 3$–16×10^{50} ergs, a range of values consistent with estimates for other SNRs.

While most SNRs show a filamentary structure, some remnants such as G290.1 − 0.8 (Kirshner and Winkler 1979), OA 184 and HB 3 (van den Bergh, Marscher, and Terzian 1973), and N120 and N206 in the Large Magellanic Cloud (Lasker 1976, 1977) do not. Therefore, the diffuse appearance of S216 does not argue decisively against its identification as a SNR. However, the apparent ionization structure mentioned above is difficult to reconcile with a picture where the optical emission comes from a gas cooling behind a shock front. In cases where SNRs show an ionization structure, the [O III] emission is found ahead of the hydrogen, [N II], and [S II] emission zones (Lasker 1977; Kirshner, Fesen, and Blair 1980).

TABLE 3

Comparison of S216 with SNRs and Shock-Wave Models

					Raymond			Shull & McKee
Line	ID	S216-B	Cygnus Loop[a]	IC 443[b]	BB 70.7 km s^{-1}	DD 90 km s^{-1}	V 100 km s^{-1}	J 100 km s^{-1}
3727	[O II]	622	1300	584	681	675	543	522
4959, 5007	[O III]	165	440	128	223	433	303	301
5876	He I	43	10	9	11	8	18	16
6300, 6364	[O I]	100	62	116	112	39	269	138
6548, 6583	[N II]	380	345	230	117	316	141	184
6563	Hα	299	308	300	301	302	298	309
6717, 6731	[S II]	249	284	344	214	168	310	479

[a] Miller 1974; Position 1.
[b] Fesen and Kirshner 1980; Position 4.

This is opposite of what is seen in S216, and thus is an obstacle to the identification of S216 as a SNR.

b) *Old Planetary Nebula?*

The circular appearance of S216 along with an ionization structure similar to that seen in photoionized nebulae suggests the possibility that S216 is an old planetary nebula (PN). It's close resemblance with the newly discovered very large and nearby PN by Purgathofer and Weinberger (1980) lends additional support to the PN identification. If this is the case, it would be among the closest and largest PNs known and would certainly have the largest angular size. According to Cahn and Kaler (1971), the largest PNs have radii ~ 0.5 pc, while the nearest PN (the Helix Nebula) is about 90 pc distant. If we assume S216 is a very large PN having a radius of 0.5–1.0 pc, then its apparent size would indicate distances of 34–69 pc.

Spectroscopically, S216 is similar to a few fairly large, low ionization PNs. In Table 4, we compare our observations for position B to two such PNs, S188 and S274 (YM 29), using data from Leibowitz (1975) and Kwitter (1979). We also list observations made by Hawley and Miller (1977) of a more typical PN, the Ring Nebula (NGC 6720). A comparison of these data indicates that strong [S II] emission relative to Hα, normally suggestive of a SNR identification, can sometimes be observed in PNs. The [S II]/Hα ratio also tends to increase toward a PN's outer regions (i.e., Pos. 4–Pos. 6 of NGC 6720). This could be a factor in a comparison of the data since our spectroscopic observations of S216 were taken near the nebula's perimeter. The strength of the [N II] lines seen in S216, while large relative to Hα, is far weaker than in these PNs.

Although the small distances associated with a PN interpretation are consistent with the small amount of observed reddening, an obvious central star candidate has not been found. From data compiled for old PNs (Abell 1966), we estimate that even a faint central star within S216 should have an absolute magnitude of roughly $M_{pg} \sim 6$–8. For distances in the range 25–100 pc, we would then expect to see a blue star with an apparent magnitude between $m_{pg} = 8$–13 (assuming no reddening) near the center of the nebula. Although this range goes below the magnitude limit of most catalogs, a search made of catalogs of early-type emission line stars (Wackerling 1970), luminous stars in the Milky Way (Hardrop, Theile, and Voight 1965), white dwarfs (Luyten 1960), O stars (Goy 1973; Cruz-Gonzales *et al.* 1974), and Wolf-Rayet stars (van der Hucht *et al.* 1981) indicates a few early-type stars within S216's large boundaries (e.g., the emission line star AS 84, Wackerling 1970). However, none of these is located sufficiently near the center of S216 to strongly suggest its connection with the nebula. Also, an inspection of the PSS revealed no outstanding central star candidates within a 10′ radius of the object's center. Theoretically, it is expected that PN central stars should cool and eventually become white dwarfs (e.g., Paczynski 1978) which have absolute magnitudes of $M_v = 10$–16. Although there has been little observational evidence that this cooling takes place on a time scale similar to the lifetime of the nebular shell (see Aller 1976), the very large PN recently discovered by Purgathofer and Weinberger (1980) does have a very faint central star which resembles a white dwarf. A central star as faint or fainter present in S216 could not be confidently identified by our search in such a large nebula.

V. CONCLUDING REMARKS

From the spectroscopic data presented here together with the optical appearance of the nebula in interference filter photographs, it is not possible to draw firm conclusions as to the nature of S216. However, our data do suggest that this object has spectral properties similar to supernova remnants and some low ionization planetary nebulae. Further observations are clearly needed to distinguish whether S216 is a supernova remnant with a low radio surface brightness and a peculiar ionization structure, or a large and nearby planetary nebula with a faint central star. Measurement of the [O III] λ4363 line intensity could decide between these possibilities by providing a measure of the [O III] electron temperature. We would expect the temperature in the O^{+2} zone to be greater than 20,000 K if the gas is shock-heated while it

TABLE 4

COMPARISON OF S216'S LINE INTENSITIES WITH THOSE OF PLANETARY NEBULAE

Line	ID	S216-B	S188[a]	S274[b]	NGC 6720[c] Pos. 4	NGC 6720[c] Pos. 6
3727	[O II]	622	1290	948	750	1980
4959, 5007	[O III]	165	320	250	1673	642
5876	He I	43	12	...	13	13
6300, 6364	[O I]	100	...	...	30	125
6548, 6583	[N II]	380	1210	1011	593	1417
6563	Hα	299	285	300	287	287
6717, 6731	[S II]	249	310	274	43	111

[a] Kwitter 1979; average spectrum.
[b] Leibowitz 1975.
[c] Hawley and Miller 1977.

would be on the order of ~ 10,000 K if it is photoionized. Also, if the electron density is above the low density limit, careful density measurements using either the [S II] $\lambda\lambda$6717,6731 or the [O II] $\lambda\lambda$3726,3729 line intensities could, when combined with Hβ flux measurements, yield accurate path length estimates for the object. This could lead to an estimate of the size of the object's emitting region as well as a distance to S216. Spectroscopy of the very faint western region, although difficult to obtain, could help decide if this region of the nebula is fainter due to intervening obscuration. More sensitive radio measurements searching for thermal or nonthermal emission from S216 would also provide valuable information concerning the nature of this curious object. Finally, if the nebula appears to be photoionized, a more thorough search for a central star candidate could be undertaken.

The object S216 has interesting implications, regardless of its eventual identification. If it turns out to be a supernova remnant, it would be only the second optical galactic remnant whose radio emission is too faint to be detected. It would also be the only known SNR with an ionization structure showing greater [O III] emission toward the center. If, somewhat more probably, S216 is a planetary nebula, it would be among the largest and closest planetary nebulae known and would have a faint central star.

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Note added in proof.—Additional spectrophotometry has been obtained during 1981 January using the Intensified Reticon Scanner (IRS) on the No. 1 0.9 m telescope at KPNO. A spectrum taken near the center of S216 shows low interstellar reddening, no increase in the [O III]/Hβ ratio over that seen for position C, and possibly weaker [S II] emission. Scans taken near position C showed slightly stronger [N II] line emission, an electron density inferred from the [S II] lines near 100 cm^{-3}, and an upper limit of 45,000 K for the [O III] temperature.

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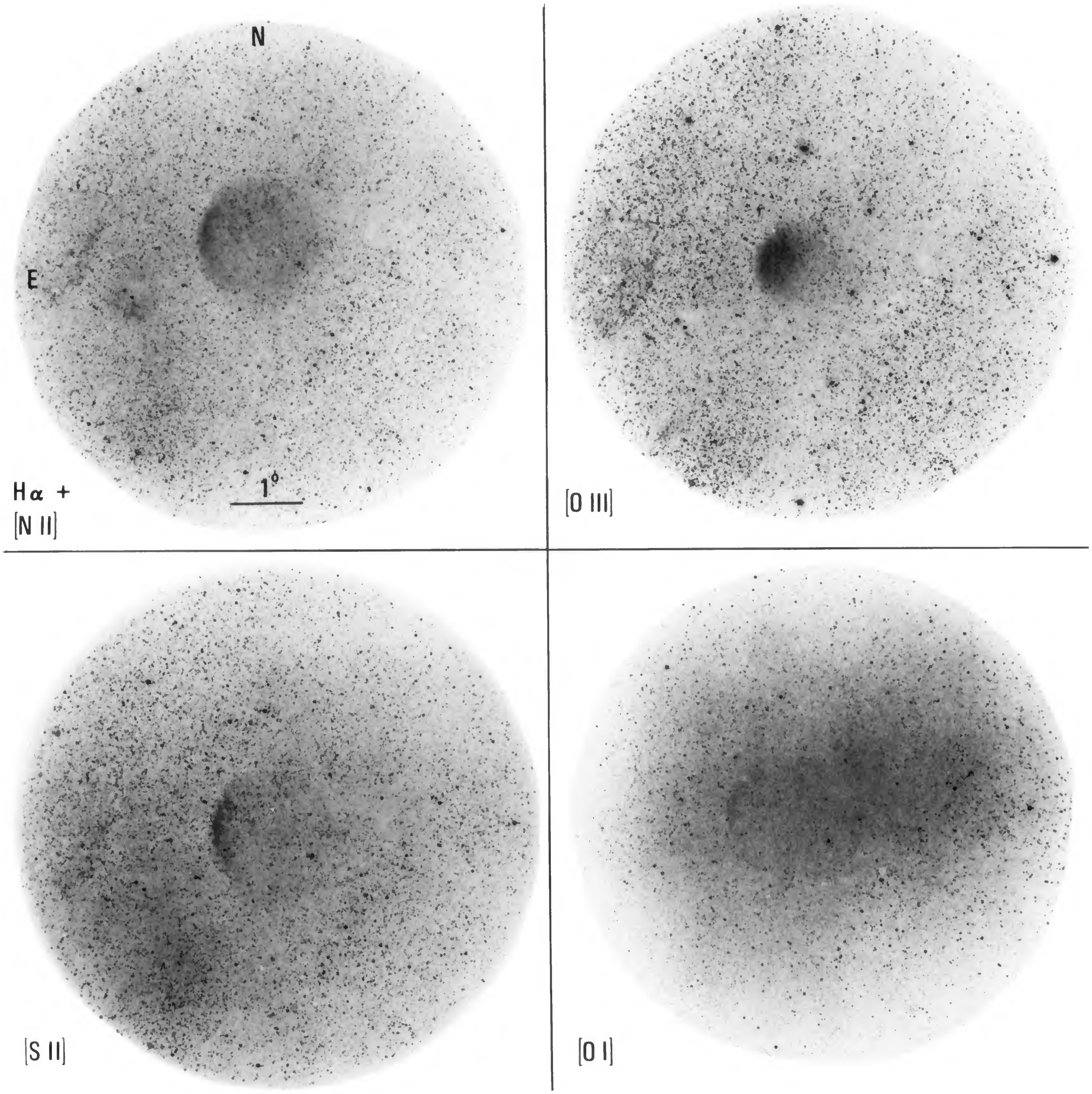

FIG. 1.—Narrow interference filter photographs of the nebula S216. The large nebulosity 2° due east of S216 is the supernova remnant HB 9.

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