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THE NATURE OF THE FILAMENTS NORTHEAST OF THE SUPERNOVA REMNANT IC 443

ROBERT A. FESEN[1]
Laboratory for Astronomy and Solar Physics, Goddard Space Flight Center
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ABSTRACT

New optical spectrophotometry of the faint filaments northeast of the bright supernova remnant IC 443 show emission-line ratios very similar to those seen in the bright filaments of IC 443 and other supernova remnants. This suggests that these northeastern filaments also represent shock-heated interstellar gas and are not simply the southern boundary of the neighboring H II region S249 as previously suspected. If these filaments are associated with IC 443, they then reveal a much more extended remnant structure than previously assumed and permit a relatively accurate determination of IC 443's distance via its interaction with S249.

Subject headings: nebulae: individual — nebulae: supernova remnants — shock waves

I. INTRODUCTION

The bright emission nebula IC 443 is a well-studied supernova remnant (SNR) located at $\alpha = 6^h14^m$, $\delta = +22°37'$ (1950) ($l = 189.0$, $b = +3.0$). Its northeastern rim is especially bright at optical and radio frequencies as a result of the interaction of the remnant's blast wave with a neighboring H I cloud (DeNoyer 1977) that is probably associated with the H II region Sharpless 249. Optical studies of IC 443's filaments made by Parker (1964), D'Odorico (1974), and Fesen and Kirshner (1980) showed it has emission-line ratios very similar to other well-evolved SNRs. A nearby line of relatively faint filaments located $\sim 20'$ east of the remnant's NE rim ($\alpha = 06^h16^m$, $\delta = 22°50'$) appears to mark the southernmost boundary of the western portion of S249. Three positions in these northeastern filaments were studied by D'Odorico (1974), who concluded they were probably not part of IC 443, but instead photoionized filaments of the H II region S249. High-resolution radio maps tend to support this conclusion in that they show the northeastern rim of IC 443 to be well defined with no confirmed nonthermal radio emission farther to the east or associated with these faint northeastern filaments.

However, we present new spectrophotometry of these northeastern filaments which shows that they have spectral properties very much like those generally observed in SNRs, and, in fact, very much like those seen in IC 443. In §§ II and III below, we describe the observational data and results, and in § IV we discuss possible interpretations of these optical filaments and their relation to the supernova remnant IC 443.

[1] NAS-NRC Research Associate.

II. OBSERVATIONS

Spectrophotometry of five regions northeast of IC 443 was obtained in 1980 November with the 2000 channel intensified Reticon spectrometer attached to the 1.3 m telescope at McGraw-Hill Observatory on Kitt Peak. This instrument is an improved version of the scanner described by Shectman and Hiltner (1976) and is a pulse-counting system employing six stages of image intensification, a self-scanned diode array, and pulse centroid-finding electronics. The scans covered the wavelength range 3700–7400 Å with 10 Å resolution. A log of the observations listing slit sizes and integration times is given in Table 1, with exact slit locations shown in Figure 1. Sky measurements with integration times equal to those for each object were taken at locations 10′ to 30′ due south where there was no noticeable emission on the Palomar Observatory Sky Survey prints. However, because the object and sky scans were not obtained simultaneously, the sky subtraction was often imperfect, resulting in some residue [O I] λ5577 airglow emission present in some of the data.

Data reduction consisted of subtracting the sky scans, placing the data on a linear wavelength scale using observations of comparison lamps, and correcting for instrumental response and atmospheric extinction. The instrumental response was determined from observations of white dwarfs whose absolute fluxes at given wavelength intervals are known (Oke 1974). The reduced spectra are shown in Figure 2. The observed line fluxes, $F(\lambda)$, and extinction corrected intensities, $I(\lambda)$, assuming the Whitford reddening law (Miller and Mathews 1972) and a theoretical Hα/Hβ ratio of 3.0, are given in Table 2 on a scale where $F(\text{H}\beta) = 100$.

TABLE 1
LOG OF OBSERVATIONS

Position	Date (UT)	Slit	Spectral Coverage (Å)	Integration Time (s)
A	1980 Nov 11	5″6 × 40″	3700–5200	3000
A	1980 Nov 12	3 × 40	3700–7400	1200
A	1980 Nov 13	3 × 40	3700–7400	1800
B	1980 Nov 13	5.6 × 40	3700–7400	1200
C	1980 Nov 12	3 × 40	3700–7400	900
D	1980 Nov 13	3 × 40	3700–7400	1500
E	1980 Nov 13	3 × 40	3700–7400	300

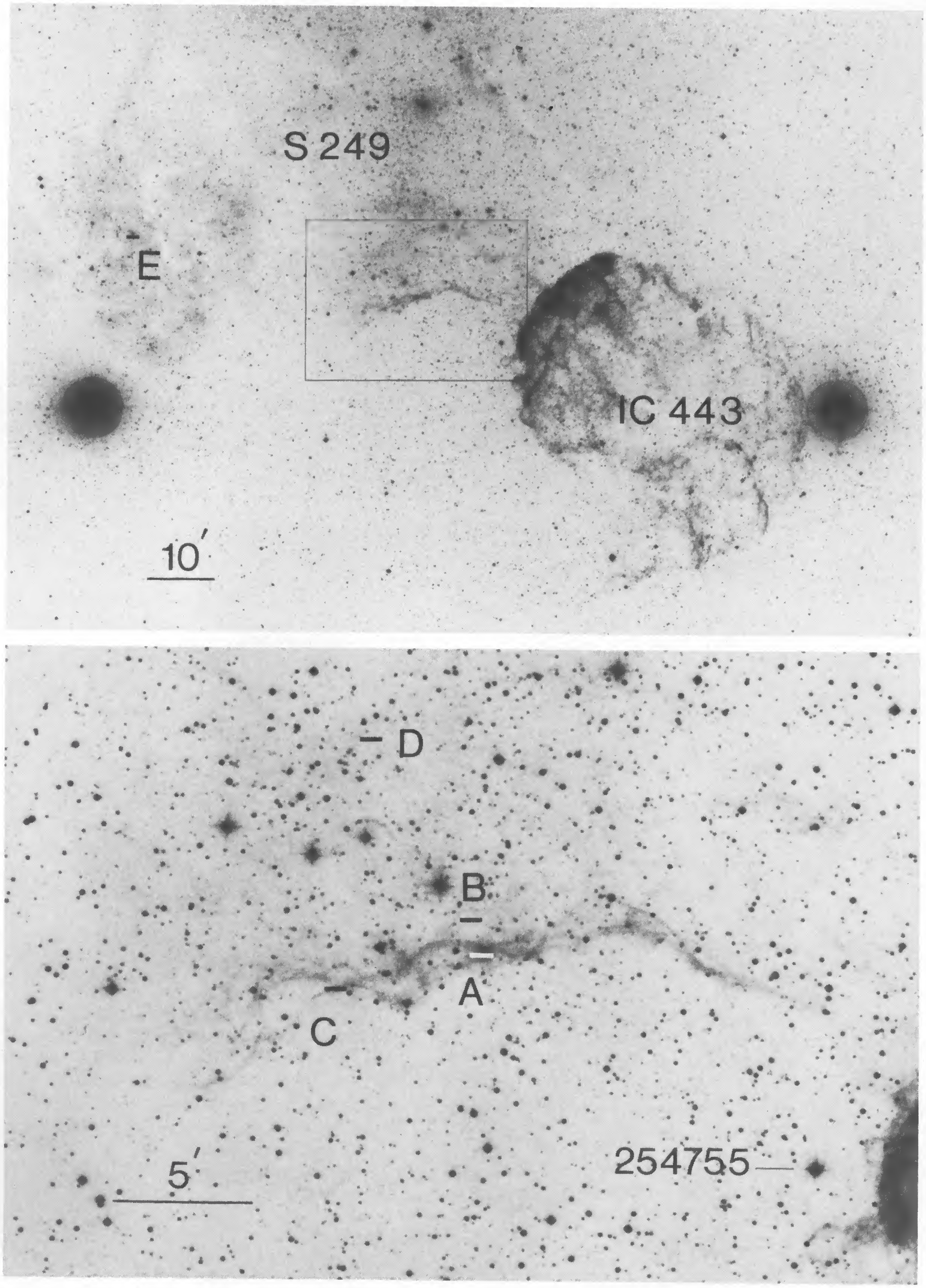

FIG. 1.—*Upper panel*: reproduction of the Palomar Observatory Sky Survey E-print showing the filaments studied along the southern border of the H II region S249 and northeast of the supernova remnant IC 443. North is up, east to the left. *Lower panel*: enlargement of these filaments showing slit positions A–D (position E is indicated in upper panel).

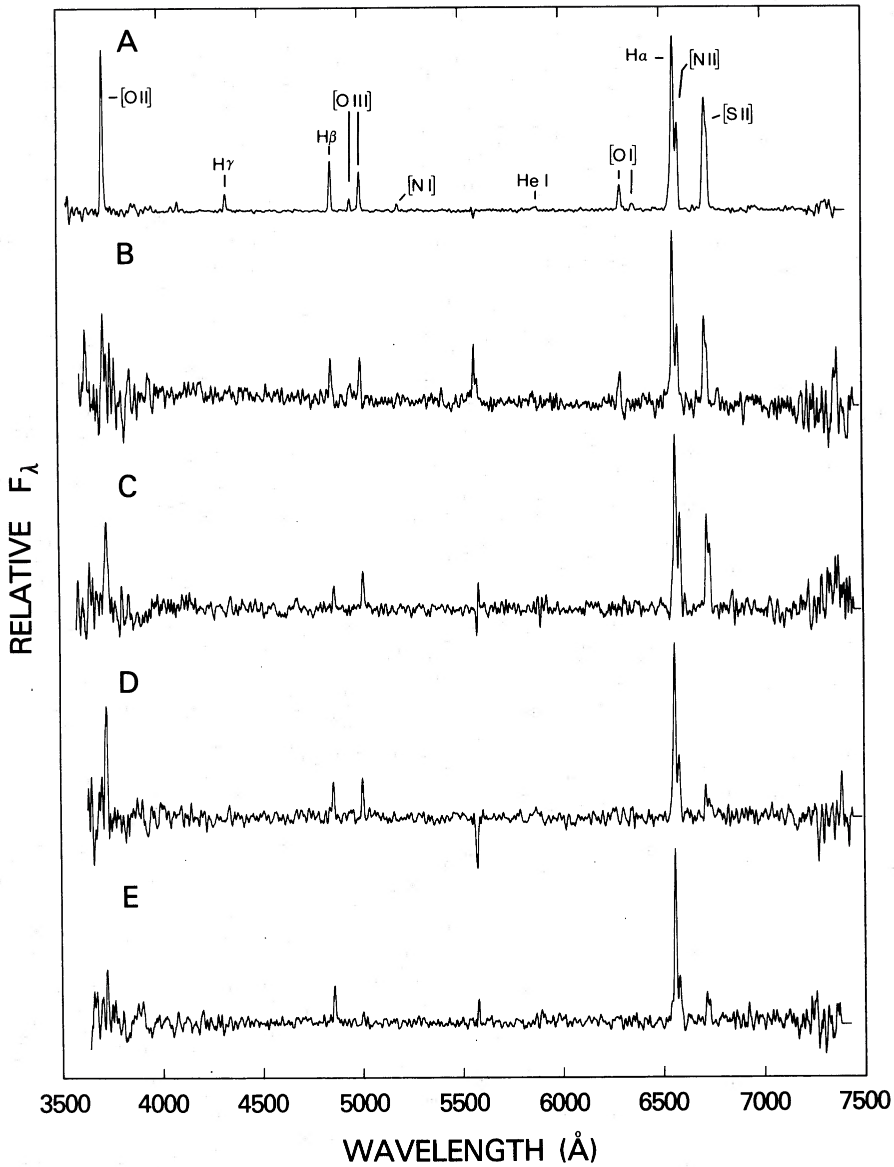

FIG. 2.—Spectra taken at three locations in the filaments northeast of IC 443 (A–C) and two regions in the H II region S249 (D and E). Relative flux (ergs cm^{-2} s^{-1} $Å^{-1}$) is plotted vs. observed wavelength. Feature at 5577 Å is due to imperfect sky subtraction of the [O I] airglow emission.

Emphasis was placed on obtaining good signal-to-noise data for one filament (position A) with much shorter integration, lower quality, exploratory scans on neighboring filaments (positions B and C) and portions of S249 (positions D and E). The relative line strength measurement errors for position A's strong lines are $\pm 20\%$ or better, but are considerably larger for weaker features and the remaining four positions. The data for position A shown in Figure 2 and listed in Table 2 are a combination of two low-resolution (10 Å FWHM) and one high-resolution (6 Å FWHM) scans.

III. RESULTS

The observed reddening for the filaments and the two regions studied in S249, assuming an intrinsic Hα/Hβ ratio of 3.0, ranges between an $E_{B-V} = 0.3$–0.8. Member stars of the Gem OB1 association lying in this direction which are responsible for the excitation of S249 show similar color excess values of $\sim$0.5–0.6 (Humphreys 1978). This amount of color excess is less than the 0.8–1.1 estimated from observations of IC 443's filaments (Fesen and Kirshner 1980) and for those Gem OB1 member stars lying in IC 443's direction (Humphreys 1978). While the absorption in this whole region appears very patchy, part of the increased extinction toward IC 443 might be due to a CO cloud lying partially in front of IC 443, as suggested by Cornett, Chin, and Knapp (1977) and Scoville *et al.* (1977).

The data for position A are sufficiently good to permit estimates of this filament's [S II] electron density and temperature. Using Pradhan's (1978) cross sections and Mendoza and Zeippen's (1982) A-values, the observed [S II] λ6717/λ6731 ratio of 1.38 indicates $N_e \approx 100$ cm^{-3}. The [S II] data for positions B and C also show λ6717/λ6731 values near the low-density limit of 1.42. A [S II] temperature estimate is uncertain because of the weakness of the λ4068 + λ4076 lines, but the observed value of 0.05 for the ratio (λ4068 + λ4076)/

TABLE 2

Relative Line Intensities ($I_{H\beta} \equiv 100$)

Line	λ (Å)	A $F(\lambda)$	A $I(\lambda)$	B $F(\lambda)$	B $I(\lambda)$	C $F(\lambda)$	C $I(\lambda)$	D $F(\lambda)$	D $I(\lambda)$	E $F(\lambda)$	E $I(\lambda)$
[O II]	3727	340	505	...	...	(360)	(730)	(300)	(403)	(135)	(185)
[Ne III]	3869	19	27	...	...	...	...	...	...	...	...
He I + H	3889	19	27	...	...	...	...	...	...	...	...
[Ne III] + H	3968	(13)	(18)	...	...	...	...	...	...	...	...
[S II]	4071	(11)	(15)	...	...	...	...	...	...	...	...
Hδ	4102	18	24	...	...	...	...	...	...	...	...
Hγ	4340	35	43	...	...	...	...	...	...	...	...
[O III]	4363	<6	<8	...	...	...	...	...	...	...	...
Hβ	4861	100	100	100	100	100	100	100	100	100	100
[O III]	4959	23	22	(30)	(29)	...	...	...	...	...	...
[O III]	5007	80	76	95	92	145	132	110	106	36	35
[N I]	5199	14	13	...	...	...	...	...	...	...	...
He I	5876	(8)	(6)	...	...	...	...	...	...	...	...
[O I]	6300	67	45	...	...	...	...	...	...	...	...
[O I]	6364	19	13	...	...	...	...	...	...	...	...
[N II]	6548	75	48	(60)	(44)	(150)	(66)	(55)	(39)	(45)	(31)
Hα	6563	475	300	410	300	685	300	420	300	430	300
[N II]	6583	230	145	190	140	395	172	170	120	125	86
[S II]	6717	280	172	210	151	365	152	88	61	75	51
[S II]	6731	205	125	150	108	280	116	55	38	(70)	(47)
$E(B-V)$		0.43		0.29		0.8		0.32		0.34	

Note.—Parentheses indicate significantly more uncertain values.

(λ6717 + λ6731) suggests $T_e \approx 9000$ K. As a result of the filament's relatively low surface brightness and weak [O III] line emission, the temperature-sensitive 4363 Å line was unfortunately not detected.

The spectrum observed at position A appears representative of the entire line of faint filaments and is substantially different from the rest of S249's emission regions. This is indicated by the strong [S II] emission reported by D'Odorico for three of the filaments, as well as by our short-integration scans at positions B–E (see Fig. 1). Position B studied the diffuse emission immediately north ($\sim 70''$) of position A, and position C sampled the filament located at the far eastern end of these filaments. Although the data quality for positions B and C are poor, both spectra show strong [S II] and [N II], with Hα/[S II] ratios of 1.16 and 1.12, respectively. Spectra taken of S249's emission considerably away from these filaments showed much weaker [S II] and [N II] line emissions. The [S II] emission is 2–3 times weaker at positions D and E than seen at positions A, B, or C. Furthermore, while [O II] and [O III] line strengths do not appear to vary much between these positions, [O I] λ6300 emission was observed only at filament positions A and B. Spectral differences between these filaments and other portions of S249 are qualitatively confirmed by [O III], [S II], and Hα + [N II] interference filter images of the whole region obtained in the Parker, Gull, and Kirshner (1979) galactic plane photographic survey. The filaments appear noticeably brighter in [S II] (and probably [O III] as well) relative to S249's diffuse regions. Therefore, the spectral properties of these filaments are considerably different from those of the rest of S249.

IV. DISCUSSION

Up to now, the faint filaments located northeast of IC 443 have been assumed to be just the southwestern boundary of the H II region S249. Despite their filamentary appearance and close angular proximity to IC 443, this assessment was based upon (i) the lack of any known nonthermal radio emission associated with these filaments, (ii) the relatively sharp and well-defined boundary of IC 443's radio and optical emissions in the northeast, and (iii) D'Odorico's (1974) photoionization interpretations of their optical spectra. However, our new optical spectra reveal emission-line intensities substantially different from those seen in normal H II regions or other sections of S249 itself, but which are very similar to those found in evolved supernova remnants and in particular IC 443. We now discuss these faint filaments' spectra in comparison to other emission nebulae and propose a possible interpretation.

a) Filaments of S249?

To begin with, our optical spectrophotometry and D'Odorico's red photometric spectra are in good agreement regarding observed relative line strengths. Our position A is very near D'Odorico's region 33 where we measure Hα/[N II] λ6583 and Hα/[S II] ratios of 2.07 and 1.01, whereas D'Odorico reports values of 2.1 and 0.96, respectively.

D'Odorico studied three positions in these filaments (Nos. 32, 33, and 34) and found their Hα/[S II] ratios range between 0.96 and 1.43. These values are larger than the 0.5–1.0 D'Odorico measured for IC 443's filaments, and he considered this difference together with the filament's lower electron densities to be significant enough to conclude that they were fundamentally different from the filaments in the IC 443 supernova remnant. He suggested that they were regions photoionized either by stars in the Gem OB1 association like the rest of S249 or by emission from IC 443.

The H II region S249 is probably excited by stars in the Gem OB1 association (Goy 1972; Georgelin, Georgelin, and Roux 1973) with four member stars classified earlier than B0

(Crawford *et al.* 1955; Hardie, Seyfert, and Gulledge 1960). The O9 V stars HD 255055 and 256036 lie near observed diffuse emission regions, with HD 254755 only 5′–10′ southeast of S249's filaments. Churchwell and Walmsley (1973), on the other hand, have suggested S249 might be a fossil Strömgren sphere. However, it is unlikely that these filaments are photoionized since they possess spectral properties unlike those of normal H II regions or other regions of S249. This is probably best indicated by their relatively strong [S II] λλ6717, 6731 emission; i.e., Hα/[S II] = 0.96–1.4. Studies of both galactic and extragalactic H II regions have shown that Hα/[S II] ratios less than 1.5 are not observed in H II regions with normal abundances (Kaler 1976, 1981; Sabbadin and Bianchini 1977; D'Odorico 1978; Blair, Kirshner, and Chevalier 1981; Dennefeld and Stasinska 1983) or in H II filaments (Dufour and Mathis 1975; Danks and Manfroid 1976; Hua and Llebaria 1981). In fact, strong [S II] emission has been a successful discriminator between photoionized nebulae (H II regions and planetary nebulae) and collisionally ionized nebulae (supernova remnants) (Mathewson and Clarke 1973; van den Bergh 1978; Blair, Kirshner, and Chevalier 1981). Although Hα/[S II] is not a completely unambiguous test, it is most effective when Hα/[S II] < 1.5 and $I(5007)/H\beta > 0.5$ (Blair, Kirshner, and Chevalier 1981; Kaler 1981), which is the case for these filaments. Moreover, the lines of He I λ5876, [N I] λ5199, and [O I] λλ6300, 6364 in position A's spectrum also appear substantially stronger than seen in normal H II regions (Kaler 1976). Therefore, the line strengths observed at positions A, B, and C, as well as D'Odorico's three locations, are clearly atypical of an H II region.

Ionization of these filaments by IC 443's X-ray emission or UV precursor from its hot filaments appears also unlikely. With a total X-ray flux of less than 10^{35} ergs s^{-1} (2–10 keV) (Charles, Culhane, and Rapley 1975), IC 433's X-ray emission is too weak to cause the observed ionization in these filaments at a distance of 2–8 (dist./1.5 kpc) pc from the remnant's NE rim (Kallman and McCray 1982). A similar argument can be made for the remnant's UV precursor emission from the hotter filaments producing an ionized region just ~0.05 pc ahead of the filaments (Shull and McKee 1979). Even if some source of photoionization could be found, it would still leave unanswered why this emission has a filamentary structure.

b) Shocked Filaments?

Filamentary morphology in an otherwise diffuse H II region, relatively strong [S II] emission, and a location along S249's apparent southern boundary taken together suggest that these filaments might represent shocked gas. Although their line strengths are atypical of H II regions, they are nearly identical to those seen in the shock-heated spectra of supernova remnants. In fact, with the exception of having a smaller amount of excitation, the spectrum observed at position A is very similar to that seen in some of IC 443's filaments. This is shown in Table 3 where position A's spectrum is compared to two filaments in IC 443 and one in the Cygnus Loop, as well as two shock model calculations of Raymond (1979). Position A exhibits similar [O III], [O II], [O I], [N II], [N I], [Ne III], [S II], and He I line strengths (relative to Hβ) to those found in these two remnants and predicted by the shock models. Considering the range of spectra observed among IC 443's filaments (D'Odorico 1974; Fesen and Kirshner 1980), it indeed would be difficult to distinguish position A's spectrum from those of IC 443's filaments. Thus, although at the boundary of an H II region, shock heating appears to be the probable ionization mechanism for these filaments. However, a decisive optical test for determining whether or not these filaments are shock heated, namely, measuring a very high [O III] electron temperature (>20,000 K), was not possible from our data.

If we interpret position A's spectrum using Raymond's (1979) shock models, then a shock velocity ~70 km s^{-1} is suggested by the reasonable agreement of the observations with model BB which used $V_s = 70.7$ km s^{-1}. Similar shock velocities of 65–100 km s^{-1} were estimated for IC 443's filaments using these same models (Fesen and Kirshner 1980). Although recent studies have raised questions about the applicability and accuracy of these steady flow models for obtaining shock parameter estimates (e.g., Fesen, Blair, and Kirshner 1982), for IC 443 the values obtained in this way agree well with the radial velocity measurements of Lozinskaya (1969) and Pismis and Rosado (1974).

In an adiabatic shock, a velocity of 70 km s^{-1} would imply an expansion velocity of $\frac{3}{4}V_s$ or ~50 km s^{-1}. A velocity this large is not likely to result from simple expansion of D-type ionization fronts within H II regions but could be produced either by supersonic stellar winds (Dyson 1977) or in supernova remnants. In the case of stellar wind–driven shells where photoionization is important, [S II] emission relative to Hα is not as strong as seen in SNRs or in these NE filaments. Examples of such stellar wind–driven filaments are the "strong" [S II] emission nebulae (i.e., Hα/[S II] ≈ 2.0) in the LMC (Lasker 1977; Dopita *et al.* 1981) and the Bubble Nebula NGC 7635 (Sabbadin and Bianchini 1977). A stellar wind–

TABLE 3

COMPARISON OF NE FILAMENTS WITH SUPERNOVA REMNANTS AND SHOCK MODELS

($I_{H\beta} = 100$)

Line	λ (Å)	NE Filaments Position A	IC 443[a] P1	IC 433[a] P2	Cygnus Loop[b] A	Model[c] BB	Model[c] V
[O II]...........	3727	505	721	578	747	681	543
[Ne III]..........	3869	27	40	(30)	25	42	68
[O III]...........	5007	76	152	32	140	167	227
[N I]............	5199	13	19	15	11	15	37
He I.............	5876	(6)	7	8	5	11	18
[O I]............	6300	45	79	73	62	84	202
[N II]............	6583	145	164	151	207	88	224
[S II]............	6725	297	322	288	192	214	310

[a] Fesen and Kirshner 1980.
[b] Fesen, Blair, and Kirshner 1982.
[c] Raymond 1979.

driven shock is also unlikely considering the estimated shock velocity and the apparent separation of the filaments from the nearest O star. The nearest likely source of appreciable stellar winds for creating these filaments is the O9 V star HD 254755. Adopting a distance of 1.5 kpc to it and S249, the 15′ separation between HD 254755 and the brightest portion of these filaments yields a minimum separation distance of 6.5 pc. Castor, McCray, and Weaver (1975) have shown that a stellar "bubble" driven by a star emitting a L_w ergs s^{-1} wind will in time, t, expand to an outer radius, $R(t)$, having an expansion velocity of $\dot{R}(t)$ in a medium of density n_0, where

$$R(t) = 27 n_0^{-1/5} \left(\frac{L_w}{10^{36}}\right)^{1/5} \left(\frac{t}{10^6 \text{ yr}}\right)^{3/5} \text{ pc} , \quad (1)$$

and

$$\dot{R}(t) = 16 n_0^{-1/5} \left(\frac{L_w}{10^{36}}\right)^{1/5} \left(\frac{t}{10^6 \text{ yr}}\right)^{-2/5} \text{ km s}^{-1} . \quad (2)$$

The luminosity of the wind is given by

$$L_w = \frac{1}{2} \dot{M}_w V_w^2 = 1.27 \times 10^{36} \left(\frac{\dot{M}_w}{10^{-6}}\right) \left(\frac{V_w}{2000}\right)^2 \text{ ergs s}^{-1} , \quad (3)$$

where $\dot{M}_w$ is the mass-loss rate in solar masses per year and V_w is the wind's terminal velocity in kilometers per second. Choosing $\dot{M}_w = 1.4 \times 10^{-7}\ M_\odot$ yr^{-1} and $V_w = 2000$ km s^{-1} which are typical values for a O9 V star (Lamers 1981; Abbott 1978), one finds $L_w = 1.8 \times 10^{35}$ ergs s^{-1}. This amounts to a relatively weak stellar wind, but one that could produce a wind-driven shell 5 pc in radius expanding at 60 km s^{-1} through a medium $n_0 = 0.1$ cm^{-3} in a time of 5×10^4 yr. However, this is a very short time considering the expected $\sim 5 \times 10^6$ yr main-sequence lifetime for a O9 V star (Maeder 1981). Longer duration stellar wind production into a denser medium would result in much weaker shocks than required to account for the observed [O III] line intensities. Moreover, the wind-driven shock velocity would be expected to decrease substantially upon interaction with the higher density medium of the H II region, making it even more questionable whether a sufficiently strong shock could be produced at S249's southern boundary.

c) *A Model*

On the other hand, these filaments' positional proximity and their similar optical emission-line properties to IC 443, together with the lack of any other known supernova remnant in the area (Clark and Caswell 1976), suggest they may represent a far northeastern extension of IC 443. Based just on their filamentary appearance, these filaments were, in fact, included as part of this remnant by Gaze and Shajn (1954). However, such a direct connection with IC 443 would imply a substantial departure from this remnant's otherwise roughly spherical appearing structure. IC 443's radius is $\sim 20'$, and the easternmost portion of the faint NE filaments is nearly 15′ outside the remnant's bright NE rim.

There is, however, some evidence for a possible link of these filaments with IC 443. A few radio studies have indicated enhanced radio emission coincident with these filaments (Hogg 1964; Higgs 1965; Duin, Strom, and van der Laan 1974; Reich 1982; Haslam *et al.* 1982; Braun and Strom, private communication). Hogg's low-resolution map even hints that they might have a nonthermal spectrum. In addition, although IC 443's X-ray emission is strongly concentrated in its north central section (Levine *et al.* 1979; Galas, Venkatesan, and Garmire 1981), the IPC data from *Einstein* do suggest faint diffuse X-ray emission extending 10′–20′ east of IC 443's eastern borders (Petre *et al.* 1984). Also, Lozinskaya (1969) reported the presence of faint emission "streams" NE of IC 443 which showed nearly the same 55 ± 10 km s^{-1} HWHM velocity structure that she observed in the remnant's bright filaments. Therefore, we conclude that these shocked filaments are probably connected with IC 443.

To explain an association between these NE filaments and IC 443, we propose a model where these filaments are the most visible evidence for a substantial breakout of IC 443's blast wave along its eastern perimeter. Breakouts of similar size do exist in other SNRs; e.g., the Cygnus Loop's southern extension (see discussion in Falle and Garlick 1982) and VRO 42.05.01 (Landecker *et al.* 1983). Large deviations from a uniform spherical expansion occur when a remnant's blast wave encounters a very inhomogeneous medium leading to different expansion velocities in the different regions. Of the known galactic remnants, IC 443 is one of the most likely objects to experience such a breakout. X-ray, optical, and radio observations show that it lies in a region with a very wide range of interstellar densities. The remnant's X-ray emission is produced by a very hot gas ($T_e \approx 1 \times 10^7$ K) which has an estimated preshock density, n_0, of 0.13 cm^{-3} (Galas, Venkatesan, and Garmire 1981). Coronal line-emission measurements indicate a cooler gas ($T_e \approx 1 \times 10^6$ K) having $n_0 = 0.4$ cm^{-3} (Woodgate, Lucke, and Socker 1979), while optical and radio data suggest the remnant's bright optical and radio emission arises from $T_e \approx 10^4$ K interstellar H I clouds with preshock densities of $\sim$1–20 cm^{-3} (Akabane 1966; DeNoyer 1977; Fesen and Kirshner 1980). Also, Cornett, Chin, and Knapp (1977) have shown evidence for a dense CO cloud ($n_0 \approx 100$ cm^{-3}) lying in the immediate vicinity of IC 443. All these data point to a large-scale, very inhomogeneous interstellar medium near the remnant whose density varies by a factor of $\sim 10^3$ or more which could certainly have led to significant departures from spherical symmetry. Substantial differences in densities to the NE and SW have already been invoked by previous investigators to explain the smaller radius of curvature exhibited in the NE sector compared to the SW (Gulliford 1974; Parkes *et al.* 1977). Also, the neutral hydrogen "jet" reported by DeNoyer (1977) in the southeastern part IC 443 might be further evidence of a breakout along the remnant's eastern hemisphere.

Models by Falle and Garlick (1982) show that a breakout need not greatly effect the evolution of the rest of the remnant. Thus, estimates for IC 443's total energy will be unaffected. Assuming a pressure throughout IC 443 of $\sim 1 \times 10^{-9}$ dynes cm^{-2} and pressure equilibrium, the breakout region's density must be lower than 0.1 cm^{-3}. [Note: the pressure difference between X-ray and optical regions described by Fesen and Kirshner (1980) is reconciled when the revised X-ray density estimates of Galas, Venkatesan, and Garmire (1981) are used.] The shock breakout through this low-density medium would have a shock velocity greater than 10^3 km s^{-1} which could travel the 5 kpc distance to S249's southern boundary in a time of $\sim 10^3$ yr, which is less than the remnant's estimated $\sim 10^4$ yr age.

If this model for the NE filaments is correct, it might help eliminate some of the uncertainty concerning IC 443's distance. Although IC 433 is generally estimated to lie at a distance similar to the 1.5 kpc for S249 on the basis of a probable interaction of its bright NE rim with the outskirts of this H II region, values from 0.5 to 2.5 kpc have been proposed (van den Bergh, Marscher, and Terzian 1973; Duin and van den Laan 1975). If these far-NE filaments are really due to a breakout of IC 443 interacting directly upon S249, then uncertainty over IC 443's distance lies only in determining the distance to S249. Distances to S249 have been estimated via its excitation by members of the Gem OB1 association. Its distance has been given as 1.4 kpc (Crawford *et al.* 1955), 1.5 kpc (Ruprecht 1966; Humphreys 1978), 1.6 kpc (Hardie, Seyfert, and Gulledge 1960), and 1.9 kpc (Georgelin, Georgelin, and Roux 1973). Values between 1.5–2.0 kpc for IC 443 are also supported by the empirical Σ–D radio relation (Milne 1979; Caswell and Lerche 1979), as well as total remnant energy considerations (Fesen and Kirshner 1980).

V. CONCLUSIONS

We have presented optical spectrophotometry on the faint filaments $\sim 15'$ NE of the supernova remnant IC 443 which are located along the southern boundary of the H II region S249. The relative line intensities observed are substantially different from those seen from other regions of S249 and other galactic and extragalactic H II regions. They are, however, very similar to those exhibited by the shock-heated interstellar gas seen in supernova remnants and in particular to IC 443's filament emission. A shock-heated origin for these filaments appears likely.

If these filaments are not part of some very old and as yet unrecognized separate SNR, then we suggest that they represent shock-heated regions along the outskirts of S249 which have been encountered by a portion of IC 443's blast wave. Their association to IC 443 is supported by new X-ray observations which suggest some faint extended X-ray emission is present in this area. A direct interaction of IC 443 with S249 would support the 1.5–2.0 kpc distance usually adopted for IC 443. The shocked nature of these filaments could be directly confirmed by measuring an [O III] electron temperature in excess of 20,000 K or by radio measurements made at several frequencies in order to establish whether the spectrum is thermal or not.

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ROBERT A. FESEN: Laboratory for Atmospheric and Space Physics, Campus Box 392, University of Colorado, Boulder, CO 80309