

A CATALOG OF ULTRAVIOLET, OPTICAL, AND NEAR-INFRARED EMISSION LINES
IDENTIFIED IN SUPERNOVA REMNANTS¹

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ABSTRACT

Optical spectra of two filaments in the Cygnus Loop are used to investigate the faint optical line spectra of supernova remnants (SNRs). Data on a bright, previously studied filament in the remnant's northeast rim (NGC 6992) provide accurate relative line strengths for many faint emission lines present in shocked, low-density interstellar gas. Spectra of a particularly strong [O III] $\lambda\lambda 4959, 5007$ filament $\{I([\text{O III}])/I(\text{H}\beta) \simeq 45\}$ reveal both a high [O III] electron temperature ($60,000 \pm 3000$ K) and many high-ionization lines, including [Ar IV], [Ar V], [Ne IV], [Ca V], [Cl III], [Fe VI], [Fe VII], and [Fe X]. Taken together, these data reveal 16 new emission lines not previously seen in any SNR, plus an additional 11 emission lines seen only once before in various remnants.

These new spectral results are incorporated into a comprehensive catalog of over 250 emission lines identified in Galactic and Magellanic Cloud SNRs within the wavelength range 900–12000 Å, and are complete through 1995. Along with accurate laboratory wavelengths and commonly observed relative line intensity information, this tabulation lists individual remnants and references for less commonly observed lines. UV, optical and near-IR lines identified in SNRs organized by element and ionization stage, and a reference list of observational papers sorted by remnant and wavelength regime are also given.

Subject headings: catalogs — infrared: ISM: lines and bands — line: identification — supernova remnants

1. INTRODUCTION

Supernova remnants (SNRs) emit a rich and distinctive emission-line spectrum in the ultraviolet (UV), optical, and infrared (IR) wavelength regimes. Because SNR emissions can simultaneously arise from cool, dense knots ($n_e \simeq 10^5 \text{ cm}^{-3}$, $T_e = 10^2$ K) and from hot, tenuous gas ($n_e \simeq 0.01 \text{ cm}^{-3}$, $T_e = 10^7$ K), remnant spectra can cover an unusually broad range of line excitations and ionization states of forbidden, intercombination, and permitted lines. The complexity of SNR spectra relative to many other emission-line nebulae results from the fundamentally nonequilibrium process of shock heating. Line emission is possible from both the shock front itself and the extended, cooling recombination zone. Spectral differences between SNRs and other nebulae can be enhanced in younger SNRs where shock-heated supernova debris may be enriched in highly processed material. Consequently, SNRs have emission-line characteristics not seen in other common nebulae such as H II regions, planetary nebulae (PNs), or stellar wind-blown shells (Baldwin, Phillips, & Terlevich 1981; Fesen, Blair, & Kirshner 1985). This has led to successful emission-line techniques for SNR identification such as the [S II] $\lambda\lambda 6716, 6731/\text{H}\alpha$ intensity ratio (see Fesen et al. 1985 and references therein).

One of the first steps in the spectral study of any nebula is identifying its line emissions. Unfortunately, no compilation of observed lines in SNRs has been collected and published. Generic nebula line lists (Meinel, Aveni, & Stockton 1975; Kaler 1976) are seriously incomplete for SNRs and do not cover most of the recently detected UV and near-infrared

(NIR) lines. Line lists found in the extensive literature of H II regions and PNs (Aller, Bowen, & Wilson 1963; Kaler, Aller, & Bowen 1965; Kaler 1976; Fehrenbach 1977; Baluteau et al. 1995; Hyung & Aller 1995a, 1995b) are of limited use in the study of SNRs. Many of the lines observed in PNs or H II regions are either simply not seen in SNRs or, when detected, often have considerably different relative intensities. Although shock heated, Herbig-Haro (HH) objects do not exhibit the range of shock velocities present in SNRs, making HH emission-line lists (e.g., Solf, Bohm, & Raga 1988) of only limited usefulness.

Lack of an emission-line list appropriate for SNRs is a particular problem when investigating the UV, optical, or NIR spectra of young remnants. This problem will grow as modern detectors allow observers to push to lower flux levels. Filament and ejecta expansion velocities, the large potential range in electron temperatures and densities of the emitting gas, as well as the richness of some heavy element spectra often make reliable SNR identifications for faint lines a confusing and difficult process. This has sometimes led to line misidentifications, which often propagate through the literature. Moreover, a full understanding of shock emission processes and conditions present in remnants will only be possible with a detailed and complete spectral line survey. As observations and shock models improve, accurate intensities of faint SNR lines will become increasingly important for determining overall nebular abundances, grain destruction rates, and the range of post-shock ionization. Unfortunately, few SNRs have reliable spectral line intensities below $\sim 10\%$ the strength of H β .

The purpose of this paper is threefold. First, using the Cygnus Loop remnant as a prototypical case, we establish accurate relative line strengths for the fainter optical lines often seen in an evolved SNR filament. This places fainter emission lines in quantitative context with the more com-

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monly observed brighter lines and highlights potential line diagnostic pitfalls due to faint line blending (e.g., the temperature sensitive [O III] $\lambda 4363$ with [Fe II] $\lambda 4358$). Second, we investigate the faint line spectrum of [O III] bright filaments, again using a Cygnus Loop filament as the case study. Motivation for this was provided by an earlier spectroscopic study of the Cygnus Loop where several previously unrecognized, high-ionization lines were detected. Third, we present a comprehensive catalog of observed SNR emission lines, including accurate laboratory wavelengths, and cross-referenced by element, ionization, and individual object. Detailed references are provided for all lines and SNRs. The overall intent of this paper is to provide a useful aid for further UV, optical, and NIR study and analysis of SNR nebulae.

2. NEW OBSERVATIONS

2.1. Optical Spectra of the Cygnus Loop

The Cygnus Loop is an evolved Galactic SNR that is large, bright, relatively nearby ($d \simeq 0.5$ – 1.0 kpc), and has a low amount of interstellar reddening [$E(B-V) = 0.08$ mag; Parker 1967]. These properties make it an excellent subject for investigating faint emission lines in a SNR. We obtained long-slit optical spectra of a bright and previously studied radiative filament in the Cygnus Loop in 1993 September using the Mark III spectrograph on the Michigan-Dartmouth-MIT (MDM) Observatory's 1.3 m McGraw-Hill telescope. This filament is the one observed by both Miller (1974; "position 1") and Fesen et al. (1982; positions M and M'). A 2000 s exposure was taken using a 1024² Tektronix CCD and 5800 Å blaze 600 lines mm⁻¹ transmission grism. Using a 8' × 1'5 slit, this setup yielded 2.5 Å per pixel dispersion and 1'6 pixel⁻¹ spatial resolution. Wavelength coverage was 4600–6900 Å. A second 2000 s exposure was later taken using this same setup but with spectral coverage from 3500–6000 Å. Although we attempted to match Fesen et al.'s (1982) M' slit positioning and slit size on the Miller 1 filament, the two spectra were subsequently found to be slightly different from this as well as from one another (e.g., [O III] line strength) and thus have been labeled "M1a" and "M1b," respectively.

Data reduction included bias subtraction and flat-field correction. Due to the bright filament's long angular extent, both long-slit spectra were divided into three equal size segments 16" long (three sky and three filament segments) and then co-added, cosmic-ray hit cleaned, and sky subtracted using IRAF software. Sky regions were taken as sections along portions near the ends of the slit where little remnant emission was detected. These data were wavelength calibrated using Hg-Ne comparison lamps and flux corrected through observations of Oke (1974) and Stone (1977) spectral standards. Based on a comparison between the overlapping regions of the two spectra and standard star calibrations, a 5%–8% calibration correction (decrease) was applied to the red end (≥ 5500 Å) of the M1a spectrum.

In order to explore the faint line emissions present in a higher temperature filament, a spectrum of a bright [O III] $\lambda\lambda 4959, 5007$ filament in the Cygnus Loop was obtained in 1994 June using the MDM 2.4 m Hiltner telescope. An east-west 4' × 1'7 slit was positioned along the [O III] strong eastern limb of the remnant's bright nebulosity NGC 6992/5 at coordinates $\alpha(2000) = 20^{\text{h}}57^{\text{m}}33^{\text{s}}.4$ and $\delta(2000) = +31^{\circ}00'$. The data were taken using the Mark III

spectrograph with the 5800 Å blaze 600 lines mm⁻¹ grism and a 1024² Tektronix CCD detector. Three 800 s exposures were obtained on this position, interspersed with equal exposure sky spectra taken by repositioning the telescope 2" to the west in a region free of any strong remnant emission. A 20" section along the slit was extracted where the ratio of [O III]/H $\beta \geq 25$ and was accompanied by numerous fainter lines, many of high-ionization species. Data were reduced and sky subtracted using standard IRAF software routines and calibrated with Hg, Ne, Ar, and Xe lamps and Oke (1974) and Stone (1977) spectral standards. Relative line intensities are believed to be accurate to better than 10% for the stronger lines [$I \simeq I(\text{H}\beta)$], 15% for the weak lines [$\simeq 0.1I(\text{H}\beta)$], and 25%–50% for the weakest lines.

2.2. Results

The dereddened spectrum for the M1 filament is shown in Figure 1, with data from slit position M1a plotted in Figure 1a and position M1b in Figures 1b and 1c. The spectra were dereddened using the extinction curve of Cardelli, Clayton, & Mathis (1989) and an $E(B-V) = 0.10$ mag. Relative line intensities for both positions are listed separately in Table 1, along with those of Miller (1974) and Fesen et al. (1982) for this filament. Our color excess is slightly larger than the $E(B-V) = 0.08$ mag (Parker 1967) value used by the previous investigators, who also used the Whitford reddening curve (see Miller & Mathews 1972). Although these differences are relatively minor, our use of the larger $E(B-V)$ value gave excellent agreement with the theoretical case B recombination line ratios of H β :H γ :H $\delta = 100:47:26$ for $T = 10^4$ K. In any case, the relative line strengths for the majority of the brighter line intensities in all four spectra agree within measurement uncertainties.

Our new spectra show a large number of faint lines over the wavelength region 3700–6750 Å (see Table 1). Nearly 50 lines weaker than $0.30 \times \text{H}\beta$ were detected, most of which have strengths just a few percent times that of H β . Many of these ($\simeq 25$) are weak [Fe II] and [Fe III] lines, with several not often reported in even relatively bright SNRs. Faint lines detected include [Fe V] $\lambda 4227$, [Ar IV] $\lambda\lambda 4711, 4740$, and [S III] $\lambda 6312$. This filament has properties fairly typical for the Cygnus Loop and for SNRs in general. We find an [O III] ($\lambda 4959 + \lambda 5007$)/ $\lambda 4363$ line ratio for M1b of 16.6, giving a derived electron temperature of $40,000 \pm 5000$ K. Miller (1974) and Fesen et al. (1982) estimated $32,000 \pm 7000$ K for this same approximate filament position. The difference is due to the strength of $\lambda 4363$, which we measure to be $\simeq 20\%$ higher, largely because of the higher extinction value used.

SNRs can show a wide diversity of emission spectra depending on how "complete" the postshock, recombination zone is observed to be; that is, how well established the postshock cooling zone is. Incomplete shocks are often identified by large (≥ 10) [O III]/H β line ratios. Figures 2a–2c show the dereddened spectrum of the [O III] bright filament located along the eastern limb of the Cygnus Loop. Table 2 lists the dereddened relative line strengths using an $E(B-V) = 0.06$ mag and the Cardelli et al. (1989) extinction curve. This reddening value gave the best match for the predicted Balmer line decrement for H β :H γ and a temperature of 20,000 K. Because of possible errors in the subtraction of the bright [O I] night sky emission, only upper

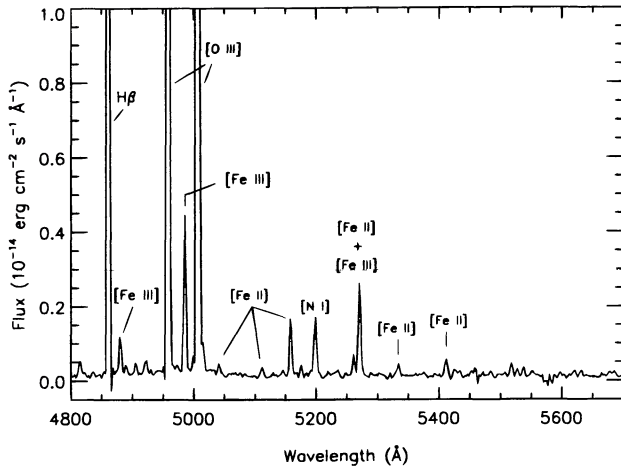


FIG. 1a

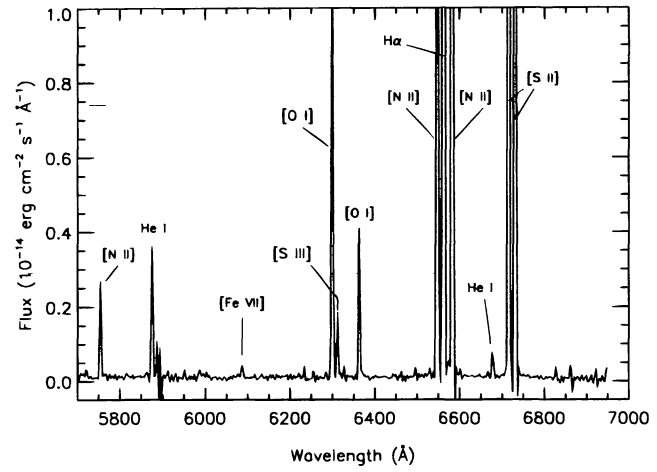


FIG. 1b

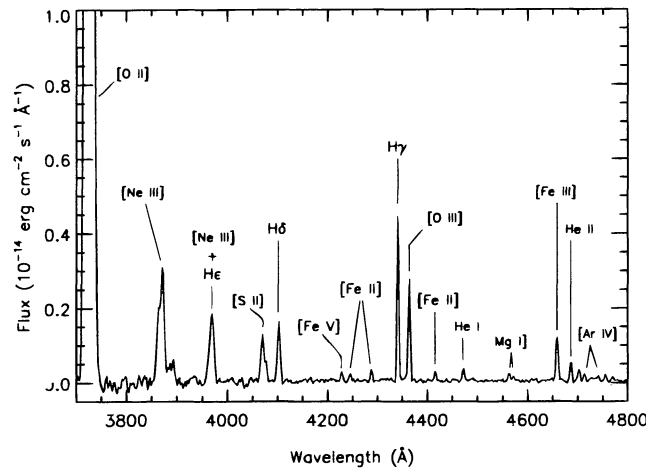


FIG. 1c

FIG. 1.—Spectra of the Cygnus Loop filament “M1”

limits are quoted for the filament's [O I] $\lambda\lambda$ 6300, 6364 emission-line strengths.

This filament's average [O III]/H β line ratio of 45 lies near the upper end of the range observed in SNRs (Hester, Raymond, & Blair 1994). As seen in these plots, the faint line spectrum of this filament is considerably different from that of the bright M1 filament discussed above. Most of the [Fe II] and [Fe III] lines are absent, replaced by several higher ionization species including [Cl III], [Ar V], [Ca V], [Fe VI], [Fe VII], and [Fe X]. Not surprisingly, this filament's [O III] derived electron temperature of $60,000 \pm 3000$ K lies near the maximum reported in the Cygnus Loop (Fesen et al. 1982).

The filament also shows an exceptional number of [Fe VI] and [Fe VII] lines, many observed for the first time in an SNR. All of the strong [Fe VI] lines from multiplets 1F and 2F are detected (see Table 3) with relative intensities in good agreement with predicted values (Garstang, Robb, & Rountree 1978). The same is true for the [Fe VII] lines (Nussbaumer & Osterbrock 1970). Interestingly, using the [Fe VII] emissivity ratios of Nussbaumer & Storey (1982), the observed ratio of λ 5159/ λ 6087 suggests an electron temperature of only around 15,000 K.

The spectrum is also remarkable in the strength of several other high-ionization lines. The [S III] λ 6312 line dwarfs the usually much stronger [O I] λ 6300 line, as does the [Fe X]

λ 6375 to the [O I] λ 6364 line (see Fig. 2c). Also, the [Ar IV] and [Ne IV] line blend near 4700–4740 Å is now more than 25 times stronger (relative to H β) than in the bright filament spectrum (Fig. 1). Finally, although we detected weak [Ca V] 5309 Å emission in this filament, this emission is unlikely to have been confused with the remnant's extended [Fe XIV] 5303 Å emission (see Woodgate et al. 1974).

3. THE CATALOG

Our new spectral data on the Cygnus Loop reveal 16 new emission lines not previously seen in any SNR, plus an additional 11 emission lines seen only once before in various remnants. These results have been incorporated into a catalog of UV, optical, and NIR emission lines identified in both Galactic and Magellanic Cloud SNRs. For this survey, we restricted the wavelength range to 900–12000 Å so as to include the majority of recent UV and NIR spectral results. The resulting SNR emission-line catalog is given in Table 4 for the UV region (900–3000 Å) and in Table 5 for the optical and NIR region (3000–12000 Å). The literature was searched using the semiannual Astronomy and Astrophysics Abstract publications, SIMBAD, and NASA's on-line Astrophysics Data System (ADS), and is substantially complete through 1995. We also searched the introductions of most papers as a completeness check and as a source of observational papers published before 1969.

TABLE 1
BRIGHT FILAMENT EMISSION IN THE CYGNUS LOOP

λ (Å)	Ion	M74	FBK82	M1a	M1b
3726.03, 3728.82	[O II]	1310	810	...	1370
3868.75	[Ne III]	80	59	...	89
3888.65, 3889.05	He I, H I	...	...	...	23
3933.66	Ca II	weak	...	...	(3)
3967.46, 3970.07	[Ne III], He	...	28 bl	...	43 bl
4068.60, 4076.35	[S II]	16	18	...	27
4101.77	H δ	24	20	...	26
4227.2	[Fe V]	weak	...	...	2.5
4243.98, 4244.81	[Fe II]	...	...	...	2.0
4287.40	[Fe II]	...	...	...	3.3
4340.49	H γ	46	43	...	47
4358.10, 4358.37, 4359.34	[Fe II]	...	...	...	(2)
4363.21	[O III]	25	24	...	29
4413.78, 4414.45, 4416.27	[Fe II]	...	...	...	2.7
4471.48, 4471.69	He I	...	...	...	4.1
4562.48	[Mg I]	weak	...	...	2.2
4571.10	Mg I	weak	...	...	1.0
4658.10	[Fe III]	...	9	18.0	15
4685.68	He II	4	4	8.8	6.2
4701.62	[Fe III]	...	3	3.9	3.7
4711.33	[Ar IV]	...	...	3.7	3.2
4724.17, 4725.60	[Ne IV]	...	...	1.1	1.0
4733.93	[Fe III]	...	...	1.4	1.0
4740.20	[Ar IV]	...	...	1.7	1.7
4754.83	[Fe III]	...	...	2.0	1.8
4769.60	[Fe III]	...	...	1.3	1.3
4777.88	[Fe III]	...	...	0.5	(0.5)
4813.9, 4814.55	[Fe III], [Fe II]	...	...	1.4	1.3
4861.36	H β	100	100	100	100
4881.11	[Fe III]	...	...	3.5	3.3
4889.63, 4889.70	[Fe II]	...	...	0.6	(0.5)
4905.35	[Fe II]	...	...	1.0	1.3
4921.93	He I	...	...	1.3	1.4
4958.91	[O III]	108	109	200	122
4973.39	[Fe II]	...	...	(0.4)	(0.5)
4985.9, 4987.2	[Fe III]	...	...	13	13
5006.84	[O III]	332	369	612	360
5015.68	He I	...	...	(1.0)	(1.0)
5039.10, 5043.53	[Fe II]	...	...	0.7	(0.5)
5111.63	[Fe II]	...	...	1.0	(0.5)
5145.8	[Fe VI]	...	...	(0.4)	(0.5)
5158.00, 5158.81, 5158.9	[Fe II], [Fe II], [Fe VII]	...	5	5.3	5.3
5176.0	[Fe VI]	...	...	(0.6)	(0.5)
5197.90, 5200.26	[N I]	...	9	5.5	5.3
5261.61	[Fe II]	...	...	1.3	2.2
5268.88, 5270.3, 5273.38	[Fe II], [Fe III], [Fe II]	...	7 bl	8.2 bl	8.3 bl
5333.65	[Fe II]	...	...	1.0	1.2
5411.52, 5412.64, 5413.34	He II, [Fe II], [Fe II]	...	...	1.5	1.4
5720.7	[Fe VII]	...	...	0.5	0.5
5754.59	[N II]	6	6	8.0	6.2
5876 blend	He I	10	8	10.3	8.6
6087.0	[Fe VII]	...	...	1.0	...
6300.30	[O I]	47	53	37	...
6312.06	[S III]	...	...	5.2	...
6363.78	[O I]	15	17	12	...
6548.05	[N II]	88	88	78	...
6562.85	H α	308	308	310	...
6583.45	[N II]	257	229	226	...
6678.15	He I	...	...	2.2	...
6716.44	[S II]	154	155	154	...
6730.82	[S II]	130	113	126	...

NOTE—Parentheses signify particularly uncertain line intensity; "bl" indicates a blend of lines.

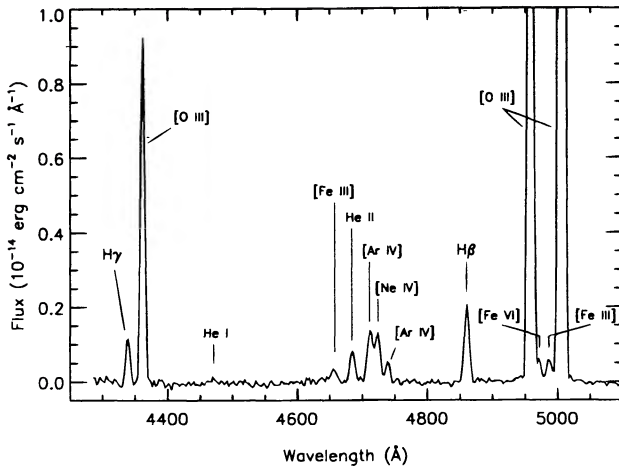


FIG. 2a

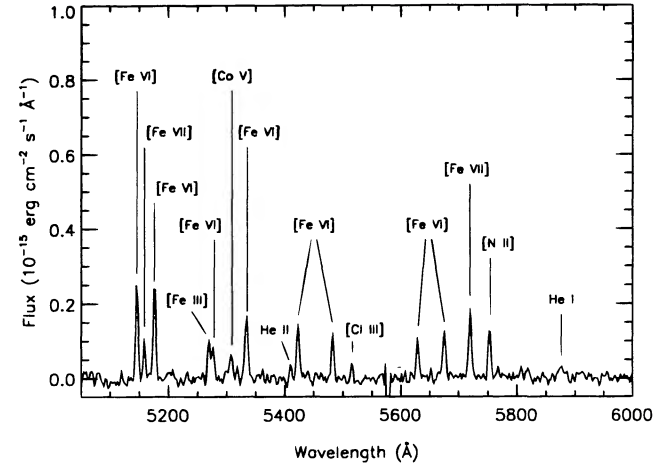


FIG. 2b

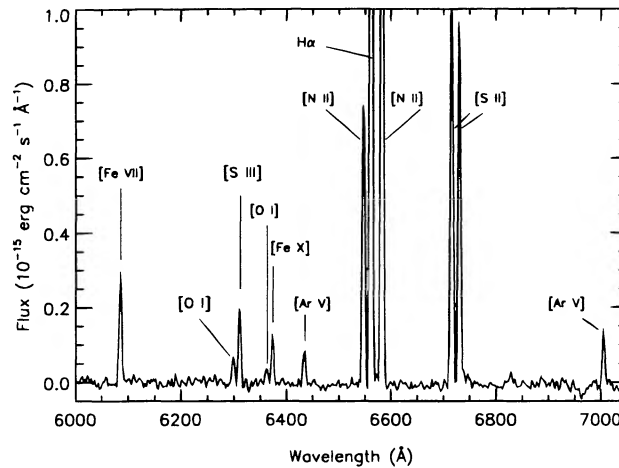


FIG. 2c

FIG. 2.—Spectra of an [O III] bright Cygnus Loop filament

The format of Tables 4 and 5 is as follows: Column (1) lists the line laboratory wavelengths to the nearest 0.01 Å wherever possible. Wavelengths for all H, C, N, and O lines both in the UV and optical are from Moore (1993), while the majority of UV line wavelengths for other elements are from Kelly (1979, 1987). A variety of other sources were used for the remaining UV, optical, and NIR lines (see Table 6). Columns (2) and (3) list the line's identified ion and multiplet; where two or more lines form a blend at moderate resolution ($\text{FWHM} = 3\text{--}5 \text{ \AA}$), the listed ions correspond to the respective wavelengths given. (Note: we have used the new multiplet numbering convention for hydrogen lines as given in Moore 1993.) Column (4) gives a rough estimate of the line's relative brightness as commonly observed in radiative SNR filaments. Because of the known differences between filament emissions even within a single SNR, the line intensity divisions are crude, with only three intensity grades: 1 = lines that are commonly strong in SNRs, 2 = lines of moderate strength ($\approx H\beta$ in the optical), and 3 = faint lines with intensities much less than that of $H\beta$. The last column lists individual SNRs where a particular line has been identified along with the reporting sources for these objects. An asterisk is used to denote lines commonly observed in SNRs, i.e., identified in more than six SNRs. References are given as abbreviations of the author name list (up to four letters of the first four authors) followed by

the last two digits of the year of publication. These abbreviations have been included in the reference list. When four or more papers report the presence of a line in an object, only an asterisk is shown.

Table 7 lists a summary of all identified UV, optical, and NIR emission lines observed in SNRs, organized by element, ion, and wavelength. Closely spaced lines ($\leq 3 \text{ \AA}$) are denoted as a blend. Aside from highlighting the large number of H, He, and forbidden Fe lines, this table allows a quick check on a line's identification through the presence of other lines from the same ionization level.

One consequence of our line list search and cataloging was a substantially complete reference list of spectral papers on individual SNRs. Tables 8 and 9 give tabulations of observational reference papers on individual SNRs organized by Galactic or Magellanic Cloud objects. Although several computer on-line services can give references for individual remnants, looking up the observational papers on several SNRs can still be quite time consuming. Our compilation serves as a convenient source listing. In Table 8 column (1) lists each remnant's Galactic coordinate name, with the object's common name given in column (2). References for each object are subdivided into wavelength regimes (UV, optical, IR). Our listing is much more complete in regard to UV/optical/IR references than that of Green (1988, 1991), who lists only a few selected papers.

TABLE 2
[O III] BRIGHT FILAMENT IN THE CYGNUS LOOP

λ (Å)	Ion	I(λ)
4340.49	Hy	49
4363.21	[O III]	360
4471.48, 4471.69	He I	4
4658.10	[Fe III]	20
4685.68	He II	40
4711.33, 4713.14, 4713.37	[Ar IV], He I, He I	75
4724.17, 4725.60	[Ne IV]	65
4740.20	[Ar IV]	23
4861.36	H β	100
4881.11	[Fe III]	3
4893.4	[Fe VII]	5
4905.35	[Fe II]	5
4942.5	[Fe VII]	4
4958.91	[O III]	1110
4972.5	[Fe VI]	15
4985.9, 4987.2	[Fe III]	16
5006.84	[O III]	3360
5145.8	[Fe VI]	21
5158.9	[Fe VII]	8
5176.0	[Fe VI]	21
5270.3	[Fe III]	9
5277.8	[Fe VI]	6
5309.18	[Ca V]	5
5335.2	[Fe VI]	15
5411.52	He II	3
5424.2, 5426.6	[Fe VI]	12
5484.8	[Fe VI]	9
5517.71	[Cl III]	3
5631.1	[Fe VI]	8
5677.0	[Fe VI]	11
5720.7	[Fe VII]	17
5754.59	[N II]	12
5876 blend	He I	2
6087.0	[Fe VII]	28
6300.30	[O I]	≤ 10
6312.06	[S III]	19
6363.78	[O I]	≤ 5
6374.51	[Fe X]	12
6435.10	[Ar V]	8
6548.05	[N II]	71
6562.85	H α	320
6583.45	[N II]	221
6716.44	[S II]	110
6730.82	[S II]	92
7005.67	[Ar V]	14

4. DISCUSSION

Over 60 UV lines (900–3000 Å) and over 220 optical and NIR lines (3000–12000 Å) have been detected and identified in Galactic and Magellanic Cloud SNRs. Although considerable, this is far less than found in some bright planetary nebulae (e.g., Hyung & Aller 1995a, 1995b). Part of this is simply the higher surface brightness of some PNs, which can be as much as 2 orders of magnitude greater than many bright filaments in the Cygnus Loop or other optical SNRs, making detection of faint lines much easier.

As seen in Tables 4, 5, and 7, a total of 18 elements have been reported in remnant spectra. With the exception of hydrogen and helium, the majority of the lines are either forbidden or semiforbidden, with few permitted lines present outside of the UV region. This is in contrast to that of planetary nebulae, where many weak permitted lines of C, N, and O are often observed. The few permitted optical and NIR lines reported in SNRs include lines from O I, Na I, Ca II, and Fe I. Emission lines found in SNRs also can cover

TABLE 3
[Fe VI] AND [Fe VII] EMISSION LINES

λ (Å)	Multiplet	Theory ^a	Observed
[Fe VI] Lines			
4967.1	2F	35	...
4972.5	2F	97	71
5145.8	2F	100	100
5176.0	2F	82	100
5277.8	1F	13	29 ^b
5335.2	1F	51	71
5424.2, 5426.6	1F	50	58
5484.8	1F	29	43
5631.1	1F	37	38
5677.0	1F	38	53
[Fe VII] Lines			
4893.4	2F	20	18
4942.5	2F	23	14
4988.6	2F	22	16 ^c
5158.9	2F	28	29
5276.4	2F	21	29 ^b
5720.7	1F	65	61
6087.0	1F	100	100

^a At $T_e = 2 \times 10^4$ K, $n_e \leq 10^3$ cm⁻³; from Garstang et al. 1978 for [Fe VI], and Nussbaumer & Osterbrock 1970 for [Fe VII].

^b Blend of [Fe VI] 5277.8 with [Fe VII] 5276.4.

^c Blend with [Fe III] 4985.9 and [Fe III] 4987.2.

an enormous range of ionization stages (e.g., Fe I–Fe XIV). The presence of strong emissions from several stages of ionization, in fact, is a characteristic of shock-heated gas like that present in SNRs. It is this property that sometimes makes line identification in SNRs complicated. This is shown in the spectrum of the strong [O III] filament in the Cygnus Loop we studied. Although [O III] emission dominates the spectrum, strong [O I] and [O II] line emissions are present as well. In addition, a few lines of [Fe III] and [Fe X] have comparable strengths. This wide range of line emission species and intensities can affect line strength measurements particularly when observed at low dispersion. For instance, the [O I] λ 6300 line may be blended with [S III] λ 6312 emission, increasing its flux by $\sim 10\%$ or more.

Only a small percentage of the 39 Galactic and 24 Magellanic Cloud optical SNRs have been well studied spectroscopically. For example, the Cygnus Loop has been the chief target of Galactic SNR research in the UV region as a result of both the comparatively low extinction [$E(B-V) \simeq 0.1$] in its direction 7° off the plane and its bright and well resolved filaments. The combination of faint filament emissions and/or large reddening precludes obtaining UV data on many Galactic objects. This has resulted in only four other Galactic SNRs having been studied in the UV: the Crab Nebula, Puppis A, Vela, and the SN 1006 remnant (G327.6+14.6). These, along with Cassiopeia A, are the same remnants that have also been the most extensively studied in the optical. In a similar fashion, N49, N63A, and N132D are the most studied LMC remnants, and are the only ones that have been detected in the UV. Only one SMC remnant, the young, oxygen-rich remnant E0102-72.3, has been detected in the UV. Faint emission and the decreased sensitivity of detectors at $\lambda \geq 8000$ Å has led to only six Galactic, six LMC, and three SMC remnants being studied in the near-infrared.

The identification of UV/optical/NIR line emissions in

TABLE 4
ULTRAVIOLET EMISSION LINES IDENTIFIED IN SUPERNOVA REMNANTS

λ (Å)	Ion	Multi- plet	Inten- sity	SNRs ^a and References
933.38, 944.52	S VI	UV 1	1	Cygnus Loop (L92)
977.03	C III	UV 1	1	Cygnus Loop (*), Puppis A (BRLK95), Vela (BVL95)
989.79	N III	UV 1	1	Cygnus Loop (B91), Puppis A (BRLK95)
1006 blend	Ne VI	...	1	Cygnus Loop (L92)
1025.72	Lβ	UV 2	3	SN 1006 (RBL95)
1031.93, 1037.62	O VI	UV 1	3	Cygnus Loop (*), N49 (V92), Puppis A (BRLK95), SN 1006 (RBL95), Vela (BVL95)
1083.99	N II	UV 1	Γ	Cygnus Loop (B91)
1084.91, 1084.98	He II	UV 14	1	Cygnus Loop (L92)
1146.1	Ne V	...	1	Cygnus Loop (B91; L92)
1238.82, 1242.80	N V	UV 1	2	*
1334.53	C II	UV 1	1	Cygnus Loop (*), N49 (BDD80), N63A (BDD80), N132D (B96), Puppis A (BRLK95), Vela (R81)
1355.60	O I	UV 1	1	SMC 0102 – 72.3 (BRDM89)
1371.29	O V	UV 7	1	Cygnus Loop (B91; L92; R80)
1393.76	Si IV	UV 1	1	*
1397.20, 1399.77	O IV]	UV 0.01	2	*
1398.13, 1404.77	Si IV]	...	1	Cygnus Loop (BDD80; R80), N49 (BDD80), N63A (BDD80)
1402.77	Si IV	UV 1	1	*
1483.32, 1486.50	[N IV], [N IV]	UV 0.01	1	Cygnus Loop (*), N49 (BDD80), N132D (B96), Puppis A (BRLK95), Vela (R81; RWB91)
1533.43	Si II	UV 2	1	Cygnus Loop (R80)
1548.20, 1550.77	Cr V	UV 1	3	*
1574.8	[Ne V]	...	1	Cygnus Loop (B91; L92; R80)
1601, 1602	[Ne IV]	...	1	Cygnus Loop (B91; L92; R80), Puppis A (BRLK95)
1640 blend	He II	UV 12	2	*
1660.81, 1666.15	O III]	UV 0.01	3	*
1670.81	Al II	UV 2	1	Cygnus Loop (BDD80)
1730 blend	N III]	UV 26.03	1	Cygnus Loop (B91)
1746.82, 1748.61	N III]	UV 0.01	1	Cygnus Loop (*), N49 (BDD80), N132D (B96), Puppis A (BRLK95), Vela (DWC80; R81; RWB91)
1807.31	Si I	UV 2	1	Cygnus Loop (BDD80), N49 (BDD80)
1808.01	Si II	UV 1	1	Cygnus Loop (BDD80), N49 (BDD80)
1816.93, 1817.45	Si II	UV 1	1	Cygnus Loop (BDD80; R80), N49 (BDD80)
1820.34, 1826.25	Si I	UV 2	1	Cygnus Loop (BDD80), N49 (BDD80)
1892.03	Si III]	UV 1	2	Cygnus Loop (*), N49 (BDD80; VBLR92), N132D (B96; BRL94), Vela (DWC80; R81; RWB91)
1906.68, 1908.73	[C III], [C III]	UV 0.01	3	*
2320.95, 2331.40	[O III]	UV 1F	1	Cygnus Loop (D80; R80)
2323.50, 2324.69	C II]	UV 0.01	3	Cygnus Loop (*), N49 (VBLR92), N132D (B96; BRL94), Vela (R81; RWB91)
2328.51, 2334.40	Si II]	UV 0.01	1	Cygnus Loop (D80), N132D (B96)
2343.49	Fe II	UV 3	1	N132D (B96)
2382.04	Fe II	UV 2	1	N132D (B96)
2418.2, 2420.9	[Ne IV]	...	1	Cygnus Loop (*), N49 (VBLR92), N132D (B96; BRL94), SMC 0102 – 72.3 (BRDM89), Vela (R81)
2470.22, 2470.34	[O II]	1.01F	1	Cygnus Loop (*), N49 (VBLR92), N132D (B96; BRL94), SMC 0102 – 72.3 (BRDM89), Vela (R81)
2585.88	Fe II	UV 1	1	N132D (B96)
2599.40	Fe II	UV 1	1	N132D (B96)
2628 blend	[Ti III] ?	...	1	N49 (VBLR92), N63A (VBLR92)
2669.17	Al II	UV 1	1	Cygnus Loop (D80)
2795.52, 2802.70	Mg II	UV 1	1	Cygnus Loop (D80; R81; R88), N49 (VBLR92), N132D (B96; BRL94), SMC 0102 – 72.3 (BRDM89)
2852.13	Mg I	UV 1	1	N132D (B96)

^a An asterisk denotes line(s) observed in more than six SNRs.

SNRs has matured to the point where virtually no lines with strengths $\geq 0.10 I(H\beta)$ have gone unnoticed, and few elements seen in other emission nebulae have not yet been detected in SNRs (e.g., Mn, F, and K). Therefore, most future increases in SNR line detections and identifications will likely come as new wavelength regimes are more fully explored. Additional weak line detections, unless tied to density or temperature diagnostics, may not significantly affect shock emission modeling over the current tabulation. The most severe limitation of the current observations is determining accurate line ratios for specific and limited regions behind the shock front in the recombination zone. While requiring higher spatial resolution than most existing

observations, such spectral data will afford the clearest match to model line strength predictions.

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TABLE 5
OPTICAL AND NEAR-INFRARED EMISSION LINES IDENTIFIED IN SUPERNOVA REMNANTS

λ (Å)	Ion	Multi- plet	Inten- sity	SNRs ^a and References
3187.74	He I	3	1	N132D (B96)
3203.10	He II	1	1	N132D (B96)
3342.42	[Ne III]	2F	1	SMC 0102 – 72.3 (BRDM89; DT84)
3345.83	[Ne V]	1F	1	SMC 0102 – 72.3 (BRDM89; DT84)
3425.87	[Ne V]	1F	1	Crab Nebula (D79; M78), Cygnus Loop (*), N132D (B96), SMC 0102 – 72.3 (BRDM89; DT84)
3586.3	[Fe VII]	3F	1	Crab Nebula (D79)
3686.83	H I	17	1	N157B (GMCM83)
3691.56	H I	16	1	N157B (GMCM83)
3697.15	H I	15	1	N157B (GMCM83)
3703.85	H I	14	1	N157B (GMCM83)
3711.97	H I	13	1	N157B (GMCM83)
3726.03	[O II]	1F	3	*
3728.82	[O II]	1F	3	*
3734.37	H I	11	1	N157B (GMCM83)
3750.15	H I	10	1	N157B (GMCM83)
3758.9	[Fe VII]	3F	1	Crab Nebula (D79)
3770.63	H I	9	1	N63A (DD74; RD90), N132D (B96), N157B (GMCM83), Vela (WB90)
3797.90	H I	8	1	*
3819.61, 3819.76...	He I	22	1	N157B (GMCM83)
3835.38	H I	7	1	*
3868.75	[Ne III]	1F	2	*
3888.65	He I	2	1	*
3889.05	H I	6	1	*
3933.66	Ca II	1	1	*
3964.73	He I	5	1	*
3967.46	[Ne III]	1F	2	*
3968.47	Ca II	1	1	*
3970.07	He I	5	1	*
4026.19, 4026.36...	He I	18	1	*
4068.60	[S II]	1F	2	*
4076.35	[S II]	1F	1	*
4101.77	H δ	4	2	*
4120.81, 4120.99...	He I	16	1	N157B (GMCM83)
4177.21	[Fe II]	21F	1	N49 (RD90), N63A (RD90)
4227.2	[Fe V]	2F	1	Crab Nebula (D79; FK82; M90), Cygnus Loop (M74; this paper), LMC 0540 – 69.3 (KMWB89)
4243.98, 4244.81...	[Fe II]	21F	1	*
4267.00, 4267.26...	C II	6	1	Crab Nebula (D79)
4287.40	[Fe II]	7F	1	*
4340.49	H γ	3	2	*
4358.10	[Fe II]	6F	1	*
4358.37	[Fe II]	21F	1	*
4359.34	[Fe II]	7F	1	*
4363.21	[O III]	2F	1	*
4413.78	[Fe II]	7F	1	*
4414.45	[Fe II]	6F	1	*
4416.27	[Fe II]	6F	1	*
4452.11	[Fe II]	7F	1	N49 (DD76a), N63A (DD74; DL85), RCW 103 (DD74)
4457.95	[Fe II]	6F	1	N103B (RD90), N49 (DD76a)
4470.29	[Fe II]	6F	1	N49 (RD90), N63A (RD90), N103B (RD90), N132D (B96), SMC 0104 – 72.3 (RD90)
4471.48, 4471.69...	He I	14	1	*
4474.91	[Fe II]	7F	1	MSH 15 – 52 (SHMC83)
4485.21	[Ni II]	3F	1	N157B (GMCM83)
4562.48	[Mg I]	1	1	*
4571.10	Mg I	1	1	*
4632.27	[Fe II]	5F	1	Crab Nebula (FKC78)
4658.10	[Fe III]	3F	1	*
4685.68	He II	1	1	*
4701.62	[Fe III]	3F	1	Cygnus Loop (FBK82; R88; this paper), IC 443 (FK80), N157B (GMCM83), Vela (WB90)
4711.33	[Ar IV]	1F	1	Cassiopeia A (CK79; HF96), Cygnus Loop (P67; this paper), N103B (RD90)
4713.14, 4713.37...	He I	12	1	Cygnus Loop (P67; this paper), N157B (GMCM83), Vela (WB90)
4724.17, 4725.60...	[Ne IV]	1F	1	Cygnus Loop (this paper), N49 (RD90), SMC 0102 – 72.3 (BRDM89; DT84)
4733.93	[Fe III]	3F	1	Cygnus Loop (this paper), Vela (WB90)
4740.20	[Ar IV]	1F	1	Cassiopeia A (CK79; HF96; KC77), Cygnus Loop (WKB77; this paper)
4754.83	[Fe III]	3F	1	Crab Nebula (FKC78), Cygnus Loop (this paper), N157B (D81; GMCM83), RCW 103 (DD74), Vela (WB90)
4769.60	[Fe III]	3F	1	Cygnus Loop (this paper)
4774.74	[Fe II]	20F	1	N49 (RD90)
4777.88	[Fe III]	3F	1	Cygnus Loop (this paper)
4813.9	[Fe III]	3F	1	*
4814.55	[Fe II]	20F	1	*
4861.36	H β	2	2	*
4881.11	[Fe III]	2F	1	Cygnus Loop (this paper), N157B (GMCM83), Vela (WB90),

TABLE 5—Continued

λ (Å)	Ion	Multi- plet	Inten- sity	SNRs ^a and References
4889.63, 4889.70...	[Fe II]	4F, 3F	1	Cygnus Loop (this paper), N49 (DD76a)
4893.4	[Fe VII]	2F	1	Cygnus Loop (this paper)
4905.35	[Fe II]	20F	1	Cygnus Loop (this paper), N63A (RD90)
4921.93	He I	48	1	Cygnus Loop (this paper), N49 (DD76a), N157B (D81; GMCM83), Vela (WB90)
4924.5	[Fe III]	2F	1	Crab Nebula (FKC78)
4930.5	[Fe III]	1F	1	N157B (GMCM83)
4942.5	[Fe VII]	2F	1	Cygnus Loop (this paper)
4958.91	[O III]	1F	2	*
4972.5	[Fe VI]	2F	1	Cygnus Loop (this paper)
4973.39	[Fe II]	20F	1	Cygnus Loop (this paper), RCW 103 (DD74)
4985.9, 4987.2	[Fe III]	2F	1	*
5006.84	[O III]	1F	3	*
5015.68	He I	4	1	Cygnus Loop (this paper), N157B (D81; GMCM83)
5039.10, 5043.53...	[Fe II]	19F, 20F	1	Cygnus Loop (this paper)
5072.40	[Fe II]	19F	1	Crab Nebula (FKC78)
5107.95	[Fe II]	18F	1	N49 (DD76a)
5111.63	[Fe II]	19F	1	*
5145.8	[Fe VI]	2F	1	Cygnus Loop (this paper)
5158.00, 5158.81...	[Fe II]	18F, 19F	1	*
5158.9	[Fe VII]	2F	1	Crab Nebula (*), Cygnus Loop (this paper)
5176.0	[Fe VI]	2F	1	Cygnus Loop (this paper)
5184.80	[Fe II]	19F	1	Crab Nebula (FKC78)
5191.82	[Ar III]	3F	1	Cassiopeia A (KC77)
5197.90	[N I]	1F	1	*
5200.26	[N I]	1F	1	*
5220.06	[Fe II]	19F	1	N49 (DD76a)
5261.61	[Fe II]	19F	1	*
5268.88	[Fe II]	18F	1	*
5270.3	[Fe III]	1F	1	*
5273.38	[Fe II]	18F	1	*
5277.8	[Fe VI]	1F	1	Cygnus Loop (this paper)
5296.84	[Fe II]	19F	1	Vela (MCC78)
5302.86	[Fe XIV]	1F	1	*
5309.18	[Ca V]	1F	1	Cygnus Loop (this paper)
5333.65	[Fe II]	19F	1	*
5335.2	[Fe VI]	1F	1	Cygnus Loop (this paper)
5376.47	[Fe II]	19F	1	Kepler (D82), N63A (DL85), N103B (DL85), N132D (B96)
5411.52	He II	2	1	Crab Nebula (FKC78), Cygnus Loop (this paper), N132D (B96)
5412.64, 5413.34...	[Fe II]	17F, 16F	1	Cygnus Loop (this paper), MSH 15–52 (SHMC83), N49 (MCC78), N132D (B96)
5424.2	[Fe VI]	1F	1	Cygnus Loop (this paper)
5426.6	[Fe VI]	1F	1	Cygnus Loop (this paper)
5484.8	[Fe VI]	1F	1	Cygnus Loop (this paper)
5517.71	[Cl III]	1F	1	Cygnus Loop (this paper)
5527.33	[Fe II]	17F	1	*
5577.34	[O I]	3F	1	Cassiopeia A (HF96; KC77), N49 (VBLR92), RCW 103 (DD74)
5631.1	[Fe VI]	1F	1	Cygnus Loop (this paper)
5677.0	[Fe VI]	1F	1	Cygnus Loop (this paper)
5720.7	[Fe VII]	1F	1	Crab Nebula (FK82), Cygnus Loop (this paper)
5754.59	[N II]	3F	1	*
5876 blend	He I	11	2	*
5889.95	Na I	1	1	N103B (RD90), MSH 15–52 (SHMC83), SMC 0104–72.3 (RD90)
5895.92	Na I	1	1	SMC 0104–72.3 (RD90)
6087.0	[Fe VII]	1F	1	Crab Nebula (*), Cygnus Loop (this paper), LMC 0540–69.3 (KMWB89), N49 (VBLR92)
6300.30	[O I]	1F	2	*
6312.06	[S III]	3F	1	Cassiopeia A (HF96), CTB 80 (HK89), Cygnus Loop (this paper), N157B (GMCM83), Vela (WB90)
6363.78	[O I]	1F	2	*
6374.51	[Fe X]	1F	1	Cygnus Loop (*), IC 443 (*), Puppis A (TP87)
6435.10	[Ar V]	1F	1	Cassiopeia A (HF96; KC77), Cygnus Loop (this paper)
6548.05	[N II]	1F	2	*
6562.85	H α	1	3	*
6583.45	[N II]	1F	3	*
6678.15	He I	46	1	*
6716.44	[S II]	2F	3	*
6730.82	[S II]	2F	3	*
6855.18	Fe I	1195	1	N103B (RD90), SMC 0104–72.3 (RD90)
7005.67	[Ar V]	1F	1	Cassiopeia A (HF96; KC77), Cygnus Loop (this paper)
7065.19, 7065.72...	He I	10	1	*
7135.80	[Ar III]	1F	1	*
7155.14	[Fe II]	14F	1	*
7171.98	[Fe II]	14F	1	*
7236 blend	C II	3	1	Crab Nebula (DP83; FK82)
7281.35	He I	45	1	Crab Nebula (DP83)
7290.42	[Fe I]	14F	1	Crab Nebula (MMMU89)

TABLE 5—Continued

λ (Å)	Ion	Multi- plet	Inten- sity	SNRs ^a and References
7291.46	[Ca II]	1F	2	*
7318.92, 7319.99 ...	[O II]	2F	2	*
7323.88	[Ca II]	1F	2	*
7329.66, 7330.73 ...	[O II]	2F	2	*
7377.83	[Ni II]	2F	1	*
7388.16	[Fe II]	14F	1	Kepler (D82)
7411.61	[Ni II]	2F	1	Crab Nebula (DP83; MMMU89), Kepler (D82), N49 (VBLR92), N63A (LKBW95), RCW 103 (D86)
7452.50	[Fe II]	14F	1	*
7637.52	[Fe II]	1F	1	N49 (RD90; VBLR92), N63A (D86; RD90), N103B (RD90), N132D (B96)
7686.19	[Fe II]	14F	1	N49 (RD90), N63A (RD90)
7686.90	[Fe II]	1F	1	N49 (D86; VBLR92), N63A (D86), RCW 103 (D86)
7751.06	[Ar III]	1F	1	Cassiopeia A (*), Crab Nebula (*), N49 (RD90; VBLR92), N63A (LKBW95; RD90), N132D (B96)
7774 blend	O I	1	1	Cassiopeia A (HF96; KC77; WRK91), Puppis A (WK85), SMC 0102—72.3 (BRDM89)
7891.80	[Fe XI]	1F	1	N49 (RD90), N63A (RD90), N103B (RD90)
7999.85	[Cr II]	1F	1	N49 (RD90; VBLR92), N63A (LKBW95; RD90), N103B (RD90), N132D (B96)
8125.22	[Cr II]	1F	1	N49 (RD90; VBLR92), N63A (LKBW95; RD90), N103B (RD90)
8229.55	[Cr II]	1F	1	N49 (VBLR92), N63A (LKBW95)
8236.77	He II	6	1	N49 (RD90), N63A (RD90), N103B (RD90)
8300.99	[Ni II]	2F	1	Crab Nebula (DP83)
8308.39	[Cr II]	1F	1	N49 (RD90; VBLR92), N63A (LKBW95)
8345.55	H I	58	1	SMC 0104—72.3 (RD90)
8357.51	[Cr II]	1F	1	N49 (VBLR92), N63A (LKBW95)
8359.00	H I	57	1	SMC 0104—72.3 (RD90)
8374.48	H I	56	1	N63A (LKBW95)
8392.40	H I	55	1	N63A (LKBW95)
8446 blend	O I	4	1	Cassiopeia A (HF96; WRK91), Puppis A (WK85), SMC 0102—72.3 (BRDM89)
8467.25	H I	52	1	N63A (LKBW95)
8498.02	Ca II	2	1	Cassiopeia A (HF96), N63A (LKBW95)
8502.48	H I	51	1	N63A (LKBW95)
8542.09	Ca II	2	1	Cassiopeia A (HF96), N49 (VBLR92), N63A (D86; LKBW95; RD90), N103B (RD90), RCW 103 (D86)
8545.38	H I	50	1	N49 (VBLR92), N63A (LKBW95; RD90), N103B (RD90)
8578.70	[Cl II]	1F	1	Cassiopeia A (HF96; WRK91), Crab Nebula (DP83; HMK84), N49 (VBLR92), N63A (D86; LKBW95), RCW 103 (D86)
8598.39	H I	49	1	N19 (RD90), N49 (RD90), N63A (RD90), N103B (RD90), SMC 0104—72.3 (RD90)
8616.96	[Fe II]	13F	1	*
8662.14	Ca II	2	1	Cassiopeia A (HF96), N49 (VBLR92), N63A (D86; LKBW95), RCW 103 (D86)
8665.02	H I	48	1	Crab Nebula (HMK84), N49 (VBLR92), N63A (LKBW95)
8727.13	[C I]	3F	1	Cassiopeia A (HF96; WRK91), N49 (VBLR92), N63A (LKBW95)
8750.47	H I	47	1	N49 (RD90; VBLR92), N63A (LKBW95; RD90), N103B (RD90)
8862.78	H I	46	1	N49 (VBLR92), N63A (LKBW95)
8891.88	[Fe II]	13F	1	*
9014.91	H I	45	1	N49 (VBLR92), N63A (LKBW95)
9033.45	[Fe II]	13F	1	N49 (VBLR92)
9051.92	[Fe II]	13F	1	Kepler (D82), N19 (RD90), N49 (RD90; VBLR92), N63A (D86; LKBW95), N103B (RD90)
9069.0	[S III]	1F	2	*
9123.60	[Cl II]	1F	1	Cassiopeia A (HF96), N63A (D86; LKBW95)
9226.60	[Fe II]	13F	1	*
9229.02	H I	44	1	Crab Nebula (DA81; DP83), N19 (RD90), N49 (RD90), N63A (RD90), N103B (RD90)
9266 blend	O I	8	1	Cassiopeia A (HF96), SMC 0102—72.3 (BRDM89)
9267.54	[Fe II]	13F	1	Cassiopeia A (WRK91), Kepler (D82), N49 (D86; VBLR92), N63A (D86; LKBW95)
9399.02	[Fe II]	13F	1	Crab Nebula (HMK84)
9470.93	[Fe II]	13F	1	N49 (VBLR92)
9531.1	[S III]	1F	2	*
9545.97	H I	43	1	N19 (RD90), N49 (RD90), N63A (D86; RD90), N103B (RD90), RCW 103 (D86)
9682.13	[Fe II]	41F	1	Kepler (D82)
9824.13	[C I]	1F	1	*
9850.26	[C I]	1F	1	*
10049.37	H I	42	1	Kepler (D82), N49 (D86; RD90; VBLR92), N63A (D86; LKBW95; RD90), N103B (RD90)
10123.61	He II	2	1	Crab Nebula (DP83; HMK84)
10286.7	[S II]	3F	2	*
10320.5	[S II]	3F	2	*
10336.4	[S II]	3F	2	*
10370.5	[S II]	3F	2	*
10830 blend	He I	1	2	Crab Nebula (DA81; RRP94), RCW 103 (OMD90)
10938.10	H I	41	1	Crab Nebula (RRP94)
11910.16	[Ni II]	1F	1	Crab Nebula (HHJ90; RRP94)

^a An asterisk denotes line(s) observed in more than six SNRs.

TABLE 6
WAVELENGTH REFERENCES

Element(s)	Reference
Fe	Fuhr, Martin, & Wiese 1988
Ne, Cl, and Ar	Kaufman & Sugar 1986
S	Martin, Zalubas, & Musgrove 1990 ^a
He and Fe	Moore 1945
H, C, N, and O	Moore 1993
Mg and Fe	Morton 1991
Ni	Nussbaumer & Storey 1982
Fe	Shirai et al. 1990
Cr	Smith & Wiese 1973
Na, Mg, Al, Si, and Ca	Wiese, Smith, & Miles 1969

^a Wavelengths calculated using the index of refraction of air given by Edlen 1966.

TABLE 7
SUPERNOVA REMNANT EMISSION LINES GROUPED BY ELEMENTS

Element	Ion	Wavelengths (Å)
Hydrogen	H I	1025.72, 3686.83, 3691.56, 3697.15, 3703.85, 3711.97, 3734.37, 3750.15, 3770.63, 3797.90, 3835.38, 3889.05, 3970.07, 4101.77, 4340.49, 4861.36, 6562.85, 8345.55, 8359.00, 8374.48, 8392.40, 8467.25, 8502.48, 8545.38, 8598.39, 8665.02, 8750.47, 8862.78, 9014.91, 9229.02, 9545.97, 10049.37, 10938.10
Helium	He I	3187.74, 3819.61, 3819.76, 3888.65, 3964.73, 4026.19, 4026.36, 4120.81, 4120.99, 4471.48, 4471.69, 4713.14, 4713.37, 4921.93, 5015.68, 5876 blend, 6678.15, 7065.19, 7065.72, 7281.35, 10830 blend
	He II	1084.91, 1084.98, 1640 blend, 3203.10, 4685.68, 5411.52, 8236.77, 10123.61
Carbon	[C I]	8727.13, 9824.13, 9850.26
	C II	1334.53, 4267.00, 4267.26, 7236 blend
	C II]	2323.50, 2324.69
	C III	977.03
	C III]	1908.73
	[C III]	1906.68
	C IV	1548.20, 1550.77
Nitrogen	[N I]	5197.90, 5200.26
	N II	1083.99
	[N II]	5754.59, 6548.05, 6583.45
	N III	989.79
	[N III]	1730 blend, 1746.82, 1748.61
	N IV]	1486.50
	[N IV]	1483.32
	N V	1238.82, 1242.80
Oxygen	O I	1355.60, 7774 blend, 8446 blend, 9266 blend
	[O I]	5577.34, 6300.30, 6363.78
	[O II]	2470.22, 2470.34, 3726.03, 3728.82, 7318.92, 7319.99, 7329.66, 7330.73
	[O III]	1660.81, 1666.15
	[O III]	2320.95, 2331.40, 4363.21, 4958.91, 5006.84
	O IV]	1397.20, 1399.77
	O V	1371.29
	O VI	1031.93, 1037.62
Neon	[Ne III]	3342.42, 3868.75, 3967.46
	[Ne IV]	1601, 1602, 2418.2, 2420.9, 4724.17, 4725.60
	Ne V]	1146.1
	[Ne V]	1574.8, 3345.83, 3425.87
	Ne VI	1006 blend
Sodium	Na I	5889.95, 5895.92
Magnesium ...	Mg I	2852.13
	Mg I]	4571.10
	[Mg I]	4562.48
	Mg II	2795.52, 2802.70
Aluminum	Al II	1670.81, 2669.17
Silicon	Si II	1533.43, 1808.01, 1816.93, 1817.45
	Si II]	2328.51, 2334.40
	Si III]	1892.03
	Si IV]	1393.76, 1402.77
Sulphur	S I	1807.31, 1820.34, 1826.25
	[S II]	4068.60, 4076.35, 6716.44, 6730.82, 10286.7, 10320.5, 10336.4, 10370.5
	[S III]	6312.06, 9069.0, 9531.1
	S IV]	1398.13, 1404.77
	S VI	933.38, 944.52
Chlorine	[Cl II]	8578.70, 9123.60
	[Cl III]	5517.71

TABLE 7—Continued

Element	Ion	Wavelengths (Å)	
Argon	[Ar III]	5191.82, 7135.80, 7751.06	
	[Ar IV]	4711.33, 4740.20	
	[Ar V]	6435.10, 7005.67	
Calcium	Ca II	3933.66, 3968.47, 8498.02, 8542.09, 8662.14	
	[Ca II]	7291.46, 7323.88	
	[Ca V]	5309.18	
Titanium	[Ti III] ?	2628 blend	
Chromium	[Cr II]	7999.85, 8125.22, 8229.55, 8308.39, 8357.51	
Iron	Fe I	6855.18	
	Fe II	2343.49, 2382.04, 2585.88, 2599.40	
	[Fe I]	7290.42	
	[Fe II]	4177.21, 4243.98, 4244.81, 4287.40, 4358.10, 4358.37, 4359.34, 4413.78, 4414.45, 4416.27, 4452.11, 4457.95, 4470.29, 4474.91, 4632.27, 4774.74, 4814.55, 4889.63, 4889.70, 4905.35, 4973.39, 5039.10, 5043.53, 5072.40, 5107.95, 5111.63, 5158.00, 5158.81, 5184.80, 5220.06, 5261.61, 5268.88, 5273.38, 5296.84, 5333.65, 5376.47, 5412.64, 5413.34, 5527.33, 7155.14, 7171.98, 7388.16, 7452.50, 7637.52, 7686.19, 7686.90, 8616.96, 8891.88, 9033.45, 9051.92, 9226.60, 9267.54, 9399.02, 9470.93, 9682.13	
	[Fe III]	4658.10, 4701.62, 4733.93, 4754.83, 4769.60, 4777.88, 4813.9, 4881.11, 4924.5, 4930.5, 4985.9, 4987.2, 5270.3	
	[Fe V]	4227.2	
	[Fe VI]	4972.5, 5145.8, 5176.0, 5277.8, 5335.2, 5424.2, 5426.6, 5484.8, 5631.1, 5677.0	
	[Fe VII]	3586.3, 3758.9, 4893.4, 4942.5, 5158.9, 5720.7, 6087.0	
	[Fe X]	6374.51	
	[Fe XI]	7891.80	
	[Fe XIV]	5302.86	
	Nickel	[Ni II]	4485.21, 7377.83, 7411.61, 8300.99, 11910.16

TABLE 8

SPECTROSCOPY REFERENCES FOR GALACTIC SUPERNOVA REMNANTS

Coordinates	Names	Band	References
4.5+06.8	Kepler, SN 1604	Optical	Blair, Long, & Vancura 1991; Fesen et al. 1989; Leibowitz & Danziger 1983; van den Bergh 1980
		Optical/NIR	Dennefeld 1982
6.4-00.1	W28	Optical	Bohigas et al. 1983; Dopita, Mathewson, & Ford 1977; Long et al. 1991
13.3-01.3		Optical	Seward et al. 1995
39.7-02.0	W50, SS 433	Optical	Kirshner & Chevalier 1980; Murdin & Clark 1980; Shuder, Hatfield, & Cohen 1980; Zealey, Dopita, & Malin 1980
53.6-02.2	3C 400.2	Optical	Blair & Long 1988; Long et al. 1991; Sabbadin & D'Odorico 1976; Winkler, Olinger, & Westerbeke 1993b
65.3+05.7	S91 + S94	Optical	Fesen et al. 1985; Sabbadin & D'Odorico 1976
69.0+02.7	CTB 80	Optical	Angerhoffer, Wilson, & Mould 1980; Blair, Fesen, & Becker 1988; Blair et al. 1984; Hester & Kulkarni 1989; Whitehead, Meaburn, & Clayton 1989
74.0-08.5	Cygnus Loop	UV	Benvenuti, Dopita, & D'Odorico 1980; Blair et al. 1991a, 1991c; D'Odorico et al. 1980; Long et al. 1992; Rasmussen & Martin 1992; Raymond et al. 1980a, 1981; Shemansky, Sandel, & Broadfoot 1979; Vancura et al. 1993
		UV/Optical	Hester et al. 1994; Raymond et al. 1983, 1988;
		Optical	Ballet et al. 1989; Fesen et al. 1982; this paper; Fesen & Itoh 1985; Heckathorn, Shulman, & Giuli 1978; Lucke et al. 1980; Miller 1974; Parker 1964, 1967; Raymond et al. 1980b; Shull et al. 1982; Teske 1990; Teske & Kirshner 1985; Woodgate, Kirshner, & Balon 1977; Woodgate et al. 1974
		NIR	Dennefeld & Andriolat 1981
78.2+02.1	γ Cygni, DR 4	Optical	Bohigas et al. 1983; D'Odorico & Sabbadin 1977
82.2+05.3	W63	Optical	Lozinskaya et al. 1975; Sabbadin 1976
109.1-01.0	CTB 109	Optical	Blair & Kirshner 1981; Fesen & Hurford 1995
111.7-02.1	Cassiopeia A	Optical	Chevalier & Kirshner 1979; Fesen 1990; Fesen & Becker 1991; Fesen, Becker, & Blair 1987; Fesen, Becker, & Goodrich 1988a; Fesen & Gunderson 1996; Kirshner & Chevalier 1977; Minkowski 1957; Peimbert & van den Bergh 1971; Reed et al. 1995; van den Bergh 1971
		Opt/NIR	Hurford & Fesen 1996; Searle 1971; Winkler, Roberts, & Kirshner 1991
		NIR	Dennefeld & Andriolat 1981
116.5+01.1		Optical	Fesen et al. 1996
116.9+00.2	CTB 1	Optical	Bohigas et al. 1983; D'Odorico & Sabbadin 1977; Fesen et al. 1985; Hailey & Craig 1994; Fesen et al. 1996
119.5+10.2	CTA 1	Optical	Fesen et al. 1981
120.1+01.4	Tycho, SN 1572	Optical	Chevalier, Kirshner, & Raymond 1980; Kirshner & Chevalier 1978; Kirshner, Winkler, & Chevalier 1987; Smith et al. 1991
126.2+01.6		Optical	Blair et al. 1980
130.7+03.1	3C 58, SN 1181	Optical	Fesen 1983; Fesen, Kirshner, & Becker 1988b; Kirshner & Fesen 1978
132.7+01.3	HB 3	Optical	D'Odorico & Sabbadin 1977; Fesen et al. 1995
160.9+02.6	HB 9	Optical	D'Odorico & Sabbadin 1977
166.0+04.3	VRO 42.05.01	Optical	D'Odorico & Sabbadin 1977; Esipov et al. 1972; Fesen et al. 1985
166.2+02.5	OA 184	Optical	D'Odorico & Sabbadin 1977; Fesen et al. 1985
180.0-01.7	S147	Optical	D'Odorico & Sabbadin 1977; Esipov et al. 1972; Fesen et al. 1985; Kirshner & Arnold 1979; Parker 1964

TABLE 8—Continued

Coordinates	Names	Band	References
184.6−05.8.....	Crab Nebula, SN 1054	UV UV/Optical Optical	Blair et al. 1992 Davidson et al. 1982 Davidson 1978, 1979; Davidson & Humphreys 1976; Fesen & Kirshner 1982; Fesen, Kirshner, & Chevalier 1978; Kirshner 1974; MacAlpine et al. 1994; Marcelin et al. 1990; Miller 1978; Shull et al. 1984; Trimble 1970; Woltjer 1958
		Optical/NIR	Dennefeld & Péquignot 1983; Henry, MacAlpine, & Kirshner 1984; MacAlpine et al. 1989; Miller 1973
		NIR	Dennefeld & Andrillat 1981; Hudgins, Herter, & Joyce 1990; Rudy, Rossano, & Puetter 1994
189.1+03.0.....	IC 443	Optical	Brown, Woodgate, & Petre 1988; D'Odorico 1974; Fesen 1984; Fesen & Kirshner 1980; Gensheimer & Teske 1986; Meaburn et al. 1990; Parker 1964; Sauvageot et al. 1990; Shull et al. 1982; Teske 1991; Woodgate, Lucke, & Socker 1979
205.5+00.5.....	Monoceros Loop	Optical	D'Odorico & Sabbadin 1977; Fesen et al. 1985
206.9+02.3.....	PKS 0646+06	Optical	Fesen et al. 1985
260.4−03.4.....	Puppis A, MSH 08−44	UV Optical	Blair et al. 1995a Clark et al. 1979; Danziger & Dennefeld 1976a; Dopita et al. 1977; Lucke et al. 1979; Shull 1983a; Sutherland & Dopita 1995; Teske & Petre 1987; Winkler & Kirshner 1985; Winkler et al. 1988, 1989;
263.9−03.3.....	Vela	UV Optical	Blair, Vancura, & Long 1995b; Danziger, Wood, & Clark 1980; Raymond et al. 1981; Raymond, Wallerstein, & Balick 1991 Danziger & Dennefeld 1976a; Dopita et al. 1977; Meaburn, Hartquist, & Dyson 1988; Osterbrock & Costero 1973; Shull 1983a; Wallerstein & Balick 1990; Woodgate, Angel, & Kirshner 1975
272.2−3.2.....		Optical	Winkler, Hanson, & Phillips 1993a
284.3−1.8.....	MSH 10−53	Optical	Rúiz & May 1986
290.1−00.8.....	MSH 11−61A	Optical	Elliott & Malin 1979
292.0+01.8.....	MSH 11−54	Optical	Dopita & Tuohy 1984; Goss et al. 1979; Murdin & Clark 1979; Sutherland & Dopita 1995; van den Bergh 1979
296.1−00.7.....		Optical	Longmore, Clark, & Murdin 1977
296.5+10.0.....	PKS 1209−51/52, Centaurus	Optical	Danziger & Dennefeld 1976a; Rúiz 1983
315.4−02.3.....	RCW 86, MSH 14−63	Optical	Danziger & Dennefeld 1974, 1976a; Dopita, D'Odorico, & Benvenuti 1980; Leibowitz & Danziger 1983; Long & Blair 1990; Lucke et al. 1979; Rúiz 1981; Westerlund & Mathewson 1966
320.4−01.2.....	RCW 89, MSH 15−52	Optical/NIR	Dennefeld 1986
326.3−01.8.....	MSH 15−56	Optical	Danziger 1983; Dopita et al. 1977; Seward et al. 1983
327.6+14.6.....	SN 1006, PKS 1459−41	Optical UV	Dennefeld 1980 Raymond, Blair, & Long 1995
		Optical	Kirshner et al. 1987; Lasker 1981a; Schweizer & Lasker 1978; Smith et al. 1991
332.4−00.4.....	RCW 103	Optical	Danziger & Dennefeld 1974, 1976a; Dopita et al. 1980; Leibowitz & Danziger 1983; Meaburn & Allan 1986; Rúiz 1983; Westerlund & Mathewson 1966
		Optical/NIR	Dennefeld 1986
		NIR	Oliva, Moorwood, & Danziger 1990

TABLE 9
SPECTROSCOPY REFERENCES FOR LMC AND SMC SUPERNOVA REMNANTS

Coordinate	Henize Number ^a	Band	References
LMC 0453–66.9.....		Optical	Smith et al. 1994a
LMC 0454–66.5.....	N11L	Optical	Chu & Kennicutt 1988; Danziger & Dennefeld 1976a, 1976b; Danziger & Leibowitz 1985; Dopita 1979; Dopita et al. 1977; Lasker 1981b; Meaburn 1987
LMC 0454–67.2.....		Optical	Smith et al. 1994a
LMC 0455–68.7.....	N86	Optical	Chu & Kennicutt 1988; Danziger & Dennefeld 1976a; Danziger & Leibowitz 1985; Dopita 1979; Dopita et al. 1980; Dopita et al. 1977; Lasker 1981b
LMC 0500–70.2.....	N186D	Optical	Dopita 1979
LMC 0505–67.9.....		Optical	Smith et al. 1991; Smith, Raymond, & Laming 1994b
LMC 0509–67.5.....		Optical	Smith et al. 1991, 1994b; Tuohy et al. 1982
LMC 0509–68.7.....	N103B	Optical	Danziger & Dennefeld 1976a; Danziger & Leibowitz 1985; Dopita 1979; Dopita et al. 1977
		Optical/NIR	Russell & Dopita 1990
LMC 0519–69.0.....		Optical	Smith et al. 1991, 1994b; Tuohy et al. 1982
LMC 0519–69.7.....	N120	Optical	Danziger & Dennefeld 1976a; Danziger & Leibowitz 1985; Dopita 1979; Dopita et al. 1977
LMC 0525–66.0.....	N49B	Optical	Danziger & Dennefeld 1976a, 1976b; Danziger & Leibowitz 1985; Dopita 1979; Dopita et al. 1977
LMC 0525–66.1.....	N49	UV	Benvenuti et al. 1980; Vancura et al. 1992b
		UV/Optical/NIR	Vancura et al. 1992a
		Optical	Chu & Kennicutt 1988; Danziger & Dennefeld 1976a; Dopita 1979; Dopita & Mathewson 1979; Dopita et al. 1977; Murdin, Clark, & Culhane 1978; Osterbrock & Dufour 1973; Shull 1983c; Westerlund & Mathewson 1966
LMC 0525–69.6.....	N132D	Optical/NIR	Dennefeld 1986; Russell & Dopita 1990
		UV	Blair, Raymond, & Long 1994
		UV/Optical	Blair et al. 1996
		Optical	Danziger & Dennefeld 1976a, 1976b; Danziger & Leibowitz 1985; Dopita 1979; Dopita et al. 1977; Dopita & Tuohy 1984; Lasker 1978, 1980; Morse, Winkler, & Kirshner 1995; Sutherland & Dopita 1995; Westerlund & Mathewson 1966
LMC 0532–71.0.....	N206	Optical	Chu & Kennicutt 1988; Danziger & Dennefeld 1976a; Danziger & Leibowitz 1985; Dopita 1979; Dopita et al. 1980; Lasker 1981b
LMC 0535–66.0.....	N63A	UV	Benvenuti et al. 1980
		Optical	Chu & Kennicutt 1988; Danziger & Dennefeld 1974, 1976a; Danziger & Leibowitz 1985; Dopita 1979; Dopita & Mathewson 1979; Dopita et al. 1977; Shull 1983b; Westerlund & Mathewson 1966
LMC 0538–69.1.....	N157B	Optical/NIR	Dennefeld 1986; Levenson et al. 1995; Russell & Dopita 1990
		Optical	Chu & Kennicutt 1988; Chu et al. 1992; Danziger et al. 1981; Gilmozzi et al. 1983
LMC 0540–69.3.....	N158A	Optical/NIR	Dennefeld 1986
		Optical	Dopita & Tuohy 1984; Mathewson et al. 1980
		Optical/NIR	Kirshner et al. 1989
LMC 0547–69.7.....	N135	Optical	Chu & Kennicutt 1988; Danziger & Dennefeld 1976a; Dopita et al. 1977; Lasker 1981b
LMC 0548–70.4.....		Optical	Smith et al. 1991; Smith et al. 1994b
SMC 0045–73.4.....	N19	Optical	Chu & Kennicutt 1988; Danziger & Dennefeld 1976a; Dopita 1979; Dopita et al. 1977
		Optical/NIR	Russell & Dopita 1990
SMC 0046–73.5.....		Optical	Danziger & Dennefeld 1976a
SMC 0057–72.4.....	N66	Optical	Chu & Kennicutt 1988
SMC 0102–72.3.....		UV/Optical/NIR	Blair et al. 1989
		Optical	Dopita & Tuohy 1984; Tuohy & Dopita 1983
SMC 0104–72.3.....		Optical/NIR	Russell & Dopita 1990

^a Henize 1956.

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