3C58'S FILAMENTARY RADIAL VELOCITIES, LINE INTENSITIES, AND PROPER MOTIONS

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ABSTRACT: Optical spectroscopy on nearly 50 filaments of 3C58 indicates a maximum expansion velocity of 1100 ± 100 km s^{-1}. A considerable range in radial velocity with projected distance from remnant center is found suggesting that the remnant's optical emission is not confined to a thin shell. Typical filament electron densities are between 200 - 500 cm^{-3} with Hα/[N II] ratios in the range 0.2 - 0.5. Optical extinction to 3C58 is modest with E[B-V] = 0.68 ± 0.08. Preliminary radial proper motion measurements for a few outlying filaments suggest values of order 0.05" - 0.07" yr^{-1}.

INTRODUCTION

The galactic SNR 3C58 is perhaps the best studied member of the subclass of remnants which have properties resembling those of the Crab Nebula. In the radio, 3C58 exhibits a filled center morphology, high degree of linear polarization, and a relatively flat spectral index (Weiler 1980; Reynolds and Aller 1985; Green 1986). It also possesses a centrally peaked X-ray emission structure with hints of an X-ray point source, suggesting the presence of a central neutron star (Becker et al. 1982). If 3C58 is indeed the remnant of SN 1181 as suggested by Stephenson (1971) and Clark and Stephenson (1977), it then also has about the same age as the Crab Nebula. However, with angular dimensions of 5' x 9' and a distance of 2.6 ± 0.2 kpc estimated from 21 cm absorption studies (Green and Gull 1982), 3C58 appears nearly 50% larger than the Crab despite being slightly younger. Since optical filament radial velocities only as large as 900 km s^{-1} have been observed (Fesen 1983), a firm connection between 3C58 and SN 1181 has not yet been established and such an association has been recently questioned based on new interpretations of the historical observations (Huang 1987).

OBSERVATIONS

In order to further investigate 3C58's optical properties and kinematics, we obtained several long slit CCD spectra covering portions of the remnant's central 5' diameter region using the Cryogenic CCD Camera attached to the KPNO 4 m telescope. These data provided radial velocity (± 75 km s^{-1}) and relative emission line intensity information on nearly 50 individual filaments. In addition, we recently obtained (Nov. 1986) deep CCD Hα interference-filter images of four of the brightest outlying emission knots. The positions of these knots on these images were compared to their locations on van den

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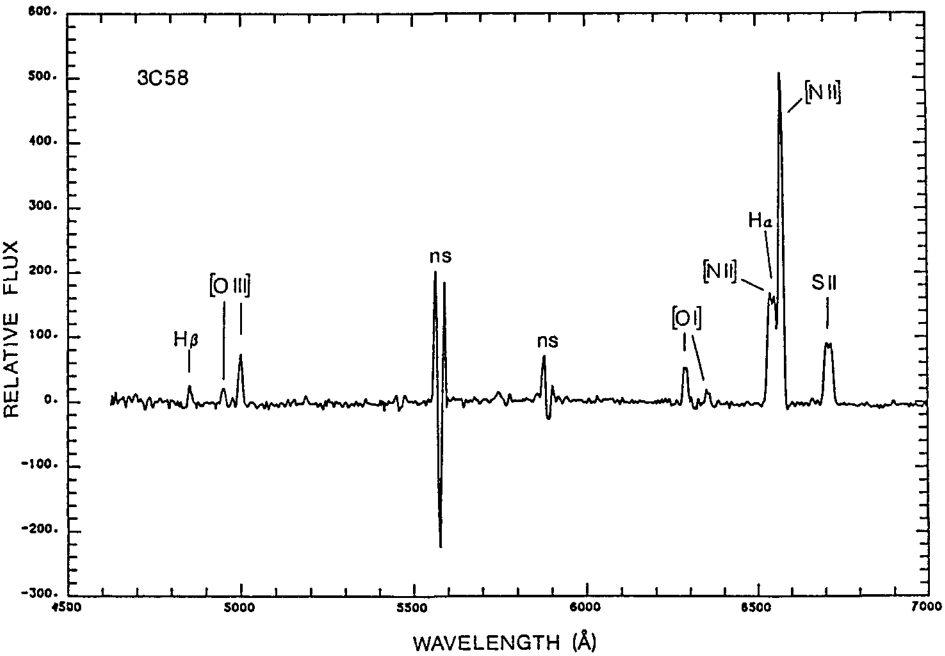

Figure 1: Optical spectrum of one of 3C58's brighter emission filaments covering the wavelength region from 4500 - 7000 Å at 13 Å resolution. Note the strong [N II] 6548,6583 and [O I] 6300,6364 lines relative to the strength of Hα. The features at 5577 and 5890 are due to imperfect subtraction of the night sky emission lines.

Bergh's (1978) red photograph in order to estimate the remnant's proper motion.

RESULTS

A representative spectrum for one of 3C58's brighter filaments is shown in Figure 1. The presence of strong [S II] 6717,6731, [O I] 6300,6364, and [O III] 4959,5007 line emissions relative to the strength of Hα is strong evidence that the observed optical emission represents shock-heated gas associated with the remnant. The electron density-sensitive [S II] 6717/6731 line ratio was found to be typically between 1.0 - 1.2 with a total range of 0.85 to 1.4. This implies a range of electron densities for 3C58's filaments of $\leq$ 100 to 1000 cm^{-3} with average values of between 200 - 500 cm^{-3}. These values in turn suggest preshock densities of order 2 - 5 cm^{-3}.

The majority of 3C58's filaments exhibit strong [N II] 6548,6583 line emission with Hα/[N II] ratios typically in the range 0.2 - 0.5, but as small as 0.15. Such strong [N II] emission is seen in Kepler's SNR and Cas A's QSF's and is believed to signify a nitrogen enrichment several times over the solar abundance. Filaments showing considerably weaker [N II] emission (Hα/[N II] = 1.0 - 1.5) like that observed in shocked interstellar gas appear limited to the remnant's northern edge (cf. Kirshner and Fesen 1978).

Measured radial velocities for nearly 50 of 3C58's filaments were found to range from +1000 to −1075 km s^{-1} (see Fig. 2). The highest velocities observed are for filaments

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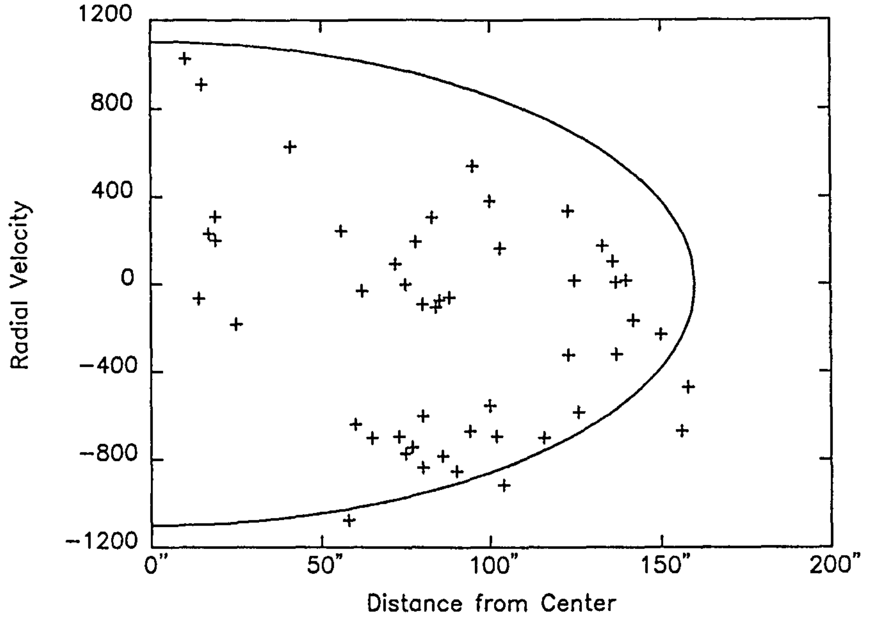

Figure 2: Observed filament radial velocity (km s^{-1}) plotted versus projected radial distance from the 3C58's X-ray point source in arcseconds. Curve represents an expansion velocity of 1100 km s^{-1} at a radius of 160".

located near the remnant's projected center suggesting a maximum line of sight expansion velocity of about 1100 ± 100 km s^{-1}. However, as can be seen from Figure 2, considerable low-velocity gas ($|V_r| \leq 300$ km s^{-1}) is also observed throughout the remnant including 3C58's center and positions immediately adjacent to filaments with V_r in excess of ± 500 km s^{-1}. This indicates that the remnant's optical emission is not confined to a thin shell as is the case in the Crab Nebula. This lower radial velocity gas does not appear significantly different from the remnant's higher velocity filaments with respect to morphology, electron density, or [N II] line emission strength.

An estimate of the reddening to 3C58 was made using the observed $H\alpha/H\beta$ ratio for the brighter filaments where $H\beta$ could be accurately measured. Assuming an intrinic $H\alpha/H\beta$ ratio of 3.0, the observed range of 5.6 - 6.6 suggests only a modest amount of optical extinction; i.e., E[B-V] = 0.68 ± 0.08 ($A_v = 2.0 \pm 0.25$ mag). While larger than the $A_v = 1.3 \pm 0.2$ value estimated by Green and Gull (1982) from H I column density observations but less than the $A_v = 3.1$ suggested by Panagia and Weiler (1980), this value is in good accord with reddening estimates for distances between 1 and 4 kpc in this general direction (Neckel and Klare 1980).

Proper motion estimates for four relatively bright outlying filaments (northern knots "A" and "B" observed by Kirshner and Fesen 1978; WNW knots at r = 170"; and a NE knot at r = 158") indicate values on the order of 0.05" to 0.07" yr^{-1} and appear to exclude values as high as 0.15" yr^{-1} for filaments having radial distances less than 160".

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DISCUSSION

Filament radial velocities of up to 1100 km s^{-1}, the presence of strong nitrogen emission indicating a probable N/H enhancement, and filament electron densities as large as 10^3 cm^{-3} suggest that 3C58's optical emission is that of a young SNR. However, if 3C58 is the remnant of SN 1181 and therefore only 800 yrs old, our measured proper motions of 0.05" - 0.07" yr^{-1} are considerably less than its average value (radius/age) of 0.2" yr^{-1}. Similarly, the observed 1100 km s^{-1} radial expansion velocity is less than half 3C58's average expansion velocity if at a distance of 2.6 kpc. A kinematic distance estimate for 3C58 from our data is complicated by the uncertainity of the remnant's tangential expansion velocity in the E-W or N-S directions. Assuming $V_T = V_R$, then our preliminary proper motion estimates suggest a distance of between 3.0 - 4.5 kpc. A 2.6 kpc distance is still quite possible, however, requiring only $\mu = 0.09"$ yr^{-1}.

A possible way to reconcile 3C58's dimensions with an 800 year age despite its observed low proper motions and radial velocities would be for its ejecta to have undergone a rapid deceleration. Such an explanation would require a substantial ambient interstellar gas density of order 5 - 10 cm^{-3} in the remnant's immediate vicinity. Interestingly, 3C58's low-velocity emission filaments might indicate the existence of such a high-density medium which might be due in part to a pre-supernova mass loss episode. In terms of radial velocity and [N II] emission strength, 3C58's low-velocity gas appears similar to the nitrogen-rich, pre-SN mass loss material found in Cas A and Kepler. The relatively bright filaments along 3C58's northern rim which exhibit weaker [N II] line emission also suggest that the remnant lies is a region containing at least some high-density interstellar gas. In any case, the presence of low-velocity gas within 3C58 represents an important difference between its optical emission and that of the Crab Nebula. Therefore, despite lower than expected radial velocities and proper motions considering 3C58's size and age relative to the Crab Nebula, 3C58 appears the likely remnant of SN 1181.

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