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Hα AND [FE II] 1.6435 μm LUMINOSITIES OF IC 443: A STANDARD CANDLE FOR COUNTING SNR IN M82

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RESUMEN

Presentamos una imagen calibrada en Hα + [N II] $\lambda\lambda$6548, 6583 del remanente de supernova IC 443 y comparamos la distribución superficial de brillo del [Fe II] 1.6435 μm, a lo largo de tres cortes E–O con cortes iguales extraidos de nuestra imagen en Hα. La emisión del [Fe II] es muy extendida. La distribución espacial de [Fe II] 1.6435 μm es muy similar en forma y posición a la emisión óptica en una superficie de 20 minutos de arco (8.8 pc a una distancia de 1.5 kpc). El cociente Hα/[Fe II] varía por un orden de magnitud en las regiones filamentarias brillantes del remanente, en escalas espaciales de 1 a 5 minutos de arco (0.4–2.2 pc). Sin embargo, globalmente, el cociente Hα/[Fe II] es $\simeq$ 2.9. Extrapolamos la luminosidad total de IC 443 en la línea de [Fe II] 1.6435 μm, ($L_{[\mathrm{Fe\ II}]} \simeq 59 \pm 21 L_{\odot}$) de nuestra luminosidad total en Hα y el valor promedio de Hα/[Fe II]. Evaluamos la utilidad de medir la luminosidad global de [Fe II] como un método para contar remanentes de supernova evolucionadas en galaxias externas usando M82 como un caso de prueba.

ABSTRACT

We present a flux calibrated image of the supernova remnant IC 443 in Hα + [N II] $\lambda\lambda$6548, 6583 and compare the [Fe II] 1.6435 μm surface brightness distribution along three E–W cuts to the same cuts extracted from our Hα image. The [Fe II] emission is very extended. The [Fe II] 1.6435 μm spatial distribution is very similar in shape and position to the optical emission over 20 arcmin (8.8 pc at a distance of 1.5 kpc). The Hα/[Fe II] ratio varies by as much as an order of magnitude in the bright filamentary regions of the remnant on spatial scales of 1–5 arcmin (0.4–2.2 pc). Globally, however, the Hα/[Fe II] ratio is $\simeq$ 2.9. We extrapolate the total luminosity of IC 443 in the [Fe II] 1.6435 μm line ($L_{[\mathrm{Fe\ II}]} \simeq 59 \pm 21 L_{\odot}$) from our total H$\alpha$ luminosity and the mean Hα/[Fe II] value. We evaluate the utility of measuring the global [Fe II] luminosity as a method of counting evolved SNRs in external galaxies using M82 as a test case.

Key words: **ISM: SUPERNOVA REMNANTS**

1. INTRODUCTION

Supernovae strongly affect their host galaxies by injecting matter and energy into the ISM. Supernova remnants (SNRs) profoundly alter the structure, energetics, chemistry, and evolution of the ISM and thereby affect star formation. Since they are present long after the supernova event, SNRs can trace the massive star formation history of a galaxy. Detailed studies of specific physical processes in local regions within SNRs are much more valuable when supplemented by global studies of a few emission lines. We present global luminosities in Hα and [Fe II] (1.6435 μm) and an estimated line ratio for the SNR IC 443. We use these data to obtain an order of magnitude estimate of the SNR content of M82.

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2. OBSERVATIONS AND RESULTS

We obtained a narrow band (40Å FWHM) 2048×2048 pixel CCD image of IC 443 in Hα + [N II] using the McDonald Observatory Prime Focus Camera (Claver & MacQueen 1995) in February 1994. We flux calibrated the image and corrected for the [N II] $\lambda\lambda$6548, 6583 contribution. Our surface brightness sensitivity limit was 1.2×10^{-5} erg s^{-1} cm^{-2} sr^{-1} and our calibration is accurate to 15%.

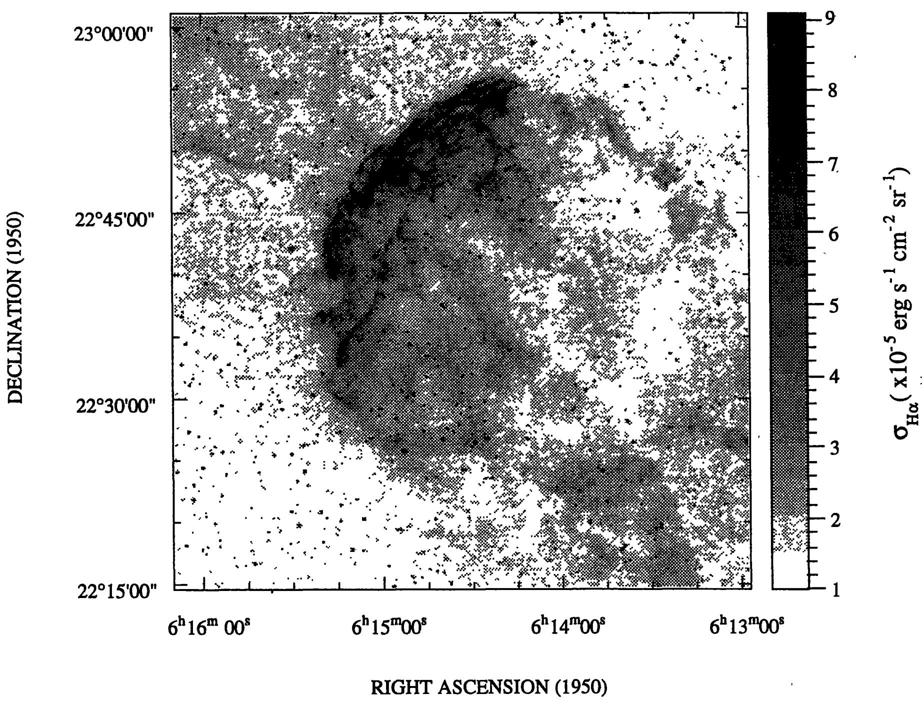

Fig. 1. Flux calibrated CCD image of IC 443 in Hα.

We also obtained spectrophotometric surface brightness measurements of IC 443 in [Fe II] (1.6435 μm), at positions given in Table 1, using the University of Texas Near-Infrared Fabry-Perot Spectrometer (Luhman et al. 1995). Our surface brightness sensitivity limit was 1.0×10^{-6} erg s^{-1} cm^{-2} sr^{-1}. Hα traces the radiative relaxation zone in SNRs as well as non-radiative (Balmer dominated) shocks, when present. The $a^4F_{9/2} \rightarrow a^4D_{7/2}$ (electric dipole forbidden) transition of [Fe II] (at 1.6435 μm) traces strong shocks in SNR. (Graham, Wright, & Longmore 1987; Graham et al. 1991; Wright, Graham, & Longmore 1988; Greenhouse et al. 1991; Bautista, Pradhan, & Osterbrock 1995).

TABLE 1

POSITIONS OF [FE II] SPECTRA

Cut	(0,0) Positions (1950) α	δ	Positions of Spectra (in arcmin west of 0,0)
1	$6^h15^m27^s$	22°40′00″	0,1,2,3,4,5,6
2	$6^h15^m27^s$	22°42′00″	2,3,4,5,6,7,9,10
3	$6^h15^m27^s$	22°44′00″	1,2,3,4,5,8,10,12,14,16

We present the Hα image and [Fe II] spectrophotometry in Figures 1 and 2. The spatial distribution of the Hα and [Fe II] emission both peak sharply along the eastern rim of the bright optical shell and become fainter to the west. The Hα/[Fe II] ratio varies by factors of up to 10 on small scales (1–5 arcmin) but approaches a single, characteristic value on larger scales (i.e., when we integrate the surface brightness over our [Fe II] cuts so that the effects of limb-brightening of the SNR shell are suppressed). For IC 443, we estimate Hα/[Fe II] $\simeq 2.9 \pm 1.0$.

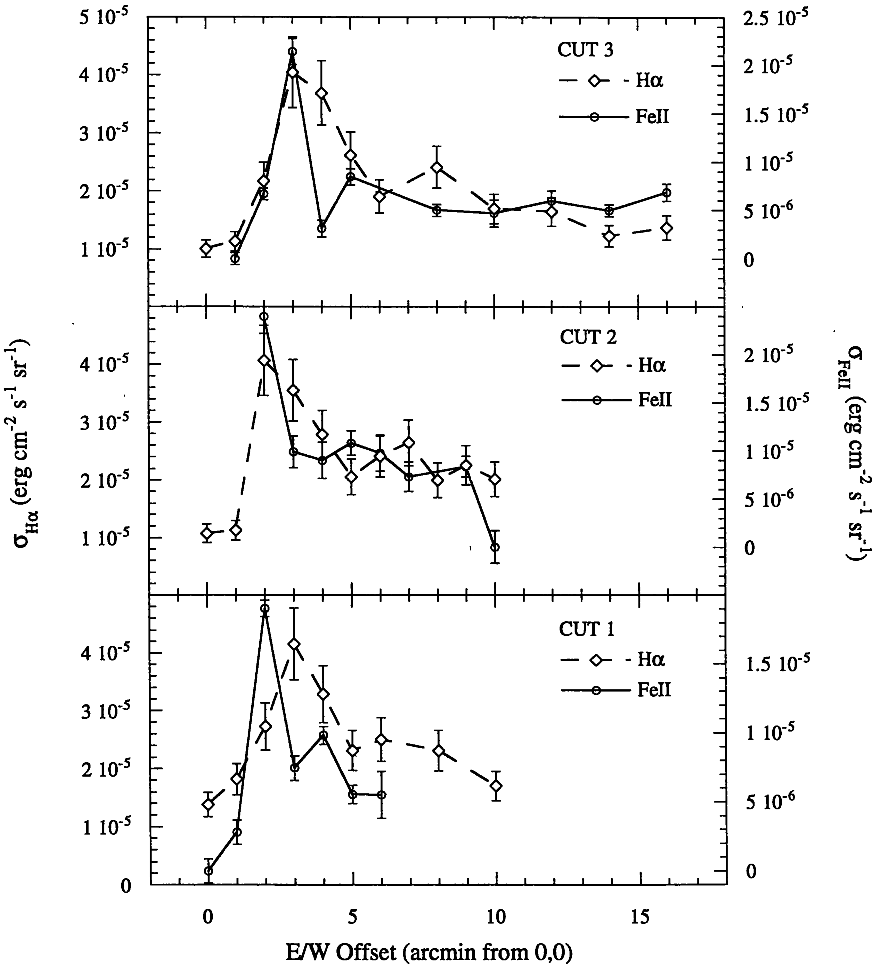

Fig. 2. East–West surface brightness distributions of Hα and [Fe II] 1.6345 μm across the bright ridge in IC 443. Positions of the data points in the image (Figure 1) are compiled in Table 1.

3. DISCUSSION AND CONCLUSIONS

From our Hα image we find $L_{\mathrm{H}\alpha\mathrm{IC443}} \simeq (6.7 \pm 1.0) \times 10^{35}$ erg s^{-1}. Using our estimated line ratio, $L_{[\mathrm{Fe~II}]\mathrm{IC443}} \simeq L_{\mathrm{H}\alpha\mathrm{IC443}}$ / (Hα/[Fe II])$\approx (2.3 \pm 0.8) \times 10^{35}$ erg s^{-1} or $L_{[\mathrm{Fe~II}]\mathrm{IC443}} \approx 59 \pm 21 L_{\odot}$. Galactic SNRs have [Fe II] luminosities in the range 0.3 – 720 $L_{\odot}$ (based on crude luminosity estimates from line fluxes at the brightest peaks in several SNRs) so IC 443 is of low to moderate luminosity but fairly represents SNRs in the Milky Way and Magellanic Clouds (Oliva, Moorwood, & Danziger 1989). $L_{[\mathrm{Fe~II}]\mathrm{M82}} = 1.2 \times 10^5 L_{\odot}$ (Greenhouse et al., 1991) so we estimate that the number of SNRs in M82 is $N_{\mathrm{SNR}} = L_{[\mathrm{Fe~II}]\mathrm{M82}}/L_{[\mathrm{Fe~II}]\mathrm{IC443}} \approx 2 \times 10^3$.

Is this reasonable? The supernova rate in M82, derived from studies of the number and evolution of compact radio continuum sources, is in the range 0.05 – 3.0 yr^{-1} (Chevalier 1982; Kronberg et al. 1985; Muxlow et al. 1994; Van Buren & Greenhouse 1994). We assume 0.1 yr^{-1} presently. Over the life time of an evolved SNR like IC 443 ($\approx 10^4$ yr) this rate corresponds to $\approx 10^3$ SNR. Furthermore, the individual SNR (or groups, as the case may be) in M82 may, in general, be more luminous than IC 443 (Greenhouse et al. 1991). Given an unambiguous tracer of SNR (like [Fe II] 1.6435 μm), we can estimate the number of SNRs in other galaxies without resolving and counting individual remnants.

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REFERENCES

Bautista, M. A., Pradhan, A. K., & Osterbrock, D. E. 1995, ApJL, in press
Chevalier, R. A. 1982, ApJ, 259, 302
Claver, C. F., & MacQueen, P. 1995, in preparation
Graham, J. R., Wright, G. S., & Longmore, A. J. 1987, ApJ, 313, 847
Graham, J. R., Wright, G. S., Hester, J. J., & Longmore, A. J. 1991, AJ, 101, 175
Greenhouse, M. A., Woodward, C. E., Thronson, H. A., Rudy, R. J., Rossano, G. S., Erwin, P., & Puetter, R. C. 1991, ApJ, 383, 164
Kronberg, P. P., Biermann, P., & Schwab, F. R. 1985, ApJ, 291, 693
Luhman, M. L., Jaffe, D. T., Keller, L. K., & Pak, S. 1995, PASP, 107, 184
Muxlow, T. W. B., Pedlar, A., Wilkinson, P. N., Axon, D. J., Sanders, E. M., & de Bruyn, A. G. 1994, MNRAS, 266, 455
Oliva, E., Moorwood, A. F. M., & Danziger, I. J. 1989, A&A, 214, 307
Van Buren, D., & Greenhouse, M. A. 1994, ApJ, 431, 640
Wright, G. S., Graham, J. R., & Longmore, A. J. 1988, in IAU Colloquium No. 101, Supernova Remnants and the Interstellar Medium, ed. R. S. Rodgers & T. L. Landecker (Cambridge: Cambridge Univ. Press), 395