INFRARED SPECTROSCOPY OF SUPERNOVA REMNANTS

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Abstract: Spectra of several galactic and LMC supernova remnants have been obtained at R ~ 1500 in the 1-2.5μm region with the cooled grating/array spectrometer, IRSPEC, on the ESO 3.6m telescope. The brightest lines observed are from [FeII]. In RCW 103, which exhibits the highest surface brightness, H (Brγ at 2.17μm) and H_2 (1-0 S(1) at 2.12μm) lines have also been detected. A good correlation is found between [FeII](1.64μm) and Hβ implying similar ionization structures and Fe abundances in a wide variety of remnants. The actual [FeII](1.64μm)/Hβ ratio of ~0.2 also implies a high depletion factor (>0.9) for Fe. Electron densities, extinctions and [FeII] luminosities derived from these data are presented and discussed and attention drawn to a potentially interesting discrepancy between H(Brγ) and Hβ fluxes.

Introduction: Transitions of [FeII] falling in the atmospheric windows between 1μm and 5μm are of great interest for determining Fe abundances, electron densities and the extinction in shock excited regions, particularly relatively high density regions where visible lines might either not be excited or obscured by dust. In the case of supernova remnants, the feasibility of such observations was first demonstrated by Seward et al. (1983) who measured strong [FeII](1.644μm) emission in MSH 15-52 using a filter spectrometer. This line has also been found to be bright in IC 443 (Graham, Wright and Longmore, 1987). With the availability of the cooled grating/array spectrometer, IRSPEC, on the ESO 3.6m telescope (Moorwood et al., 1986) we have pursued observations of this and other [FeII] lines, plus the H (Brγ at 2.165μm) and H_2 (1-0 S(1) at 2.12μm) lines in some cases, on a sample of supernova remnants including Puppis A, Kepler and RCW 103 in the Galaxy and N63A, N49 and N103B in the Large Magellanic Cloud.

Observations: These have been made since November 1985 using the IRSPEC spectrometer which yields R ≃ 1500 with a 6" × 6" entrance aperture at the ESO 3.6m telescope. The H band, 1.5-1.8μm, spectrum of RCW 103 shown in Fig. 1 demonstrates the prominence of the [FeII](1.644μm) line but also contains several other [FeII] lines of astrophysical interest. In particular, the relative intensity of the

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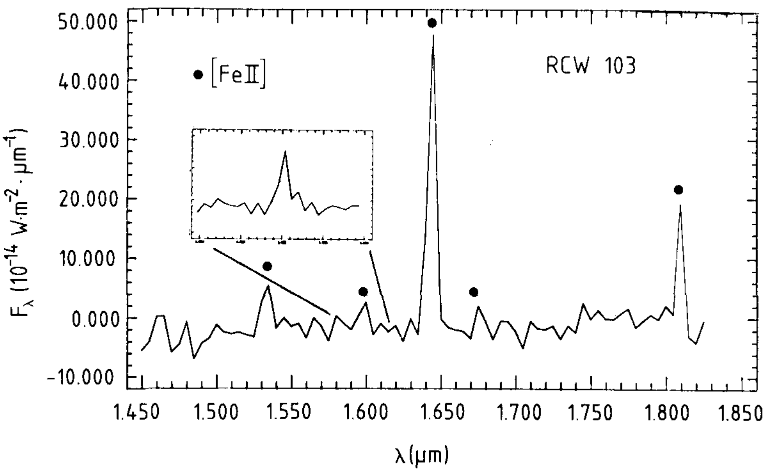

Fig. 1. H band spectrum of RCW 103.

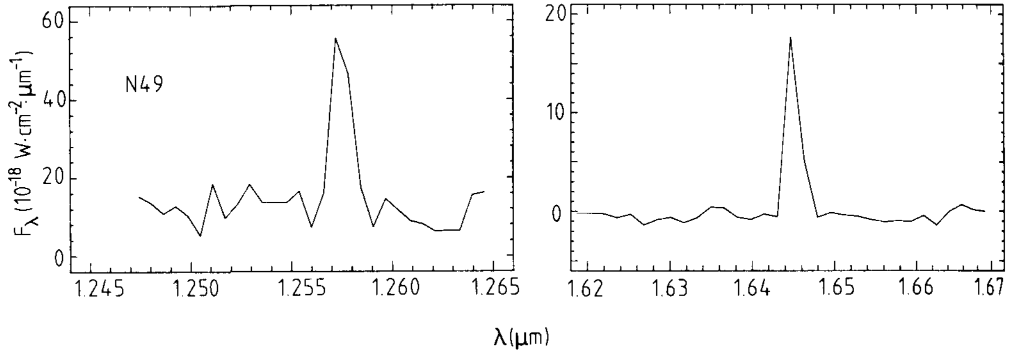

Fig. 2. [FeII] lines at 1.256μm and 1.644μm in the LMC remnant N49.

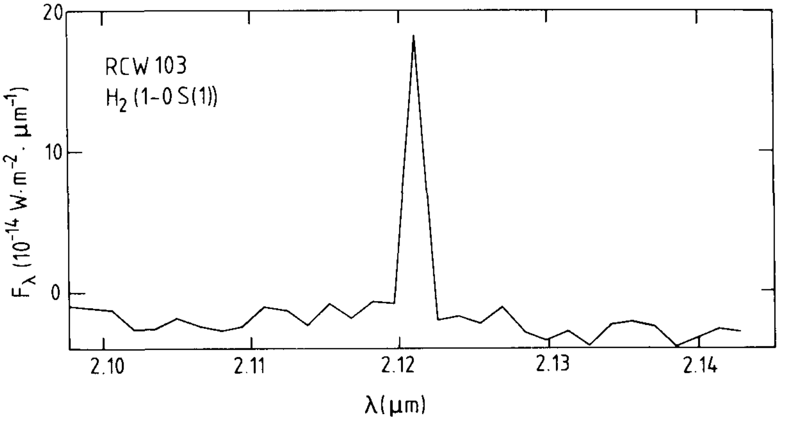

Fig. 3. Peak of H_2 (1-0 S(1)) line emission in RCW 103.

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[FeII](1.599μm) line is density sensitive and the insert spectrum shows a higher s/n ratio measurement of this line made with a longer integration time. Fig. 2 shows the [FeII](1.644μm) and [FeII](1.256μm) lines in the LMC remnant N49. These lines share the same upper level and their ratio is thus a sensitive extinction indicator. In the absence of extinction, the 1.256μm line is the stronger by ≃ 30% but IRSPEC itself is relatively less sensitive at this wavelength than at 1.64μm. This latter line has been detected in all the remnants observed to date and RCW 103 in the Galaxy and N63A and N49 in the LMC have been partially mapped in order to better estimate the total luminosities in this line. Of all the remnants, RCW 103 exhibits the highest surface brightness and, in addition to the several [FeII] lines detected, is the only case where H (Brγ at 2.165μm) and H_2 (1-0 S(1) at 2.12μm) emission (fig. 3) has also been detected.

Results and Conclusions:

- Fe/H. For the remnants Kepler, RCW 103, N63A and N103B for which suitable optical data are available we find an extremely good correlation between the [FeII](1.64μm) and Hβ surface brightnesses. The Crab nebula (observed with a filter spectrometer at the Italian infrared TIRGO Observatory), MSH 15-52 and IC443 also fall on the same relation. This implies that neither the Fe abundance nor the ionization structure exhibits much variation from remnant to remnant. The mean [FeII](1.64μm)/Hβ ratio is measured to be 0.2 or about an order of magnitude smaller than predicted by the shock models of McKee, Chernoff and Hollenbach (1984) for Fe depletion factors ≃ 0.5 which are in accord with the shock destruction of grains predicted by Seab and Shull (1983). From the observed ratio we obtain $Fe^+/H^+ \simeq 10^{-5}$ or $Fe/H < 2.10^{-6}$ with $Fe^+ = Fe$ and $H^+ < 0.2$ H computed from a simple ionization structure model. The data appear therefore to indicate a much higher Fe depletion factor $\gtrsim 0.9$ and thus less shock destruction of grains than expected.

  In RCW 103 we can also derive the Fe/H relative abundance using our measurement of H (Brγ) on the [FeII](1.64μm) peak. The result is a factor ≃ 4× larger and the ratio Brγ/Hβ the same factor smaller than expected applying standard recombination theory. In this specific case, the discrepancy might be attributed to possible lack of spatial coincidence between the Brγ and Hβ observations. In N49 however we also observe a Brγ upper limit which is too low relative to Hβ and Graham et al. (1987) have noted the same discrepancy in IC443. The fact that Brγ is relatively fainter than expected makes it difficult to account for by extinction and the normal Balmer decrements tend to exclude collisional population effects. As a next step in understanding this problem therefore we are planning more extensive Brγ observations on regions with well measured Hβ fluxes.

- Ne. The following electron densities have been derived from the [FeII](1.60/1.64) line ratios: Kepler ($> 2.10^4$ cm^{-3}), RCW 103 ($3\text{-}5.10^3$), N49 ($3\text{-}9.10^3$), N63A ($4\text{-}11.10^3$). These densities are systematically higher (about a factor of 2 taking the lower limits)

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than derived from the [SII] line ratios in Leibowitz and Danziger (1983) and Danziger and Leibowitz (1985). As the [FeII] ratio has a higher critical density this could result from a weighting towards higher density regions. Such an effect could of course also be attributed to errors in the transition probabilities and/or collision strengths.

- Av. The [FeII](1.26/1.64) ratios observed on the relatively unobscured LMC remnants N63A and N49 are close to the expected ratio of 1.3 (Nussbaumer and Storey, private communication). In the quite highly obscured galactic remnant RCW 103 the ratio is only 0.8 implying $A_v \simeq 6$ mag. adopting $A_\lambda = A_\alpha\ (\lambda/0.656)^{-1.85}$ (Landini et al., 1984), $A\alpha/A\beta = 0.65$ and $A_v/A\beta = 0.86$. As this is rather a steep reddening curve which probably overestimates A_v, the infrared value can be considered to be in reasonable agreement with the $A_v \simeq 4.7$ mag. derived by Leibowitz and Danziger (1983) from the Balmer decrement.

- [FeII](1.64μm) Luminosities. Partial maps of RCW 103, N63A and N49 yield lower limits of 200, 200 and 700 $L_\odot$ respectively for the total luminosities in this line.

- H_2. A region containing the bright, southern, optical filament in RCW 103 (see Leibowitz and Danziger, 1983 for a photograph) has been partially mapped in the H_2 (1-0 S(1)) line as well as [FeII] (1.64μm). The H_2 emission extends over several arcminutes along the filament but is displaced ~ 30" from the [FeII] emission in the direction away from the centre of the remnant. Its peak surface brightness (fig. 3) reaches ~ 30% of that in [FeII] (1.64μm) whereas it is only 6% on the [FeII] peak itself.

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