NEAR INFRARED SPECTROSCOPY OF GALACTIC AND MAGELLANIC CLOUDS SUPERNOVA REMNANTS

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The spectral range redwards of about 7300 Angströms has up to now been rarely explored for any kind of object because of lack of adequate detectors. This situation is changing with the availability of silicon detectors whose response extends up to 1.1μ with reasonable quantum efficiency. We have used the ESO Reticon System behind the Boller and Chivens Spectrograph at the Cassegrain focus of the ESO 3.6m telescope to obtain spectra of several Supernova Remnants in the range 6000-10500 Å. The spectral resolution was 8 Å and the dual array allowed a clear sky-subtraction, indispensable because of the presence of numerous atmospheric OH bands in this region. Data reduction was done with standard techniques using wavelength calibration, flat-field correction, response curve determination through observations of standard stars and extinction correction. We present below results based on the first spectra obtained for the Galactic remnants RCW 86, RCW 103 and Kepler SNR and the Magellanic Cloud ones N 49 and N 63A. The Crab Nebula will be discussed separately at the end.

As already seen for the visible range (Danziger and Dennefeld, 1976), the spectra present striking similarities. The strongest lines are, as expected, the [S III] lines 9069-9532 Å. Other typical lines are the [S II] quadruplet around 10300 Å however faint because of the drop in sensitivity redwards of 10000 Å and the Paschen series of hydrogen. The [C I] doublet 9827-9850 Å previously identified in the Cygnus Loop (Dennefeld and Andrillat, 1981) is detected with reasonable strength in all objects and opens interesting perspectives for carbon abundance determinations. Several new [Fe II] lines are detected in this spectral range, among them the strongest one seen in the whole visible range λ 8616.9 Å from multiplet 13 F with strength about 5 % of H alpha. A detailed description of the iron spectrum has been given for Kepler SNR by Dennefeld (1982). Note that the iron spectrum of Kepler SNR is 3 to 4 times stronger than in the other studied remnants. Other interesting lines are [Ca II] 7292 and the lines at 7379 and 7412 which are assigned to [Ni II] as discussed later.

The [S III] 9069-9532 to [S II] 6717-6731 ratio shows a very well

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defined correlation with |S II|/Hα for all objects available :
SNR, H II regions and Planetary Nebulae, about 60 objects in total. The slope of the line is close to 1, indicating that |S II| is indeed a better discriminator than |S III| between different types of objects. The correlation deviates from the straight line for the SNR, as expected because photoionization is not the dominant ionization mechanism in those objects.

Availability of the far red |S II| lines allows a model independent reddening determination (Miller, 1968) by comparison of the observed |S II| 10300/|S II| 4070 ratio with the theoretical value. For the objects under study, the reddening found was always compatible (within the observational errors) with the one derived from the Balmer decrement under assumption of simple recombination. There is therefore no evidence for collisional excitation of hydrogen. However this effort is expected to be dominant only in low velocity shocks (Shull and Mc Kee, 1979) which are not represented in our sample.

An abundance determination for species like iron, calcium, carbon or nickel, accessible from our spectra, requires a detailed comparison with model predictions. The only models making specific predictions (but only for |C I| and |Ca II|) are those of Raymond (1979). We note that, on the average, the |Ca II| predictions fall short by an order of magnitude, while those of |C I| are too large by a factor of 2 to 3 and more so for galactic objects than for the Cloud ones (possibly indicating an abundance effect). However, a full appraisal of the data requires models including charge exchange reactions and updated atomic coefficient, with specific predictions for the lines observed here. Waiting for such calculations to be made, we try meanwhile some empirical comparisons between specific line ratios, with emphasis on the possible differences between Galactic objects on one hand and the Magellanic Cloud ones on the other. These comparisons should however be taken with caution, if only because of the small number of objects involved.

Starting with lines of neutral species, the ratio |C I|/|O I| gives an average value of 0.18 for Galactic objects and 0.05 for LMC. The difference is significant (remembering the established underabundance of oxygen in LMC) and points towards a lower C/O ratio in LMC than in the Galaxy. This is in accordance with the results found for H II regions by Dufour et al. (1982).

Neutral carbon and singly ionized calcium both have ionization potentials below 13.6 eV and should therefore partly coexist.
The ratios of |Ca II| to |C I| show, after correction for collisional de-excitation of the |C I| line, an average value of 1.0 in the Galaxy compared to 2.6 in LMC. This difference could be entirely accounted for by the carbon deficiency in LMC (as suggested above and by the IUE observations of Benvenuti et al., 1980) and detailed calculations are required before a conclusion can be reached for calcium.

The situation is less clear as far as iron is concerned : for four

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objects, the |Fe II| 8616/Hα ratio shows a very similar value around 0.05, the exception being Kepler with a value about three times higher. There is no similar situation for the |Fe III|/Hβ ratio so that an abundance effect is excluded. More likely, the stronger |Fe II| spectrum in Kepler is due to a density effect as suggested by Danziger (this conference) and there is up to now no evidence of a large iron abundance difference between the Galaxy and LMC.

The line at 7379 has been a puzzle for a long time. Systematically seen in most SNR (Danziger and Dennefeld, 1976) it was tentatively ascribed to |Ni II| by Fesen and Kirshner (1980). However, it is only since the latest computations of atomic coefficients by Nussbaumer and Storey (1982) that this identification gains some support on the basis of a second |Ni II| line at 7412 Å detected in our spectra with an intensity compatible with the predictions for standard nebular conditions (see the discussion by Dennefeld, 1982). With this identification and the coefficients of Nussbaumer and Storey (1982) we calculate the Ni^+/Fe^+ ionic abundance ratios to find, with very little scatter, 0.45 for the galactic objects and 0.18 for LMC. Under the reasonable assumption that so closely similar atoms as Fe and Ni should have very similar distributions in the post-shock region of a SNR, Ni^+/Fe^+ would reflect the total abundance ratio of those species and indicate a difference between the two galaxies. However, if one remembers that the cosmic abundance ratio of Ni to Fe is about 0.050 (Astrophysical Quantities) one sees that Ni^+/Fe^+ alone would already indicate a large overabundance of nickel with respect to iron.

Even if a number of people would like to see large quantities of nickel and preferably iron be produced in Supernovae, specially of type I, some of the hypotheses or parameters used might prove to be wrong before the conclusion be accepted. In order of decreasing likelihood : the ionic distributions of Ni and Fe could nevertheless be largely different, the abundance ratio could be modified by selective absorption on grains, a yet unknown mechanism might selectively enhance the |Ni II| lines, the atomic coefficients could still be wrong or the identification of the |Ni II| line still erroneous. The importance of these two elements for nucleosynthesis theories justifies some efforts to solve the question.

Finally, several filaments of the Crab Nebula have been observed in similar conditions. The surprising presence of the |C I| lines (Dennefeld and Andrillat, 1981) is confirmed in spectra which otherwise show large resemblances with those of shock-excited SNR. The strength of this |C I| is largely variable from filament to filament, its intensity going from equal or larger than |S III| 9532 to less than one tenth of the same line. The a-priori surprising presence of neutral carbon (ionization potential well below 13.6 eV) in a photoionized nebula such as the Crab could find some explanation in mechanisms as for example dielectronic-recombinations, as shown in the latest models by Péquignot (this conference) who calibrated them with the planetary Nebula NGC 7027 where |C I| is seen also (Péquignot and Dennefeld, 1982).

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Ni II| lines are also seen in the Crab Nebula and analysis of Ni/Fe abundance ratio leads to the same problems as encountered above despite the different ionization mechanism (Dennefeld and Péquignot, 1982).

Finally we would like to emphasize the presence in one of the near IR spectra of the Crab Nebula of faint features attributed to high velocity filaments. The velocities are measured at +3380 and +4940 km/s respectively and are much higher than seen up to now. They are in fact much closer to what one would except from a young remnant of type II supernova.

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DISCUSSION

SHULL: You indicated that |S II|/Hα ≃ 0.8 for N 63A and N 49. By |S II| do you mean one or both of the doublet lines ?

DENNEFELD: In the diagram, I have always used the sum of the |S II| lines 6717-6731 and the sum of the |S III| lines 9069-9532 Å.

DOPITA: I was very pleased to see how your data discriminates between excitation mechanisms according to the |S III|/|SII| ratio. Theoretical models predict this and also predict that a plot of |SIII|/|SII| against |O III|/|O II| will very clearly define regions excited by shocks, thermal sources and non-thermal sources. The theoretical uncertainties in such a plot are caused principally by the uncertainty in the $O^{++} + H \rightarrow O^{+} + H^{+}$ charge exchange reaction. Have you plotted such a diagram, and if so, what is the result ?

DENNEFELD: Yes, I have done it. A relation exists, but the scatter is much larger than in the case of the relation |S III|/|S II| versus |S II|/ Hα. I am afraid that in the controversial cases (like bubble-type objects for example) this diagram taken alone will not make the decision because of the overlap between weak shocks and low-ionization H II regions. However a combination of several such diagrams might do.

SHULL: Concerning your request for the inclusion of Fe-lines in theo-

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retical shock models, I would like to mention that Chris Mc Kee, Greg Seab and I have added Fe to our shock code (see poster display). The strongest lines of [Fe II] are at 1.26μ and 1.6μ, with strengths comparable to Hα.

DENNEFELD: I am glad to see the [Fe II] lines included. The strongest lines you mention are unfortunately just located at the sensitivity boundary of two very different observational techniques and might be difficult to observe.

I would also be happy to see the [C I], [Ca II] and [Ni II] lines included in model predictions for the corresponding abundance determination.

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