CHEMICAL ABUNDANCES IN THE INTERSTELLAR MEDIUM OF GALAXIES FROM SPECTROPHOTOMETRY OF SUPERNOVA REMNANTS

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1. INTRODUCTION

In the recent past supernova remnants (SNR) have been identified in external galaxies as far as 5 Mpc. These galaxies are: M 33(12), M 31(12), NGC 6822(1), IC 1613(1), NGC 2403(2), NGC 300 (2), NGC 4449(1), where the numbers of SNR confirmed by optical spectroscopy are given in parenthesis. Data for objects in the Magellanic Clouds are discussed extensively elsewhere in this volume.

With the exception of the SNR in NGC 4449, characterised by broad [OIII] emission lines associated with a non-thermal radio source, all the other SNR have been identified by their [SII]/Hα line intensity ratio. An updated description of this technique and of its limitations is given by Blair et al., (1981) and Dennefeld and Kunth (1981). By now it is also clear that the SNR with a high [SII]/Hα ratio do not represent the global SNR population in a galaxy. This can be verified from the data on the Magellanic Clouds, where by combining the optical, radio and X-ray observations a rather complete sample of SNR with different characteristics has been obtained. The sulfur strong SNR are however the optically brightest and serve well as probes of the chemical composition of the interstellar medium of the galaxies they belong to.

In the next paragraphs we present the first spectrophotometric data for four of the remnants mentioned above. We also show the emission line intensity ratio trends for SNR in different galaxies and, by comparison with theoretical models, interpret them in terms of variations in the chemical composition.

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2. SPECTROPHOTOMETRY OF THE SNR IN IC 1613, NGC 6822 AND NGC 300

The candidates were taken from the list of D'Odorico et al. (1980) and include beside the single SNR identified in IC 1613 and NGC 6822, #2 and #5 in NGC 300. The four objects were observed both with the AAT 3.9m telescope in October 1979 and with the ESO 3.6m telescope in September 1980.

At the ESO telescope, the spectra were recorded with the IDS (Cullum 1979) attached to the Boller and Chivens spectrograph. Two separate spectral regions, λλ5400-7600Å and λλ 3600-5800Å, were observed at a resolution of 7Å. Figure 1 shows the ESO spectrum of IC 1613.

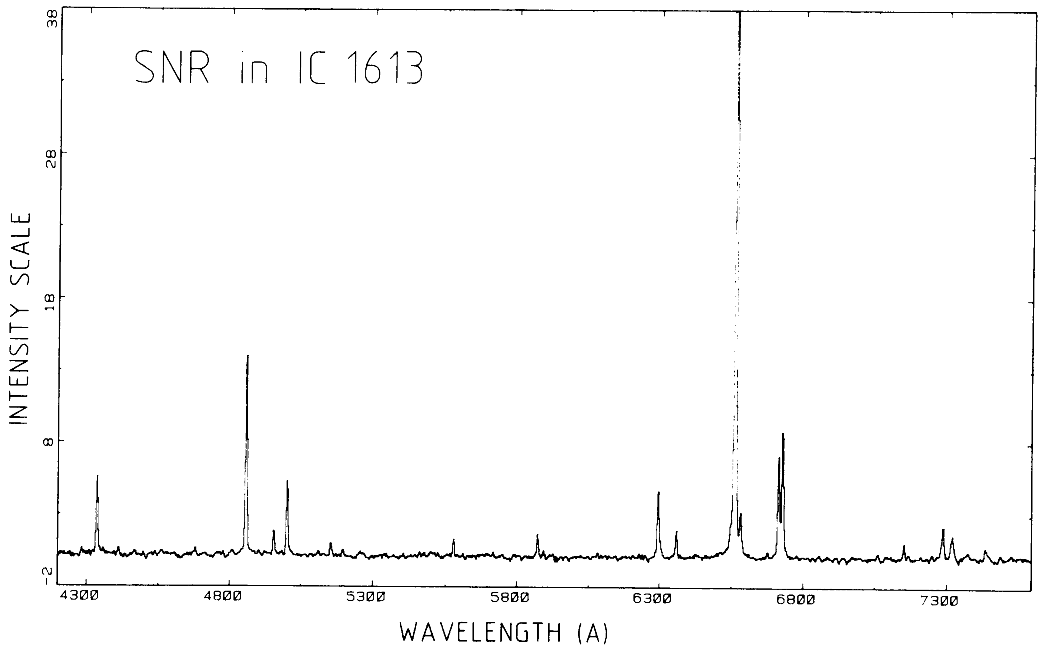

Figure 1 The combined blue and red ESO spectra of the SNR in IC 1613 are shown. The line identifications are given in Table 1.

The AAT spectra were recorded with the IPCS and cover the spectral region λλ3600-7000Å at a resolution of about 10Å.

Both sets of data have been corrected for the spectral sensitivity of the instruments by observations of standard stars. The ESO data have been combined with the AAT by using Hβ as a reference point for the blue spectra and Hα for the red ones. The agreement between the two sets of data was always within 20%, with the exception of NGC 300/#2 where however a contiguous HII region may have contaminated the spectra. The averaged

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Table 1 - REDDENING CORRECTED AND MODEL PREDICTED LINE INTENSITIES IN SNR*

Object	$C_{H\beta}$	3727 [OII]	4100 Hσ	4340 Hγ	4959 [OIII]	5007 [OIII]	5876 HeI	6300 [OI]	6563 Hα	6583 [NII]	6717 [SII]	6731 [SII]
IC 1613/SNR[ø]	0.6	174	24	43	12	34	8	30	266	20	36	45
		184	25	46	10	30	6	30	299	19	42	47
NGC 6822/SNR	0.6	377	-	41	24	73	-	74:	253	21	65	63
	-	406	25	46	23	66	7	46	300	17	49	54
NGC 300/#2	0.2	470	25	38	45	133	-	35	260	81	103	84
	-	572	25	46	34	100	7	55	300	99	87	95
NGC 300/#5	0.2	753	28	44	54	128	-	80	290	105	131	134
	-	723	25	46	46	136	7	44	303	102	120	125
f(λ)[+]	-	0.298	0.195	0.132	-0.021	-0.032	-0.216	-0.281	-0.332	-0.335	-0.355	-0.357

* With respect to H_β = 100. ø Other line intensities: 4069-76 [SII] = 20; 4363 [OIII] = 2.6; 4415 [FeII] = 3.4; 4686 HeII = 3.6; 5158 [FeII] = 5.5; 5198 [NI] = 2; 7155 [FeII] = 3; 7291 [CaII] = 12; 7325 [OII] = 9.

\+ Adopted reddening function.

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spectra were further corrected for reddening. The reddening constants $C_{H\beta}$ and the assumed reddening law are given in table 1. In the IC 1613 SNR the reddening of $C_{H\beta}$ = 0.6 which fits well the Balmer decrement is much higher than the value of 0.13 derived by Humphreys (1980) from the blue stars in the galaxy, suggesting that dust must have been associated with the pre-supernova star.

The reddening corrected values are given in Table 1. From the scatter of values from spectra obtained on the two different instruments, we estimate the line intensities to be accurate to better than 30%.

3. SNR AS INDICATORS OF THE CHEMICAL COMPOSITION OF THE INTERSTELLAR GAS IN GALAXIES

It was evident from the beginning of the spectroscopic survey of SNR in external galaxies that chemical abundance differences were affecting in a systematic way the line intensity ratios in SNR. This stimulated the development of models for the emission of collisionally excited gas to interpret the spectra and determine the abundances. Results in this field have been obtained by Dopita et al. (1980), Blair et al. (1982), Dennefeld and Kunth (1981), Binette et al. (1982) where references to earlier works can also be found.

The new observations of the SNR in the metal poor galaxies IC 1613 and NGC 6822 reported here have been combined with the previous results in Fig. 2 and 3, which show the behaviour of the main line intensity ratios. In both figures two clear correlations emerge, which can be attributed to changes in the chemical abundances.The trend from high to low metal abundances goes from the SNR in the most massive galaxies in the sample (M31, the Galaxy) through intermediate systems like M33, NGC 300 and the LMC to low mass galaxies like IC 1613, NGC 6822 and the SMC. This is in agreement with what is known on the chemical abundances of these galaxies from the HII regions and the stellar population. To put these results in a quantitative form, we can use a new self consistent model for the emission of shock ionized gas (Dopita in this volume and Binette, Dopita, Tuohy, 1982). The computations show that in the regime where hydrogen is fully preionised up to shock velocity larger than 300 Km s^{-1}, the intensity of the prominent optical forbidden lines with respect to Hβ vary little with velocity and the details of the preionisation. It is therefore possible to produce a set of models with constant shock parameters but variable abundances, to explore the effect of chemical composition on the line ratios. The results of these calculations are shown in detail elsewhere (Dopita, Binette, D'Odorico 1982). In Figure 2 and 3 we have superimposed on the observed points the theoretical curves for these line ratios. The [OIII] versus [OII] intensity diagram shows that the oxygen abundance for the SNR lie between 0.5 x 10^{-4} and 1.2 x 10^{-3}. It illustrates also the saturation effect which affects the [OII] lines at high oxygen abundances.

In Fig 3. we see that the 6548,6584/Hα ratio determines well the N/O abundance ratio once the oxygen abundance is known. The SNR in the galaxies

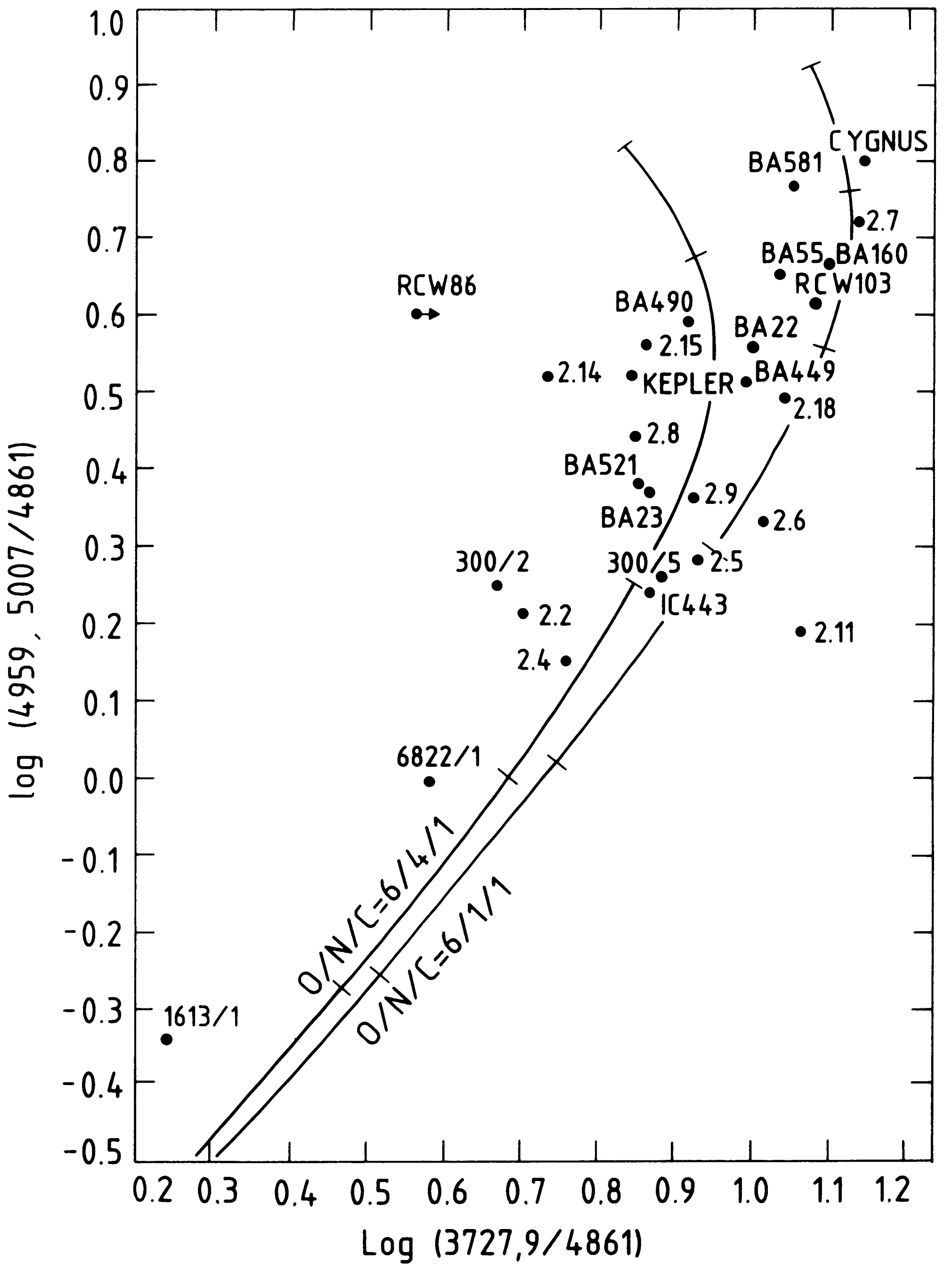

Figure 2. Data for the SNR in this figure are from this paper and from Dopita et al. (1980) for M33; Blair et al. (1982) for M31; Leibowitz and Danziger, (1982) for galactic objects. The ticks in the theoretical curves mark variations by a factor of two in the abundance of elements heavier than helium, the highest points corresponding to an oxygen abundance of 2.4 x 10^{-3}. All of the models used to build up the grid assume a preshock density of 10 cm^{-3} and a shock velocity of 106 km/sec.

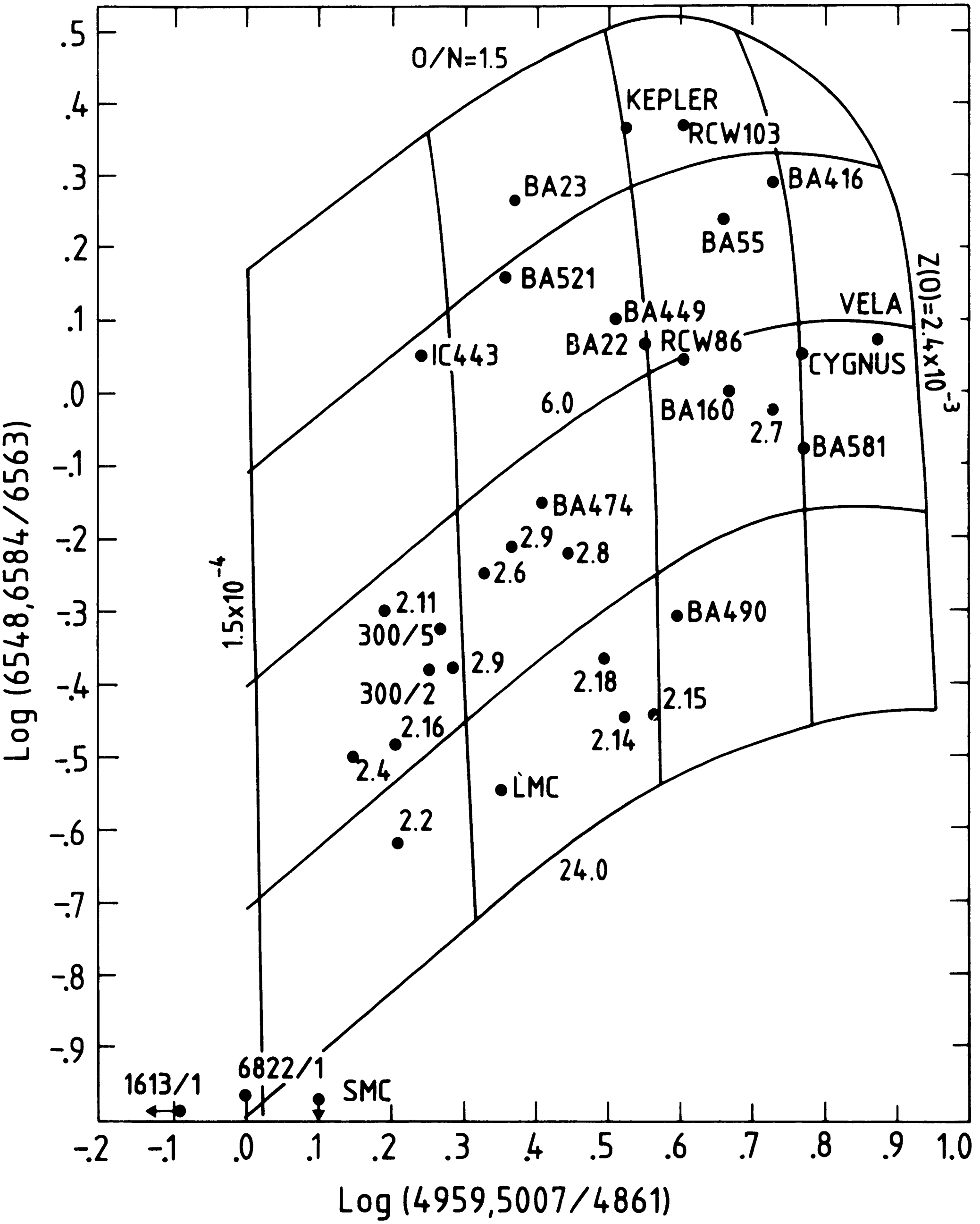

Figure 3. Data for the SNR in this figure are from the sources quoted in Fig. 2 and from Danziger, in this volume, for the LMC and SMC. The theoretical grid shows the effect of a change in the abundance of oxygen (vertical lines) and of the O/N ratio (diagonal lines). Both sets of lines are plotted at intervals corresponding to a factor of two change. Parameters of the shock as specified in Fig. 2.

IC 1613, NGC 6822 and the SMC have oxygen abundance lower than 2 x 10¯ and O/N larger than 24.

The theoretical grids give the possibility of understanding the gross variations of the line intensity ratios in terms of abundance, but more accurate, ad hoc models for a particular remnant can be found by an iterative process. Table 2 lists the shock parameters and the chemical abundances in number of atoms relative to H which give the best fit for the four remnants discussed in this paper. The predicted line intensities are given in table 1 and comparison with the unreddened values shows that the agreement is good.

Table 2 - Parameters of the Best Fit Models

Object	n_0 (cm¯)	Shock velocity	He	C	N	O	Mg	Si	S
IC 1613	20	131	8E-2	1.1E-5	5E-6	4E-5	2.3E-6	2.3E-6	1.1E-6
NGC 6822	10	131	8E-2	2E-5	4.5E-6	1E-4	2E-5	4E-6	1.6E-6
NGC 300/2	10	131	8E-2	3E-5	2.5E-5	1.4E-4	5E-6	5E-6	3E-6
NGC 300/5	10	131	8E-2	5E-5	3E-5	2.2E-4	1E-5	1E-5	6E-6

4. CONCLUSIONS

Six years ago, no supernova remnants were firmly identified beyond the Magellanic Clouds. Since then it has been possible to extend the identifications to galaxies as far as 5Mpc, and to use the spectrophotometric data on SNR in combination with theoretical modelling of emission of the shock ionised gas to determine chemical abundances of the interstellar matter. This method can be applied to high metallicity systems without the shortcomings met in the study of HII region observations, (e.g. poor knowledge of the temperature). A new, powerful tool to investigate the chemical composition and evolution of galaxies has become available.

ACKNOWLEDGEMENTS

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DISCUSSION

McKEE: I have two questions concerning the effects of ejecta on your observations. First, the supernovae in irregular galaxies should eject as much metals with the ambient gas as do SN in our galaxy. Since the ambient metal abundance is much lower, however, the ejecta should be relatively much more important. Do you see evidence for this? Second, Mike Dopita indicated earlier in the conference that there is evidence for a large oxygen abundance even in remnants as old as the Cygnus Loop. Do you see such effects in your survey?

D'ODORICO: Our observations are representative of the emission from the entire remnants in a stage where most of the emission comes from the swept up material . We clearly reveal the differences in chemical abundances of the IM in the different galaxies, but are not yet able to detect "second order" effects. To answer the second point, but also in relation to the first remark, it is only in galactic remnants (and possibly in the Magellanic Clouds) that we can still reveal overabundances related to the stellar ejecta. At which epoch and how well in a SNR the enriched material is mixed with the IM is still an open question.

SHULL: Shocks of velocity 100km/s can destroy 50-80% of silicate grains (see contribution by myself, Seab and McKee). Thus, part of the oxygen abundance variations you report could be due to shock processing of interstellar grains. Since N and S are probably undepleted, their abundance variations are unaffected.