6. THE INTERSTELLAR MEDIUM

THE INTERSTELLAR MEDIUM OF THE MAGELLANIC CLOUDS FROM ABSORPTION LINES

KLAAS S. de BOER
Sternwarte, University of Bonn
Auf dem Hügel 71
D-5300 Bonn
F.R. Germany

ABSTRACT. General aspects of ISM studies using absorption line studies are given and available data are reviewed. Topics are: galactic foreground gas, individual fields in the Magellanic Clouds (MCs) and MC coronae. Overall investigations are discussed. It is demonstrated that the metals in the gas of the Large Magellanic Cloud (LMC) and Small Magellanic Cloud (SMC) are a factor of 3 and 10, respectively, in abundance below solar levels. The depletion pattern in the LMC is similar to that of the Milky Way.

1. Introduction

The classification of the Large and Small Magellanic Cloud as irregular galaxies is obviously justified when one compares the spatial distribution of the stars with that of the gas. A large fraction of the mass of the gas in the LMC is concentrated in a projected area of about 2 kpc^2 extending southward of 30 Doradus. The HII regions, which are so prominent in the visual, are more evenly distributed, although the 30 Dor Nebula itself is the dominant luminous nebula. The location of the maximum intensities in the maps of UV radiation of the LMC illustrates the distribution of the younger stars (if not obscured) and these again emphasize that the gas has a rather irregular distribution. Although fewer data sets are available for the SMC, similar conclusions are also justified there. Recent comprehensive reviews on the Magellanic Clouds are available by Westerlund (1989, 1990).

Taking the projected area of the MCs (about 40 kpc^2 for the LMC, about 20 kpc^2 for the SMC), it is clear that, with classical techniques, the investigation of the structure of the interstellar medium is a gigantic task. In the radio domain, there is the serious problem of the telescope beam size. The Parkes radio telescope has a beam width of about 15 arcmin, corresponding to 250 pc in the LMC. This is an area of a size where we begin to realise that in the solar neighbourhood clouds with scale lengths of a parsec exist and where physical conditions change dramatically over similar distances. It is for this reason that a synthesis telescope was needed in the southern hemisphere and this symposium is a tribute to those who accomplished the Australia Telescope.

The effect of projection in the MCs works in much the same way as in the solar neighbourhood. We can "see" the entire MCs, but it remains difficult to find structure in the third dimension (the line of sight direction), just as it is difficult to define the gas structure in the solar neighbourhood in the radial dimension. The methods of investigation are clear: one samples interstellar spectra for as large a number of stars as possible within a limited directional cone and then derives the depth structure of the gas from the absence or presence of interstellar cloud absorption components in the spectra. In the solar neighbourhood this method works well because there are ample stars for use

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and their luminosities can be determined to provide the distances. A good example of the method is the classical study of the location of the Perseus Arm in the Milky Way (Münch 1957).

The investigation of the depth structure of the gas in the MCs has an extra difficulty, in that the distances of the individual stars within each galaxy cannot be determined in a very reliable way. Although photometry of the stars can be performed to high precision, the determination of the stellar luminosity (normally based on log g from spectral line profiles) has uncertainties easily of the order of 20%, a value which would place every star in the LMC anywhere between 50 and 60 kpc from us. Only for objects with well-calibrated luminosity, like some variables, can individual distances be determined more accurately. This means that, for each interstellar spectrum recorded, the gas clouds seen as absorption components could be at any depth in the MCs (but always in front of the star, of course).

Another major difficulty in the investigation of the gas with the help of absorption lines is the apparent faintness of the background lightsources. For useful spectroscopy at the required spectral resolution of a few times 10^4, exposure times with the biggest telescopes easily take over an hour. The number of suitable stars is also limited. Therefore, it is understandable that the number of in-depth investigations has remained rather small.

Finally, in the visual regime the absorption by, in effect, only two species (CaII and NaI) is accessible. On the other hand, the multitude of absorption lines in the satellite UV can be reached (up to now) only through the very modest 40-cm telescope of the International Ultraviolet Explorer (IUE) satellite. Among these UV lines, however, are those with a very large optical depth so that column densities of gas can be discovered that are much smaller than the smallest ones measurable in the HI emission line.

2. Survey of the data

The first publication on interstellar absorption line measurements in the MCs was by Feast *et al.* (1960), who gave some Ca interstellar line data based on spectra with a resolution of 1Å. The improvement of optical instrumentation and the construction of new telescopes in the southern hemisphere (e.g. the AAT and the ESO 3.6m) resulted in renewed interest in ISM studies of the MCs. This was amplified with the first measurements of spectra of MC stars with the IUE (Savage & de Boer 1979). Yet, the number of publications based on data with adequate spectral resolution (better than 10^4) only makes a short list (see, for example, Garcia 1989). Lists of interstellar line publications can be found in de Boer *et al.* (1987) and in Ferlet and Vidal-Madjar (1989). New work has been done by Wayte (1990) and Molaro *et al.* (1990).

3. Foreground gas

Along the sight lines to the MCs galactic halo gas is also sampled. Due to the differential galactic rotation, the velocities are spread out nicely along the LMC line of sight, but only modestly toward the SMC. The separation between the Galaxy and the LMC was set at 180 km s^{-1} in velocity space, based on the shape of the CII absorption profile (Savage & de Boer 1981) although others preferred the value of 150 km s^{-1}. Right between these two limits an absorption component exists and it is not clear if it is to be associated with the LMC or with the Galaxy. The cloud near 130 km s^{-1} has normally been associated with the Galaxy, but Songaila *et al.* (1986) and Blades *et al.* (1988) imply that it is LMC gas. The former produce no clear evidence for their claim, the latter use the metal abundance derived as an argument for an LMC origin. Unfortunately, N(H) had to be taken from other lines of sight, and the Blades *et al.* (1988) gas cloud abundances are thus uncertain by at least a factor of three (de Boer 1990), which precludes a reliable association of the clouds with either the Galaxy or the LMC. On the other hand, in a HI survey of a strip at declination -67°, de Boer *et al.* (1990) could show that both the 60 and the 130 km s^{-1} component extends on the sky beyond the LMC boundaries at almost the same velocity and thus must be in the galactic halo. It would be very hard to imagine how such a gas structure, if associated with the LMC, could persist with a coherent velocity with a size of several kpc.

The SMC has a systemic velocity of 150 km s^{-1} and the SMC velocities spread more into the galactic velocity regime so that detailed investigations of foreground halo gas are more difficult along this line of sight. Normally, the separation between the galaxy and the SMC is put near 80 km s^{-1} in velocity.

4. Magellanic cloud gas

4.1 INDIVIDUAL FIELDS

Several lines of sight toward the central part of the 30 Dor nebula in the LMC have been observed. The SiII lines establish a much wider range in velocity in the R136 spectrum than that found from HI emission, reflecting the difference in optical depth of the UV and the radio lines. Several absorption components are seen, both in neutral quiescent gas, as well as in excited gas (SiII*) and in highly ionized gas (CIV). R136 is probably in a heated and ionized cavity on this side of the bulk of the neutral gas (de Boer *et al.* 1980). Using the numerous but very weak CI lines and combining those data with ionization balance considerations (radiation field from Koornneef 1978), de Boer *et al.* (1985) were able to derive for the gas at 290 km s^{-1} a density of 300 cm^{-3} at a temperature of 100 K in a sheet of 5 pc thickness in front of R136.

Absorption line spectra in HD 36402 in the LMC and emission line data for N51D from the literature were combined by de Boer and Nash (1982) to study the gas in this HII region at the southern edge of Shapley III. Most of the neutral gas was found to be behind HD 36402, so that in respect to the supershell LMC4 (Goudis & Meaburn 1978), N51D is at the front side. Electron densities derived agree with those from emission lines. The integrated OAO-2 UV fluxes of the region (see Koornneef 1990), the shape, and the column densities of gas are all consistent with models for HII bubbles (de Boer & Nash 1982).

The region around SN1987A has been investigated in detail by Molaro and colleagues. For over a dozen stars Ca and Na lines were observed and they were able to derive depth structure for the gas in this region. Their results appear in these proceedings (Molaro *et al.* 1990). The line of sight to SN 1987A itself was investigated in several papers (see, for example Savage *et al.* 1989).

The region around HD 5980 in the SMC was investigated in detail by Fitzpatrick and Savage (1983). Gas at 120 km s^{-1} is thought to be SMC disk gas, gas at 160 km s^{-1} (the bulk) is in the background. NV is present and cannot be associated with a specific origin. Some gas is seen at 200 km s^{-1}, as well as an ionized high-velocity cloud approaching the SMC (observed at 300 km s^{-1}).

Sk159 (SMC) data were analysed by Fitzpatrick (1984). The bulk material is at 150 km s^{-1} and a sheet is present at 215 km s^{-1}. There is the suggestion that the sheet (as in HD 5980), being at velocities like those in the Magellanic Stream, is well in front of the SMC.

4.2 MAGELLANIC CLOUD CORONAE

As a consequence of the existence of hot and well-ionized halo gas around the Milky Way (Savage & de Boer 1981, Savage & Massa 1987) it has been speculated that the MCs also possess coronae of ionized gas (de Boer & Savage 1980). This topic was reviewed at IAU Symp. 108 (de Boer 1984); no new evidence has been brought forward since then.

4.3 OVERALL STUDIES OF MAGELLANIC CLOUD GAS

The amount of interstellar line data has been expanding. Songaila (1981) and Songaila *et al.* (1986) have collected several interstellar Ca spectra of LMC and SMC stars. Mathewson *et al.* (1986) investigated the depth structure of the SMC using interstellar Ca data and they found that the SMC is split up. Houziaux *et al.* (1985) investigated stars in the SMC and find evidence for the diffuse 4430Å band, but its strength does not seem to correlate with other dust parameters. A very interesting study has been completed recently by Wayte (1990). All useful interstellar Ca spectra were collected and a fair number of new observations were added in order to compare the velocity components of absorption with those of 21-cm emission. For each line of sight Wayte could then determine which of the clouds was behind or in front of the stars. He then continued to correlate these findings with measurements of polarization. Some stars showed little polarization and some absorption components, others more polarization and other components. In this way, Wayte could associate the 247 km s^{-1} velocity gas with the polarization and thus with the magnetic field. The B-vector has a spatial direction in line with the Bridge Region, thus establishing the connection of the Pan Magellanic Field with the LMC 247 km s^{-1} component. In the SMC no clear association could be found.

5. Abundances

Since the number of detailed investigations of the absorbing gas in the MCs is small, there is only scant information on the abundance of the free ions in interstellar gas. In the visual, the Na/Ca ratio gives indications for relative abundances, but it is hardly used. IUE spectra give access to many lines with the added advantage that one can derive the column of hydrogen in front of the star from the spectrum itself.

Abundances of the elements in MC cloud gas are given in Table 1. Abundances are available to R136 from de Boer *et al.* (1980 - BKS) and de Boer *et al.* (1985 - BFS: in this paper several > and < signs are missing in Table 2), toward R144 from BKS, toward HD 36402 from de Boer and Nash (1982 - BN). In the SMC Fitzpatrick (1984 - F84) gives some abundances. Relative abundances can be found in Bomans *et al.* (1990). Abundances for the MC Nebulae are taken from Dennefeld (1989 - D89). Solar reference and galactic interstellar gas abundances for low extinction lines of sight are from de Boer *et al.* (1987 - BJS).

The collected data (see Table 1 and Figure 1) show that the non-refractory elements S and Zn are, in the LMC, a factor of three, and in the SMC, a factor of 10, below galactic abundances. A comparison of the free ion abundance in the gas of the LMC with that of the Milky Way (thus assuming that there is depletion by dust) shows that there is 0.4 dex difference, with only a slight trend with atomic weight. One can conclude that the depletion in the LMC is similar in the Milky Way and thus that the dust in both galaxies is of the same kind, although the heavier elements may, in the LMC, have intrinsically lower abundance.

Table 1. Abundance of the elements in Magellanic Cloud gas

	Sun	LMC			LMC		SMC		Galaxy
		R136	R144	36402	mean	EmNeb	Sk159	EmNeb	low ext
He	10.9	-	-	-	-	10.9	-	10.9	-
C	8.62	-	-	>6.4	>6.4	7.9	-	7.2	8.3
N	8.0	-	-	>6.6	>6.6	7.0	-	6.5	7.8
O	8.84	8.5	<9.4	>6.7	8.5	8.4	-	8.0	8.6
Ne	8.05	-	-	-	-	7.6	-	7.2	-
Mg	7.54	6.8	-	>5.6	6.8:	-	6.5	-	7.2
Si	7.55	6.7:	>6.9	>7.0	7.0	-	5.8	-	7.0
S	7.20	6.1	>6.8	-	6.8:	6.7	6.0	6.3	7.2
Cl	5.5	4.0	-	-	4.0	4.8	-	4.7	5.2
A	6.57	-	-	-	-	6.2	-	5.8	-
Ti	5.05	<2.7	-	-	<2.7	-	-	-	3.0
Cr	5.7	4.0	-	-	4.0	-	-	-	4.2
Mn	5.4	4.2	-	-	4.2	-	-	-	4.7
Fe	7.50	-	-	>6.3	>6.3	-	-	-	6.1
Ni	6.25	4.1	-	-	4.1	-	-	-	4.9
Zn	4.6	3.9	-	4.2	4.0	-	3.5	-	4.5
CO	-	<3.3	-	-	<3.3	-	-	-	-
refs:		BKS,BFS	BKS	BN		D89	F84	D89	BJS

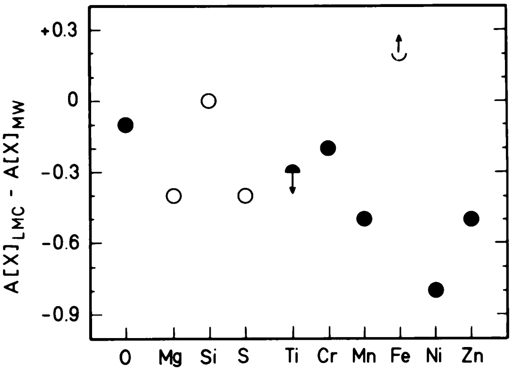

Figure 1. The abundance of the elements studied in absorption lines in the LMC is compared with the abundance of elements in Milky Way gas of low extinction. Open symbols are used for uncertain values (data from Table 1).

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