METALS AND MOLECULES IN HALO CLOUDS

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The abundance of the elements in clouds of halo gas, as determined from observations, is an important parameter for the test of the validity of models explaining the existence of, e.g., the high latitutude high-velocity clouds (HVCs) of the Milky Way. Individual HVCs have been detected in absorption only on very few lines of sight so that the distance of the HVCs, another important parameter for the models, stays ill determined as well. We will follow here the more or less established convention by calling HVCs those with /v/ >100 km s^{-1} and IVCs (intermediate-velocity clouds) those with 50 </v/ <100 km s^{-1}. We will define halo as the space with /z/> 1 kpc, although for /b/> 45° also /z/> 0.5 kpc is used.

Only in very few cases have interstellar absorption lines of individual HVCs or IVCs been seen. In fact, to our knowledge, the only HVCs detected as well defined absorption structures are in the direction of the LMC (Savage and de Boer, 1981), in the direction of the galaxy Fairall 9 (Songaila, 1981), and toward HD 135485 (Albert et al., 1989). IVCs have been found in the direction of M3, M13, HD 93521, HD 97991, the LMC, and HD 215733 (see Table 1). Note that the HVC at 120 km s^{-1} in the direction of the LMC is definitely not associated with the LMC (de Boer, Morras, Bajaja, 1990). Note also, that the interstellar nature of the spectral structure seen in the spectra of stars towards Chain A and Complex C (Songaila et al., 1988) most likely is stellar (Lilienthal, Meyerdierks, de Boer, 1990). In many other directions interstellar lines were looked for but either no absorption was seen at velocities sufficiently different from the LSR or the absorption profiles were rather smooth without revealing individual clouds (see e.g. Pettini and West, 1982; Pettini et al., 1982; Albert, 1983; Danly, 1989). For a listing of papers with non-detections see de Boer (1989). Further IVCs will be given by Danly (these proceedings).

The absorption lines show that the detected HVCs and IVCs contain metals indeed (for Ca detected in HVCs against extragalactic probes see van Woerden et al., 1989). In some cases only limits to the abundance can be given due to saturation of the absorption lines. For vZ1128 and

H. Bloemen (ed.), The Interstellar Disk-Halo Connection in Galaxies, 161–164.

B29 it is found that Ab(C) > -1.5 dex of the Solar value (de Boer and Savage, 1984) whereas the metals detected in the HVC and the IVC in the general direction of the LMC are close to Solar. In fact, combining the UV data from Savage and de Boer (1981) with HI from McGee et al. (1983) one finds that in the 60 and 130 km s^{-1} clouds Fe has an abundance of -4.8 and -4.6, respectively, within a factor of 2 of Solar. The Ti investigated by Albert (1983) is -1.0 dex of Solar, the Ca (from various studies) is between -2 and -3 of Solar abundance.

Intermediate velocity gas is present in a fair portion of the (well studied) northern sky at high galactic latitudes. A detailed summary of the earlier data has been given by Wesselius and Fejes (1973). They list two Ca-H coincidences, toward HD 93521 and HD 97991, where the Ca abundance ranges from -2 to -3 dex. Basing themselves on earlier ideas, they give two possible interpretations for the rather widespread intermediate velocity gas. The gas may be the material swept-up by the approaching shell of supernova gas while, alternatively, it may be gas collected in a collision with a big complex coming from l= 120°, b=+40°. This large IV gas structure then reemerged (of course) in all later observational surveys, such as those of Giovanelli (1981), Albert (1983), Hulsbosch and Wakker (1988), and Danly (1989).

Another piece of evidence for the nature of the metallicity of the halo gas is the scale height of the galactic z-distribution of the various elements. Such scale heights are, admittedly, a function of the

Table 1 Individual HVCs and IVCs detected in absorption at b>25°

Name	l	b	z kpc	v(abs) km s^{-1}	Element	v(HI) km s^{-1}	Ref •)
vZ1128 M3	42	+79	10	-60	CII,CIV		dBS84
B29 M13	59	+41	4.1	-80	CII,MgII	-80	dBS83
HD 203664	61	-28	-0.7	-55	"all"		DB89
				+70	"all",CIV		DB89
HD 215733	85	-36	1.5	-50	CaII,TiII	-50	A83
Mk 106	161	+43	x)	-156	CaII	-140	SWW89
HD 93521	183	+62	1.8	-55	CaII,TiII	-50	WF73, A83
LMC *)	270	-33	28	130	"all"	130	SdB81, MNM83
				60	"all"	60	B+88, S+89
Fairall 9	295	-58	x)	193	CaII	195	S81 MB86
HD 135485	347	+35	1.4	-128	CaII		A+89

*) LMC objects: R136, HD 36402, SN 1987A and many others; note that the N(HI) given by B+88 for the SN 1987A line of sight clouds is uncertain by at least a factor 2, a factor propagating into the abundances given by B+88.
x) Mk 106 and Fairall 9 are extragalactic.
•) references are explained in the final reference list.
"all" means all ions common in neutral gas.

spatial distribution of the gas, convolved with the ionization balance and influenced by the possible depletion of metals due to dust. In fact, some scale height values may suffer from selection effects in that data to the most distant stars not always have been or could be included in the determination. Due to the use by Edgar and Savage (1989) of FeII data from only the Copernicus satellite, very few large z sight lines could be included in their analysis. On the other hand, Ca and Ti data are available for very distant stars so that even few entries with enhanced column densities will result in enlarged scale heights. Determinations of the scale heights include those by Edgar and Savage (1989) for CaII ($\approx$1 kpc), TiII (>2 kpc), and FeII (0.5 kpc), by Savage and Massa (1987) for SiIV ($\approx$3 kpc), CIV ($\approx$3 kpc), and NV ($\approx$2 kpc), and by Reynolds (1989) for electrons ($\approx$2 kpc). The scale height of HI is approximately 0.5 kpc. Nevertheless, heavy metals such as C and Si, as well as Ti are present out to well above z= 2 kpc.

When halo clouds fall to the disk of the Milky Way, they will interact with the disk gas. Shock fronts will run into the gas complexes resulting in a change in the physical conditions of the gas, in particular compression. This may lead to a phase of enhanced formation of molecules which then show up with velocities of disk approach. A review of such scenarios is given by Mebold et al. (1989a).

In addition to the well known high latitude CO and cirrus at velocities near the LSR (Magnani et al., 1985), three molecule-containing clouds have up to now been detected at intermediate velocity (Table 2). The Draco cloud is well studied and shows all the characteristics of a cloud compressed and pierced by a HVC (Mebold et al., 1985, 1987). In particular, Herbstmeier (1990) could show from a principal component analysis that in the Draco interaction zone the so-called X-factor is well over an order of magnitude smaller than thought previously (de Vries et al., 1987; Heithausen and Mebold, 1989). In this zone, almost all C seems to have been processed into CO and H_2CO, while there is very little HI at the same velocities. A second high-latitude intermediate-velocity CO cloud is reported by Heiles et al. (1988); it is in a gas complex known already by Wesselius and Fejes (1973), who in general put intermediate velocity gas at z-distances of a few 100 pc. A third cloud of this kind has been discovered by Désert et al. (1990).

Summarizing, we have collected all information available on the abundances of metals in and on the existence of molecules induced by halo clouds.

Table 2. Molecules detected in the halo in IVCs

Object	l	b	v	molecules	ref.	d	ref
Draco	90	+39	-25	CO, H_2CO, NH_3	Mebold et al. 1989b	>500	M+89b
	135	+54	-45	CO	Heiles et al. 1988	>100	WF73
DBB 306	211	+63	-39	CO	Désert et al. 1990	<400	WF73

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