Diffuse Ionized Gas in the β CMa Tunnel

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Abstract. We present HST observations of the interstellar medium toward the star β CMa known to be located in a low density extension of the Local Bubble. Most of the matter in the sight-line is ionized and clumped in two main components. One of them, as well as one of the components detected toward ϵ CMa, is mostly ionized and only slightly depleted. Their ionization ratios are compatible with collisional ionization at T∼25 000 K. These clouds could have been ionized by shocks related to the Local Bubble creation and also responsible of some dust grain sputtering.

1 Introduction

Copernicus (Gry et al. 1985), ground-based (Welsh 1991) and *HST* observations (Gry et al. 1995) have shown an extension of the Local Bubble in the direction of Canis Majoris. This tunnel free of neutral gas extends up to the stars β CMa ($l = 226°, b = -14°$, B1 II-III) and ϵ CMa ($l = 240°, b = -11°$, B2 I) located ∼150 pc away from the Sun, making these stars the brightest sources of the sky in the EUV (Cassinelli et al. 1995, 1996). These sight-lines with their long pathlength within the hot gas and their low column densities are the best opportunities to study the diffuse clouds embedded in the Bubble. Diffuse clouds elsewhere are often masked by larger absorption components.

First, we will give a short description of the β CMa sight-line and then we will focus on the physical characteristics of the two ionized clouds detected toward ϵ and β CMa.

2 Observations

The data for β CMa discussed here were obtained in December 1992 (cycle 2) by Vidal-Madjar and collaborators using the Goddard High Resolution Spectrograph onboard the Hubble Space Telescope. They consist of two sets of data at two different resolving powers. The Ech-B spectra (wavelengths from 1800 to 3000 Å) have a resolution of ∼ 3.5 $\mathrm{km\,s^{-1}}$ and present lines of Fe II, Mg II, Mn II, Mg I, Si II and Al III. The G160M spectra (from 1100 to 2000 Å) are less resolved (∼ 15 $\mathrm{km\,s^{-1}}$) and show lines of N I, O I, H I, D I, S II, Si II, Al II, C II, Si III, Si IV and C IV.

3 The Structure of the Sight-Line

3.1 Overview

The highly resolved Ech-B lines show four components, labelled A, B, C and D in order of increasing velocities (Figure 1). We focus on the components C and D for which column densities and b-values are well determined.
The medium resolution G160M data do not allow to separate the different components detected with the Ech-B, but they contain important lines for our study like SII and SiIII. The absorption feature in SiIII occurs at the velocity close to that of the component D while in NI and OI, it occurs at the velocity of component C. We thus conclude that D is mostly ionized while C is mostly neutral.
More details about this sight-line can be found in Dupin and Gry (1997).

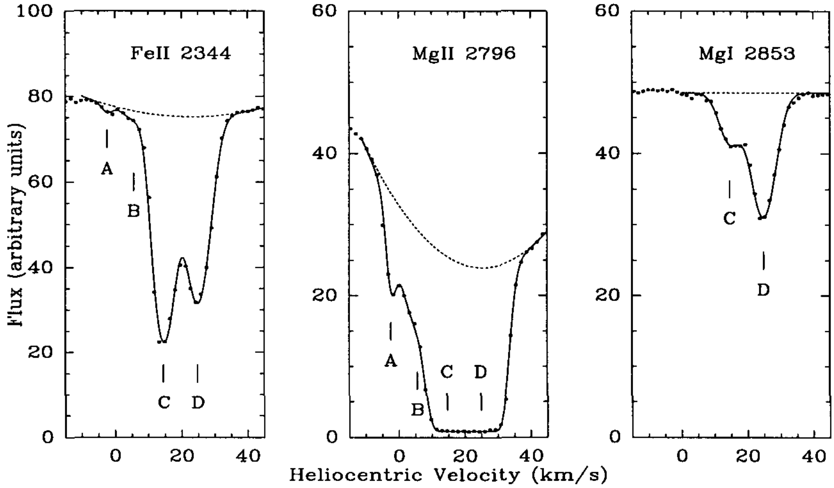

Fig. 1. Ech-B Fe II, Mg II and Mg I lines of β CMa. The dots are the observations, the dashed line the stellar continuum and the solid line the fit to the interstellar absorption profile

3.2 Temperature and Electron Density

Using the Fe II and Mg II b-values and thanks to the mass difference between these two elements we are able to separate the thermal and turbulent broadenings of the lines. Unfortunately, the uncertainties allow the Mg II b-value to be greater than that of Fe II and thus we only derive upper limits for the

Table 1. Column densities of important species (log N in at cm^{-2}) derived from the observations

	FeII	MgII	MgI	SiII	SiIII	SII
Cloud C	13.07 ± .04	13.48 ± .08	10.90 ± .03	13.75 ± .03	$\leq$ 12.70	14.01 ± .17
Cloud D	13.00 ± .05	13.77 ± .06	11.40 ± .05	13.87 ± .02	14.59 ± .51	14.35 ± .10

cloud temperatures. We find $T \leq 9500$ K for C and $T \leq 13\,500$ K for D. For turbulent velocities, we find $V_{turb}=3.1$–3.7 km s^{-1} for C and $V_{turb}=3.7$–4.6 km s^{-1} for D, the upper values being achieved for purely turbulent broadening (i.e. for b(Mg)=b(Fe)). We also infer lower limits on temperature using the Mg I/Na I ratio (Pettini et al. 1977). Taking the Na I upper limit by Welsh (1991), we find $T \gtrsim 3000$ K for C and $T \gtrsim 6000$ K for D.
Assuming the ionization equilibrium between Mg I and Mg II, we derive the electron density in the clouds (see Gry et al. 1995). We find $n_e = 0.03 - 0.61$ cm^{-3} and $n_e=0.02$–1.34 cm^{-3} for the cloud C and D respectively. The large uncertainties come from the strong dependence of n_e on temperature.

4 Characteristics of the Ionized Components

We now focus our attention on the ionized cloud D and component 3 detected toward ϵ CMa (Gry and Dupin 1997), which present depletion and ionization similarities.

4.1 Depletion

As sulfur is usually undepleted in the interstellar medium, we derive the total hydrogen column density in cloud D from N(S II)+N(S III): we find $N(H_{tot})=19.0$–19.2 dex. On the other hand, we have a lower limit on the total silicon column density in cloud D: N(Si II)+N(Si III)$\geq$14.34 dex. Thus, we derive a silicon gas-phase abundance in cloud D of $A(Si)=\log(N(Si)/N(H_{tot}))\geq -4.86$, and a silicon depletion of $D(Si)=A(Si)-A(Si)_{cosmic}\geq -0.41$. Similarly for ϵ CMa component 3 we have a lower limit on the silicon depletion of -0.5. The silicon depletion in these clouds is thus within a factor of 2 of the minimum depletion found in the halo high velocity clouds (Fitzpatrick 1996). Thus, component D and 3 are only slightly depleted.

4.2 Ionization

We derive an upper limit for the neutral gas column density in component 3 from OI and NI : N(H I)$\leq$ 15.7 dex (Gry and Dupin 1997). For the total gas column density, we derive an upper limit from S II+S III and a lower limit from Si II+Si III: $17.06 \leq \log(N(H_{tot})) \leq 17.38$. This cloud is thus more than

96% ionized. From the upper limit on N(H I) we can derive the maximum column densities expected for the species which have an ionization potential close to that of H I, and which are therefore commonly supposed to arise from H I region. The derived values for Si II, Mg II and Fe II derived with the solar abundances of the species, are about one order of magnitude greater than the mesured values. Note that if some depletion of these species is considered, the discrepancy would be even worse. These results show that H I is much more ionized than Si II, Mg II and Fe II: this can be explained by photoionization only with a very sharp radiation spectrum, very unlikely for any stellar photoionization source. We have similar results for cloud D although in this case the upper limit on the neutral gas can only be derived from the HI column density of the whole line of sight : $N(HI) \leq 18.34$ dex (Gry et al. 1985 and Cassinelli et al. 1996).

We can however interprete this ionization in terms of collisional ionization. The ionization ratios of the species we observe are roughly compatible with collisional ionization at temperatures from 20 000 to 25 000 K, as given by Arnaud and Rothenflug (1985) and Sutherland and Dopita (1993). The temperature measured in the clouds by line fitting are however lower, of the order of 10 000 K for both components. We propose that the gas, previously collisionally ionized has already been cooling but is still in the process of recombining.

These clouds might thus give the evidence that shocks have been travelling in the area in the past; they could be the left-over from the blast-wave that created the Bubble.

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