The Abundances of the Fe Group Elements in Three Early B Stars in the Large Magellanic Cloud

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1. Motivation

The atmospheres of early main-sequence-band B stars provide perhaps the most accurate information on the present-day abundances of the elements in a galaxy and its chemical evolution. Often called *pristine*, these abundances are not subject to uncertainties due to 1) the empirical models used for the ISM and plasma parameters, 2) depletion of some species onto grains, and 3) NLTE, atmospheric motions, & possible contamination from recently produced products in the evolved star's interior as are abundances from H II regions & supernova remnants (cf. Russell & Dopita 1992) and giant/supergiant/WR stars (cf. Reitermann et al. 1990, Spite et al. 1989, Russell & Bessell 1989, Venn 1999).

The abundances of the Fe-peak elements (Ti, V, Cr, Mn, Fe, Co, and Ni) are of interest as they are important for assessing opacities for stellar evolution calculations, confirming theoretical calculations of explosive nucleosynthesis, and inferring the past history of SN Ia and II that are believed to inject the heavy elements into the ISM. Except for four weak multiplets of Fe III (4, 114, 118, 119) there are no measurable lines from the Fe group in the optical region. Rapid rotation in B stars complicates matters more, as the weak lines are either lost in the star's continuous flux or blended with nearby stronger features. On the other hand the FUV spectral region contains a large number of strong, analyzable lines from the Fe group.

2. Sharp-Lined Early B Stars in the LMC

Korn et al. (2000) identified seven main sequence, or near main sequence early B stars in the Large Magellanic Cloud for which the photospheric lines are sharp enough that it is feasible to undertake detailed abundance analyses. They determined chemical abundances from high resolution optical spectra using a combination of LTE and NLTE spectrum synthesis codes. We have observed the three stars with the largest values of log g with the FUSE spacecraft in order to find the abundances of the Fe group elements, whose spectral lies were either weak or absent in the optical data of Korn et al.

3. Observations & Analysis

The program stars listed in Table 1 were observed with the FUSE spacecraft in July and August of 2003. The observations of NGC1818-D1 were carried through with the LWRS aperture, but the MDRS aperture was used for the stars in NGC 2004 to avoid light contamination from several nearby bright stars. Data from each of the channels were smoothed with a standard IDL function (the number of points ranged from 7-10) and analyzed independently.

The Kurucz LTE model atmosphere/spectrum synthesis codes ATLAS9/SYNTHE were used to analyze the FUSE data. We adopted model parameters close to those found by Korn et al. A grid of spectra were computed for [M/H] = -0.3, -0.5, -0.7, -0.9, and -1.1 dex and a Gaussian instrumental broadening parameter of 20,000 representative of FUSE spectra was adopted.

TABLE 1
PROGRAM STARS[†]

Star	V	Sp. Type	T_{eff} (K)	log g	ξ_{turb} (km s^{-1})	$v \sin i$ (km s^{-1})
NGC1818-D1	14.93	B1 V	24700	4.0	0	30
NGC2004-B15	14.18	B2 III	19900	3.1	6	25
NGC2004-B30	13.83	B1 III	23450	3.3	14	30

[†] Model parameters are from Korn et al. (2000).

4. Overview of Results

We concluded that our LTE analysis produced good results only for NGC 1818-D1, the object that has the largest surface gravity. As NLTE studies of the other B stars in NGC 2004 are in progress, we will feature the results from NGC 1818-D1 here. Selected plots in which the observed spectrum is compared with a grid of theoretical profiles are shown in Figures 1–4. The theoretical spectra were computed for T_{eff}/log g or 25000/4.0. The abundance results are presented in Table 2 and compared with those determined from AV 304 in the SMC (Peters & Adelman 2005) and ISM features.
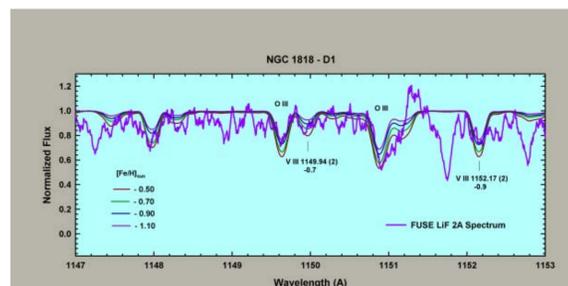

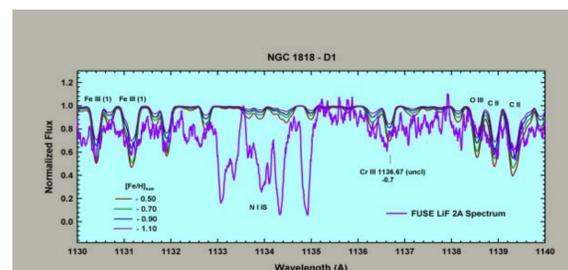Fig. 1- The spectral region containing the strongest V III lines. Individual lines are marked.

Fig. 2 - The spectral region containing the cleanest Cr III line.

5. Vanadium and Chromium in NGC 1818-D1

Only a trace of a strong V III multiplet, λ1149.94,1152.17 (UV2) was found in the spectrum of NGC 1818-D1. The spectral region containing these lines is shown in Fig. 1 along with a grid of SYNTHE calculations. The abundance of V in the sun is quite low (4.0 dex on a scale with H = 12.0, Asplund, Grevesse, & Sauval 2005), and if it is reduced by another factor of 5–10 in the LMC one would expect to observe only the strongest features. The two V III lines yield a vanadium abundance, [V/H]$_\odot$, of -0.8 dex. Most of the potentially good Cr III lines are blended with stellar and interstellar features. The best line, λ1136.67 (Fig. 3), suggests an abundance of -0.8 dex relative to the sun's value.

6. Iron in NGC 1818-D1

The strongest and best set of Fe III lines in the FUSE spectral region is the resonance multiplet UV1, 9 lines between 1122-1132 Å. The fit to this multiplet is shown in Fig. 3. Seven lines suggest [Fe/H]$_\odot$ = -0.69±0.13 dex. Korn et al. obtained a larger abundance of -0.11 dex from five weak optical lines. Russell & Dopita (1992) adopted a mean Fe abundance of -0.22 dex from the analysis of lines in the ISM.
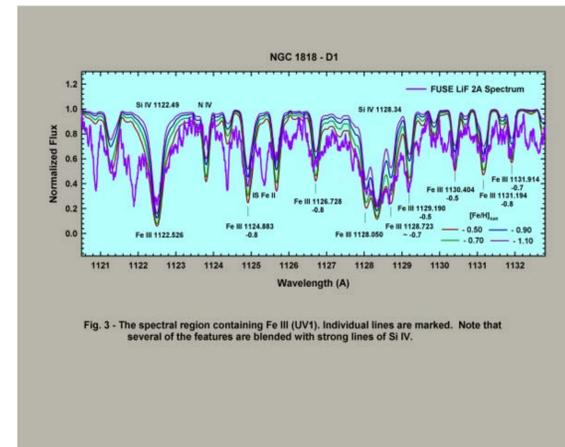

Fig. 3 - The spectral region containing Fe III (UV1). Individual lines are marked. Note that several of the features are blended with strong lines of Si IV.

Table 2
Comparison with AV 304 and the LMC ISM
[M/H]$_\odot^*$

Element	NGC 1818-D1	AV 304[1]	ISM[2]
V	-0.8	-0.70	-0.53
Cr	-0.7	-1.10	-0.57
Fe	-0.7	-0.61	-0.66

[1] Peters & Adelman (2005)
[2] Russell & Dopita (1992)

[*] Solar abundances are from Asplund, Grevesse, & Sauval (2005)

7. Carbon & Nitrogen in NGC 1818-D1

The abundances of C and N are good indicators of the chemical evolution in a galaxy. The FUSE spectral region contains several lines of carbon and nitrogen, including resonance lines of C III and N III. The latter are not good for analysis as they are blended with the ISM features. In Fig. 4 we show the fit to two strong multiplets. Based upon these fits, C appears depleted relative to H by -0.70 dex and N by $\sim$ -0.90 dex. The C/N ratio in the sun is 0.61 dex (Asplund et al. 2005) but in NGC 8181-D1 we find C/N~0.20 dex. The elevated abundance of nitrogen relative to carbon suggests that CNO-processed material from the star's core (first dredge-up) may have mixed with the original pristine photospheric material. Or perhaps the star has undergone mass transfer from a close companion. Korn et al. also noted the peculiar C/N ratio in this star. NGC 1818-D1 is quite in contrast to AV 304 in the SMC in which an extremely low N abundance was found (Peters & Adelman 2005). The photospheric abundances in AV 304 appear to be unaltered by processed material from the interior and this star represents the current composition of the ISM in the SMC in the region of this field star.
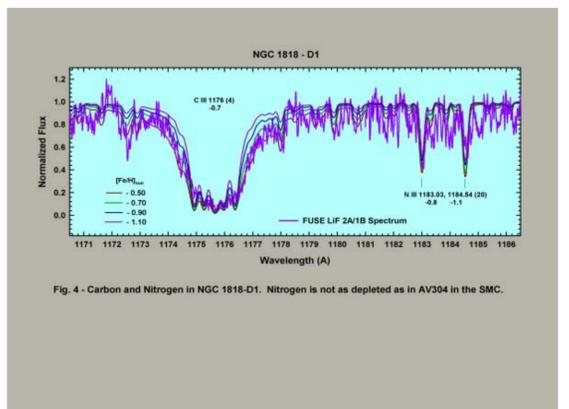

Fig. 4 - Carbon and Nitrogen in NGC 1818-D1. Nitrogen is not as depleted as in AV304 in the SMC.

8. Concluding Remarks

This project is part of an ongoing attempt to determine the abundances of the Fe group and lighter elements in the Magellanic Clouds directly from the photospheric spectrum of early B stars. We have completed our analysis of AV 304 in the SMC and are currently pursuing an NLTE study of four other sharp-lined early B stars in the Magellanic Clouds as the first step toward mapping the abundances of the Fe group elements in these galaxies from photospheric data. Objects include NGC346-637 (B0V), NGC346-11 (B0V) in the SMC and NGC2004-B15 (B2III), and NGC2004-B30 (B1III) in the LMC.

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