NITROGEN ABUNDANCES IN CHEMICALLY PECULIAR STARS

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ABSTRACT

Nitrogen abundances are derived for 9 Ap stars and for two comparison stars from high-resolution IUE spectra. LTE synthetic spectra are calculated in three spectral regions around low-excitation N I multiplets, taking into account the new atomic data for iron-peak elements recently computed by Kurucz. The two comparison stars (π Cet and ν Cap) are found to be mildly nitrogen deficient, while our results suggest that Ap stars have large nitrogen underabundances. We discuss and compare our results with the recent work of Roby and Lambert, who deduced CNO abundances from high-excitation lines in the red spectrum. We outline the importance of CNO abundances to understand the origin of the chemical anomalies of Ap stars.

Keywords: Ap stars – IUE spectra – nitrogen abundances – stellar atmospheres

1. INTRODUCTION

While Ap stars are known for a long time to have photospheric anomalous chemical abundances (Si, iron-peak elements, rare-earths) from their blue spectrum, the study of their ultraviolet spectrum is of special interest because it contains some low-excitation lines of several species, not detected in the optical spectrum (e.g. Gallium), which could allow to gain an insight into the origin of these peculiarities. Diffusion of the elements in a stable atmosphere under the competing influences of gravitation and radiative pressure (Ref. 1), or magnetic accretion of interstellar material (Ref. 2), have been put forward to explain these anomalies. This origin still remains sometimes debated although the first one is now generally accepted. In this context, CNO abundances are more particularly interesting, because they could indicate if a nuclear process should be considered or not.

Up to now, studies of these elements are very scarce in the literature, due to the absence or the weakness of lines of these three elements in the blue spectrum. It is specially the case for nitrogen: only upper limits (one tenth of the solar abundance) are available for three magnetic Ap stars and two Ap HgMn stars (Refs. 3,4), although an other study indicates a possible overabundance (+0.8 dex) for the B9 Si star HD 34452 (Ref. 5). It is the reason why one of us initiated some years ago an analysis of UV low-excitation N I lines in Ap stars, and gave some preliminary results for three magnetic Ap stars (Ref. 6). Very recently, Roby and Lambert (Ref. 7) completed a systematic study of high-excitation lines of neutral C, N and O in the red with similar purposes. Generally speaking, they found that Ap stars have lower CNO abundances than the cosmic values, with particularly large underabundances (up to 2 dex) for stars with T eff ≈ 9000 K and HgMn stars.

We present here first results for 9 Ap stars and two normal slowly-rotating main-sequence stars deduced from high resolution IUE spectra and a LTE spectrum synthesis performed in the region of three low-excitation N I multiplets (λ 1412, 1492-95, 1743-45 Å).

2. METHOD OF ANALYSIS

2.1. The data

From the large set of Ap stars observed by IUE (about 150 stars), we selected a restricted set of stars having different typical anomalies. A unique SWP well-exposed image was kept for each star to avoid to consider the stellar variability. The selected stars and the de-archived images are listed in Table 1 with some other general stellar data. The spectra are extracted from the original data by means of a software developed at Meudon Observatory by J. Borsenberger (Ref. 8). In the case of HD 133029, we derived a mean spectra from six consecutive SWP images showing no variations (Ref. 6). To perform a differential analysis, we also consider two normal main-sequence stars with similar effective temperature, namely π Cet and ν Cap, for which we got co-added spectra from about ten SWP images (Ref. 9).

A most delicate point is the normalization of these spectra to the continuum. It is particularly difficult in the UV spectra of these iron-rich stars due to the lines crowding. We finally prefer the simplest way, taking linear continuum through high points in 50 Å intervals centered around the three multiplets. This method fails in some cases for the most peculiar magnetic stars in the wavelength range around λ1740 Å, because the spectra of these stars present broad absorptions at λ1720 Å and λ1770 Å (Ref. 10), holding up the choice of a satisfactory continuum.

2.2. Model atmospheres and LTE spectrum synthesis

The photospheric parameters $T_{\text{eff}}$ and $\log g$ were firstly inferred from the Geneva and Strömgren photometry with the appropriate calibrations (Refs. 6, 11-13) and are listed in Table 1. The model atmospheres were then derived from the fully-blanketed models calculated by Kurucz (Ref. 14), assuming a solar metallicity for normal and HgMn stars and a 10 times solar metallicity for the magnetic Ap stars. Artru and Lanz (Ref. 10) discussed the problem of the inadequacy of such models to the photospheres of magnetic Ap stars, but it is presently the only models approaching more or less these photospheres.

Spectrum syntheses were calculated in three regions of about 5-6 Å around each N I multiplets. The line list was set up basically from the laboratory line lists from Kelly (Ref. 15), and was extracted from the list used for the spectrum syntheses of the UV spectrum of α Cet and ν Cap between 1250 and 2000 Å (Ref. 9). The list was complemented by the new iron–peak line list from Kurucz (Ref. 16). We adopt the experimental oscillator strengths given by Goldbach et al. (Refs. 17, 18) for the N I multiplets. They fixed the absolute scale with the multiplet at λ4393 Å, for which they adopt a value 0.2 dex lower than the one listed by Wiese and Martin (Ref. 19). Kurucz and Peytreomm (Ref. 20) gave a slightly lower value by 0.1 dex. For the two other multiplets, Kurucz and Peytreomm got $gf$-values greater by about 0.2 to 0.3 dex. We therefore estimate the uncertainty on $gf$-values to be of the order of 0.2 dex. This should be kept in mind only when comparing the absolute abundances and the solar value, but this is discarded if we just look to the abundance differences between normal and Ap stars.

Stark and radiative damping were taking into account for line broadening. We adopt the Stark widths given by Griem (Ref. 21) for N I multiplets, and those calculated by Kurucz (Ref. 16) for iron–peak elements lines. Radiative widths are assumed to correspond to the classical damping constant, except for the lines calculated by Kurucz (Ref. 16). Magnetic intensification through desaturation by Zeeman splitting could be ignored in the ultraviolet due to the quadratic dependance of the Zeeman effect with wavelength.

The computation of the spectrum syntheses was performed with the ADRS code (Refs. 22, 6), assuming a homogeneus plane-parallel atmosphere, LTE in line formation and Voigt profiles in the line absorption coefficient. The continuous opacity includes the most recent photoionisation data for metals, and the red wing of the hydrogen Lyman α line is calculated according to Vidal et al. (Ref. 23). Null microturbulence was taken for Ap stars, except for φ Her (Ref. 24), as they were expected to have quite stable photospheres. For the two normal stars, we adopted the microturbulence deduced from an analysis of optical iron lines (Ref. 25). The theoretical spectral were then convoluted twice to account for the stellar rotation and the instrumental profile. Rotational velocities were extracted from the catalogue of Uesugi and Fukuda (Ref. 26), and were adjusted only in a few cases when they obviously appear incorrect. We looked finally for the best fit with the observational data, varying the only nitrogen abundance and correcting for the radial velocity. For gallium-rich stars (Ap HgMn), we had to estimate also the gallium abundance, because strong resonance lines of Ga II and Ga III have wavelengths close to N I lines. The N I lines are also heavily blended by Fe II lines. We therefore need an accurate estimation of the iron abundance, which was previously determined from several Fe II lines around λ640 Å with a similar method. These iron abundances are well compared to the values deduced from analyses from optical spectra (≈ 0.1 dex in several test cases).

3. RESULTS AND DISCUSSION

The nitrogen abundances (relative to H) are listed in Table 2 for each multiplet, and some of the fits are presented in Fig. 1. The stars are ordered in Table 2 by increasing effective temperature. Missing results are due either to a coincidence of a resonance–mark with the λ412 N I lines which prevents us from using this multiplet for several stars, or to the unsatisfactory choice of any continuum around λ1740 Å. In some cases, only upper limits could be derived: a feature is observed at the location of the N I lines, but could be accounted only for Fe II lines. The precision on the nitrogen abundance from the fitting procedure (due to the noise in the stellar data) is estimated to be generally around 0.2 dex, maybe a bit better for the two normal stars with co-added spectra, and worse (0.3 to 0.5 dex) in a few cases indicated by a colon.

The results from the three multiplets are finely consistent for the two normal stars, although the multiplet at λ4392 Å leads to slightly smaller abundances. Different interpretations of this discrepancy could be considered. The adopted $gf$ values could be too large by about 0.4 dex. But Goldbach et al. (Refs. 17, 18) used this multiplet to define the absolute scale of their $gf$-values, so we would expect a systematic effect on the three multiplets; further the difference is much larger than the internal errors quoted by Goldbach

<table>
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<tr>
<th>Name</th>
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<th>$T_{\text{eff}}$</th>
<th>$\log g$</th>
<th>$V\sin i$</th>
<th>$\text{IEUE images}$</th>
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<td>[cm/s²]</td>
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(a) Mean spectrum (SWP 6097-6102) (Ref. 6).
(b) Mean spectrum (Ref. 9).

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et al. The choice of the continuum does not seem to be called into question. More probable are non–LTE effects, or surestimation of some Fe II blending lines, due to incorrect oscillator strengths. If there is no systematic error in the gf–values tabulated by Kurucz (Ref. 16), individual lines could show discrepant values. We therefore could consider to add 0.4 dex to the LTE abundances derived from these lines when comparing for Ap stars the results inferred from different multiplies. The agreement with the results for π Cet from the high excitation lines (Ref. 7) is very good and encouraging. It appears then that these two late–B main–sequence stars are mildly nitrogen deficient compared to the sun (solar abundance: $\xi_N = -4.01$, Ref. 27).

Nitrogen appear very clearly to be underabundant in Ap stars. But the situation does not look so favourably than for normal stars. Differences between the UV multiplies are larger (typically 0.5 dex), but above all the discrepancies with the results of Roby and Lambert are striking (up to 2 dex) for magnetic stars. The differences between UV multiplies might be assigned partly to noisy data, especially as the N I lines are weaker in Ap stars than in normal stars (note in particular that the A1493 multiplet gives for two stars higher abundances than the A1412 multiplet). A further uncertainty comes from the blending Fe II lines, which are strengthened in Ap stars. Several possibilities could be mentioned to explain the discrepancies with the results from high–excitation multiplies. Magnetic Ap stars are well–known spectroscopic variables (due to inhomogeneous distribution of the chemical elements over the stellar surface), but these differences would imply a strongly inhomogeneous distribution of nitrogen. Furthermore all four stars in common with Roby and Lambert give lower abundances from UV lines than from red lines; this is rather unlikely if we would put forward variability. One might also suggest that these differences come from a vertical stratification of nitrogen, which would be less abundant towards the surface. The effect seems nevertheless a bit large, although radiative diffusion calculations predict the appearance of such vertical inhomogeneities (e.g. Ref. 28). In fact such differences between low and high–excitation lines, from the UV and red spectra, affecting only the magnetic Ap stars raise up again the problem of the adequacy of the present model atmospheres to magnetic stars. Finally we could point out no obvious dependence of the nitrogen abundance with the effective temperature, the type of peculiarity, the degree of peculiarity (through the Geneva photometric index for example) or the magnetic field strength. We could also note that HD 34452 (a strongly Si–rich star) has a slightly higher abundance than its comparison π Cet. It is apparently a quite different behaviour, and it would somehow confirm the previous results of Tomley et al. (Ref. 5).

4. CONCLUDING REMARKS

These first results from low–excitation N I multiplies confirm that Ap stars show definite nitrogen underabundances. We should now in a next step understand the reasons of the discrepant abundances derived from UV and red multiplies with a full NLTE calculation for nitrogen. We could expect some departures from LTE similarly to neutral carbon and oxygen. From similar underabundances of carbon and oxygen (see Ref. 7 and references therein), we could conclude that Ap stars present a total CNO content clearly lower than the cosmic value. Thus it seems very unlikely that the accretion of nuclear processed material (from an evolved giant companion or from supernovae ejecta) could be invoked to explain the chemical peculiarities of Ap stars. Further arguments support this view, such as the large overabundances of the odd–element Gallium, or the very low number (<1/1000) of A stars which could be affected by accretion (Ref. 29). We have now a full set of CNO abundances for chemically peculiar stars, and it is therefore very important to carry out new radiative diffusion calculations to investigate if this theory is able to reproduce the observed CNO underabundances.

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REFERENCES


**Figure 1**: Examples of *IUE* observations fitted by spectrum syntheses: *IUE* spectra (full lines) are compared to theoretical spectra (dotted lines).