

## NLTE Spectral Analysis of Iron Group Elements in the Hot Subluminous O-Star BD+28°4211

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**Abstract.** An analysis of UV spectra of BD+28°4211 obtained with the STIS spectrograph onboard the HST is presented. The spectral analysis is based on NLTE model calculation with a detailed treatment of line blanketing of the iron group elements. Improved model atoms for iron group elements were set up and new inter-band cross sections were calculated. Comparison with observation allowed us to identify Mn and Cr lines for the first time. The derived abundances of Fe, Ni, Cr and Mn indicate the presence of diffusion processes in the atmosphere of BD+28°4211.

### 1. Introduction

BD+28°4211 is one of the brightest and hottest ( $T_{\text{eff}} = 82\,000\text{K}$ ) sdO stars in the sky. Its gravity ( $\log g = 6.2$ ) and normal He content (Napiwotzki 1993) indicates that it is a post-AGB star and an immediate progenitor of a DA white dwarf. It has been well observed in the optical (e.g. Herbig 1999) and in the ultraviolet (Haas et al. 1996). Iron and nickel abundances have been derived from IUE UV spectra by Haas et al. (1996).

Here we report on new NLTE model atmosphere calculations which include additional iron group elements, and compare them to improved UV spectra taken with the STIS spectrograph onboard the *Hubble Space Telescope*. In the UV range, a large fraction of the total energy is emitted, and the number of spectral lines of the iron group elements is largest there. Therefore, the lines of iron group elements have a large impact on the flux distribution and the atmospheric structure.

Due to the high effective temperature of BD+28°4211 and the associated mean free path of the photons, radiation from deeper layers becomes very important for the population of atomic levels. Atomic processes such as excitation and ionization are characterized by the non-local radiation field. Therefore the assumption of LTE (local thermodynamic equilibrium), in which the state of matter is described by local quantities such as pressure and temperature, cannot be maintained in the outer atmospheric layers. The deviation from this is called NLTE (non local thermodynamic equilibrium).

The models were calculated with detailed model atoms including the iron group elements in order to describe the line blanketing properly.

## 2. Numerical Method

The numerical method used in this work is the ALI (Accelerated Lambda Iteration) method with approximate  $\Lambda$ -operators (ALO), first introduced by Cannon (1973), and later reformulated in a practical way by Scharmer (1981). In the following years the ALI method was improved by Husfeld & Werner (1985), Werner (1986, 1987, 1988) for the iron group elements with a large number of line transitions. Details can be found in Werner & Dreizler (1999).

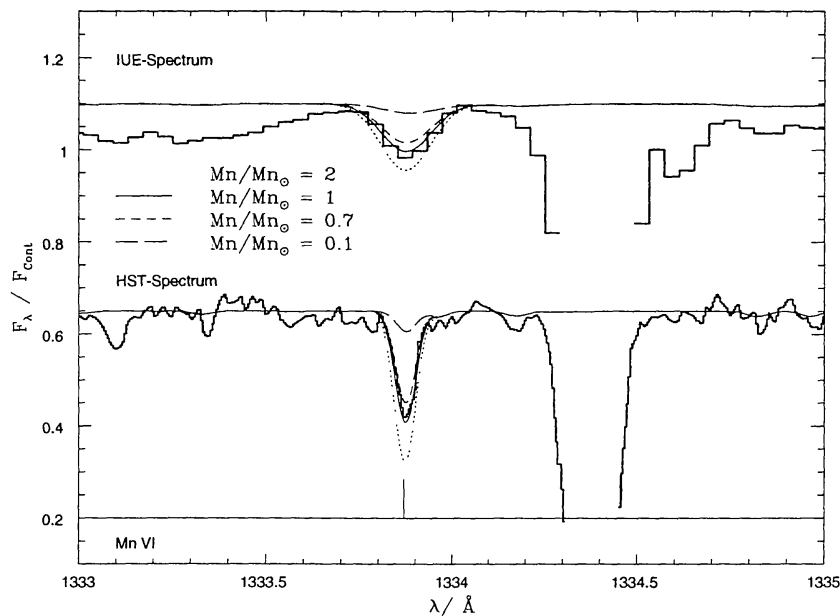


Figure 1. Comparison of spectra from IUE (Haas et al. 1996) and HST/STIS spectra with model spectra. Mn VI line at  $1333.874 \text{ \AA}$ ,  $\log gf = 0.343$ , is clearly present. The abundance of Mn is varied from 0.1 solar to 2 solar.

## 3. Observations

A STIS spectrum covering the range  $1250 - 1450 \text{ \AA}$  with a resolution of  $0.05 \text{ \AA}$  was retrieved from the HST archive. Figure 1 compares a section of this spectrum to the IUE spectrum (superposition of 28! SWP observations) used in the previous analysis of Haas et al. (1996). Figure 1 demonstrates the superior quality of the HST-STIS spectrum. Note the presence of a Mn VI line in this part of the spectrum, which was identified for the first time in BD+28°4211.

#### 4. Model Atoms

The model atoms for H, He, C, N, O, Fe, Ni were set up already by Haas et al. (1996). We expand it with a new model for iron and a generic model for the rest of the iron group (Sc, Ti, V, Cr, Mn, Co). The iron group elements are treated in the ionization stages III-VIII.

The model for iron and for the rest of the group were set up using Kurucz (1991) data, starting out with a grouping of levels into model bands. For the rest group the approach of the "generic ion" is used. The idea is to combine the same ionization stages of all elements weighted with their relative abundances into one model ion. This approximation is justified because the ionization potentials of the iron group elements are quite similar. With this atomic data the model atmospheres and synthetic spectra are calculated for different abundances of the iron group. We then examine whether lines of the iron group elements can be identified in the observed spectrum and be used for determining the abundances.

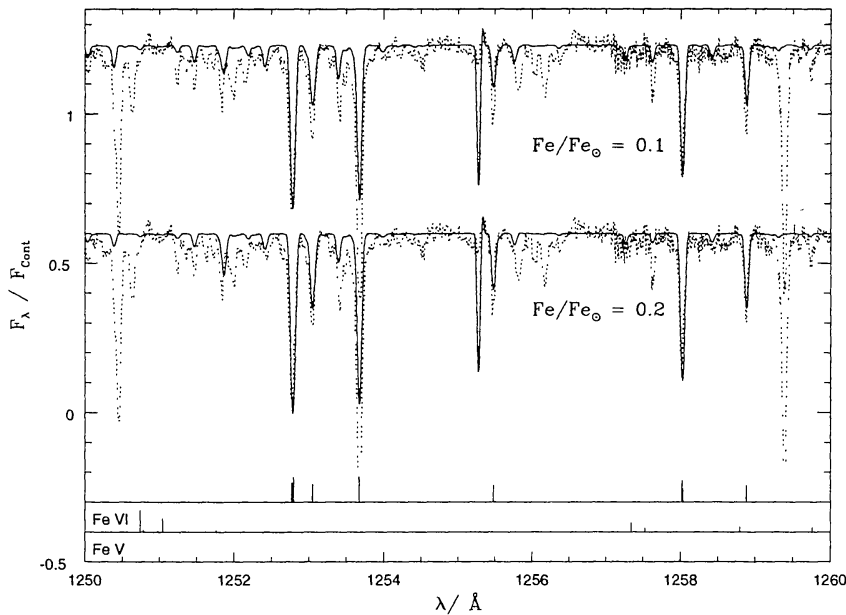


Figure 2. Comparison of two model spectra (solid line) with model spectra for different iron abundances.

#### 5. Results

For the first time, we have identified lines of Mn VI (Fig. 1) and Cr VI in the HST/STIS spectrum of BD+28°4211. We found an underabundance of manganese and an overabundance of chromium with respect to the solar values (Table 1). The value for chromium however is uncertain, because only one line of Cr VI was identified in the wavelength range of interest of the HST STIS spectrum.

The abundance of iron was redetermined from the HST spectrum (Fig. 2), and the subsolar value (Tab. 1) deduced by Haas et al. (1996) from IUE spectra was confirmed. The  $n_{\text{Fe}}/n_{\text{Ni}}$  ratio, as well as the  $n_{\text{Fe}}/n_{\text{Mn}}$  and  $n_{\text{Fe}}/n_{\text{Cr}}$  ratios have a subsolar value (Tab. 1). Notice that the solar  $\left(\frac{n_{\text{Fe}}}{n_{\text{Ni}}}\right)_{\odot}$  ratio is 20,  $\left(\frac{n_{\text{Fe}}}{n_{\text{Cr}}}\right)_{\odot}$  is 76 and  $\left(\frac{n_{\text{Fe}}}{n_{\text{Mn}}}\right)_{\odot}$  is 105. This peculiar abundance distribution points to diffusion processes in the stellar atmosphere.

Table 1. Results for BD+28°4211: Abundances of Fe, Ni, Mn, Cr.

Star	$\frac{n_{\text{Fe}}}{n_{\text{Fe}}^{\odot}}$	$\frac{n_{\text{Ni}}}{n_{\text{Ni}}^{\odot}}$	$\frac{n_{\text{Mn}}}{n_{\text{Mn}}^{\odot}}$	$\frac{n_{\text{Cr}}}{n_{\text{Cr}}^{\odot}}$	$\frac{n_{\text{Fe}}}{n_{\text{Ni}}}$	$\frac{n_{\text{Fe}}}{n_{\text{Cr}}}$	$\frac{n_{\text{Fe}}}{n_{\text{Mn}}}$
BD+28°4211	0.1 - 0.2	1.0	0.9	2 - 4 (only 1 line!)	3.0	3.8	17.5

Table 2. Identified lines of Mn and Cr.

Element	Wavelength / Å	gf
Mn VI	1 264.107	0.280
	1 272.443	0.307
	1 333.874	0.343
	1 345.495	0.331
	1 391.157	0.298
	1 391.217	0.331
Cr VI	1 417.660	0.300

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