

**STARK BROADENING DATA FOR
SPECTRAL LINES OF RARE-EARTH
ELEMENTS**

Zoran Simić

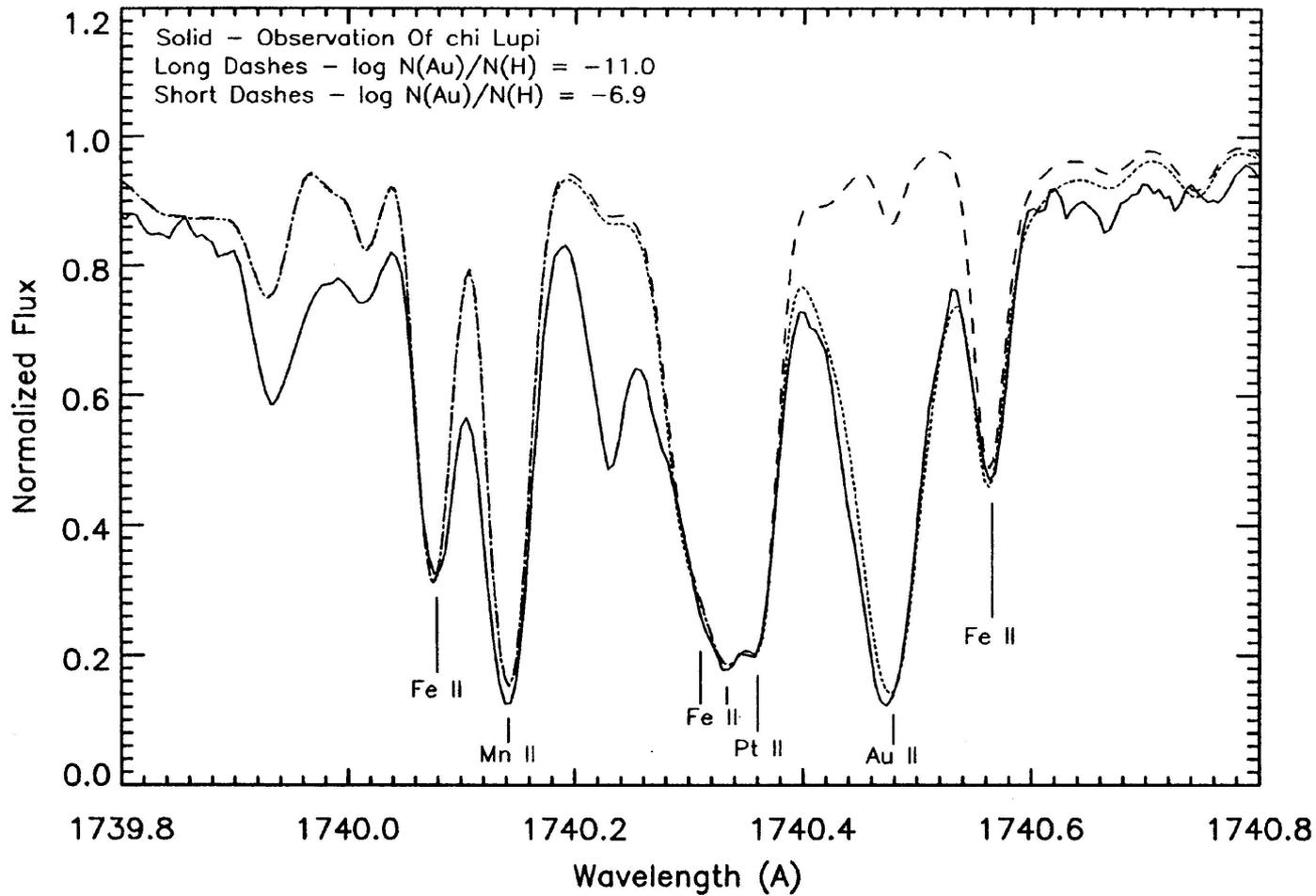
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Stellar spectroscopy needs atomic and line-broadening parameters for a very extensive list of line transitions for various elements in neutral and ionized states.

With the development of space-born observational techniques data on trace elements become more and more important for astrophysical problems as stellar plasma analysis and modelling, stellar opacity calculations and, interpretation and numerical synthesis of stellar spectra.

GHR-SPECTRA OF χ LUPI

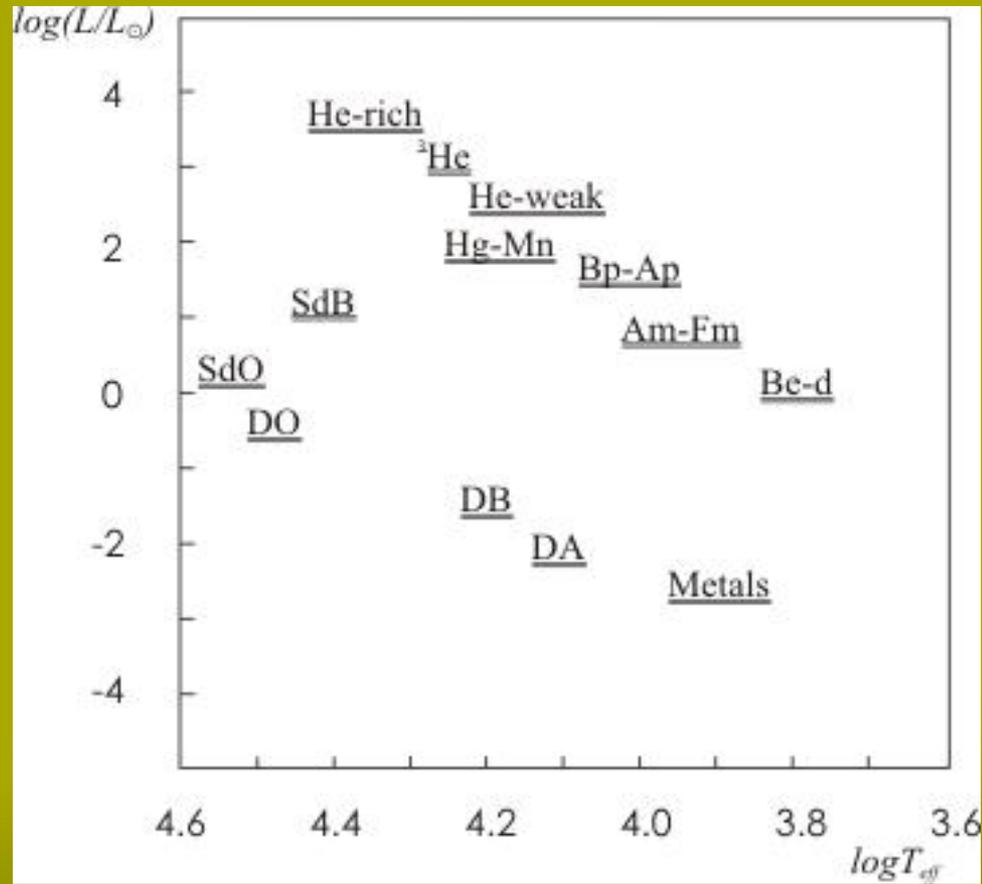


High-resolution spectra allow us to study different broadening effects using well-resolved line profiles.

Stark broadening is the most important pressure broadening mechanism for A type stars and especially for white dwarfs.

Neglecting this mechanism may therefore introduce significant errors into abundance determinations and spectra modelling.

HR graph



Shape of spectral line - laboratory plasma:

- *NATURE*
- *DOPPLER*
- *PRESSURE*

In stellar plasma: turbulence, rotation and magnetic field

SEMICLASSICAL THEORY

(Sahal-Bréchet, 1969ab)

$$w + id = N \int_0^{+\infty} v f(v) dv \int_0^{+\infty} 2\pi \rho d \rho (1 - S_{ii}(\rho, v) S_{ff}^{-1}(\rho, v))_{sr},$$

$$2w = N \int_0^{+\infty} v f(v) dv \left(\sum_{i' \neq i} \sigma_{ii'}(v) + \sum_{f' \neq f} \sigma_{ff'}(v) + \sigma_{el} \right),$$

$$d = N \int_0^{+\infty} v f(v) dv \int_{R_3}^{R_D} 2\pi \rho d \rho \sin 2\phi_p.$$

ab initio

It is possible also to perform calculations *ab initio*, using atomic energy levels and oscillator strengths calculated together with the Stark broadening parameters (Nessib et al., 2004).

MODIFIED

SEMIEMPIRICAL THEORY

(Dimitrijević & Konjević, 1980, Dimitrijević & Kršljanin, 1986).

$$\begin{aligned} w_{\text{mse}} = & C \frac{N}{\sqrt{T}} [\bar{R}_{l_i, l_i+1}^2 \tilde{g}(x_{l_i, l_i+1}) + \bar{R}_{l_i, l_i-1}^2 \tilde{g}(x_{l_i, l_i-1}) + \\ & + \bar{R}_{l_f, l_f+1}^2 \tilde{g}(x_{l_f, l_f+1}) + \bar{R}_{l_f, l_f-1}^2 \tilde{g}(x_{l_f, l_f-1}) + \\ & + \sum_{i'} (\bar{R}_{ii'}^2)_{\Delta n \neq 0} g(x_{ii'}) + \sum_{f'} (\bar{R}_{ff'}^2)_{\Delta n \neq 0} g(x_{ff'})], \end{aligned}$$

$$\begin{aligned} d_{\text{mse}} = & C \frac{N}{\sqrt{T}} [\bar{R}_{l_i, l_i+1}^2 \tilde{g}_{sh}(x_{l_i, l_i+1}) - \bar{R}_{l_i, l_i-1}^2 \tilde{g}_{sh}(x_{l_i, l_i-1}) - \\ & - \bar{R}_{l_f, l_f+1}^2 \tilde{g}_{sh}(x_{l_f, l_f+1}) + \bar{R}_{l_f, l_f-1}^2 \tilde{g}_{sh}(x_{l_f, l_f-1}) + \\ & + \sum_{i'} (\bar{R}_{ii'}^2)_{\Delta n \neq 0} g_{sh}(x_{n_i, n_i+1}) - 2 \sum_{i(\Delta E_{ii'} < 0)} [(\bar{R}_{ii'}^2)_{\Delta n \neq 0} g_{sh}(x_{i, i'})] - \\ & - \sum_{f'} (\bar{R}_{ff'}^2)_{\Delta n \neq 0} g_{sh}(x_{n_f, n_f+1}) + 2 \sum_{f(\Delta E_{ff'} < 0)} [(\bar{R}_{ff'}^2)_{\Delta n \neq 0} g_{sh}(x_{f, f'})] \\ & + \sum_k \delta_k], \end{aligned}$$

The investigations of the influence of Stark broadening in stellar spectra started in Belgrade in 1988, when the influence of this broadening mechanism was analyzed for a typical late B type stellar atmosphere with $T_{\text{eff}} = 13\,000\text{ K}$ and $\log g = 4,2$ (Lanz et al., 1988).

In a number of papers, the influence of Stark broadening on Au II (Popovic et al., 1999b), Co III (Tankosic et al., 2003), Ge I (Dimitrijevic et al., 2003a), Ga I (Dimitrijevic et al., 2004) and Cd I (Simic et al., 2005) on spectral lines in chemically peculiar A type stellar atmospheres was investigated and for each spectrum investigated atmospheric layers are found where the contribution of this broadening mechanism is dominant or could not be neglected.

As a model for the atmosphere of an A type chemically peculiar star, a model with stellar parameters close to those of χ Lupi HgMn star of Ap type was used. Such investigations were also performed for DA and DB white dwarf atmospheres (Popovic et al., 1999b; Tankosic et al., 2003) and it was found that for such stars Stark broadening is dominant in practically all relevant atmospheric layers.

Stark broadening of rare earth ions (La II, La III, Eu II and Eu III) was considered in chemically peculiar Ap stars by Popovic et al. (1999a) and found that its neglect introduces errors in equivalent width synthesis and corresponding abundance determination. Also, the influence of Stark broadening on the so called “zirconium conflict”, namely the difference in abundances obtained from weak Zr II optical lines and strong Zr III lines (detected in UV) in the spectrum of HgMn star ν Lupi, was considered (Popovic et al., 2001a).

Rare Earth elements:

Sc, Y, La, Eu, Nb, Lu

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List of the ions for which we are going to calculate the electron impact broadening parameters (Popović and Dimitrijević, 1998)

I	II	III	IV	V	VI
La II	3+x	SMSE+RST	La III	6+x	MSE+RST
La IV	x	RST	Ce II	x	RST
Ce III	5+x	SMSE+RST	Ce IV	4+x	MSE+RST
Pr II,III	x	RST	Nd II	5+x	SMSE+RST
Nd III	x	RST	Sm II	x	RST
Eu III	2+x	SMSE+RST	Gd II	2+x	SMSE+RST
Tb III	3+x	SMSE+RST	Ho II	2+x	SMSE+RST
Ho III	x	RST	Er II	1+x	SMSE+RST
Er III	x	RST	Tm II,III	x	RST
Yb II	5+x	MSE(SMSE)+RST	Yb III	3+x	MSE+RST
Yb IV	x	RST	Lu II	2+x	SMSE+RST
Lu III	5+x	MSE+RST	Lu IV	3+x	MSE+RST

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Stark broadening data for spectral lines of rare-earth elements: Nb III[☆]

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Abstract

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The electron-impact widths for 15 doubly charged Nb ion lines have been theoretically determined by using the modified semiempirical method. Using the obtained results, we considered the influence of the electron-impact mechanism on line shapes in spectra of chemically peculiar stars and white dwarfs.

Keywords: rare-earths; line profiles; atomic data

1. Introduction

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Spectral lines of rare earth elements (REE) are present in stellar spectra, especially in spectra of chemically peculiar (CP) ones and white dwarfs.

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Table 1: This table presents Nb III electron-impact broadening parameters (full width at half maximum W) for $4d^2 ({}^3F) 5s - 4d^2 ({}^3F) 5p$ transitions obtained by the modified semiempirical method (Dimitrijević & Konjević, 1980) for a perturber density of 10^{17} cm^{-3} and temperatures from 10,000 up to 300,000 K.

Transition	T(K)	W(Å)	Transition	T(K)	W(Å)
	10000.	0.929-01		10000.	0.858-01
	20000.	0.657-01		20000.	0.607-01
${}^4F_{3/2} - {}^4G_{5/2}^o$	50000.	0.415-01	${}^4F_{9/2} - {}^4F_{7/2}^o$	50000.	0.384-01
2599.7 Å	100000.	0.302-01	2469.5 Å	100000.	0.278-01
	200000.	0.249-01		200000.	0.228-01
	300000.	0.238-01		300000.	0.219-01
	10000.	0.736-01		10000.	0.823-01
	20000.	0.521-01		20000.	0.582-01
${}^4F_{3/2} - {}^4D_{1/2}^o$	50000.	0.329-01	${}^4F_{9/2} - {}^4F_{9/2}^o$	50000.	0.368-01
2274.6 Å	100000.	0.238-01	2414.7 Å	100000.	0.267-01
	200000.	0.195-01		200000.	0.218-01
	300000.	0.188-01		300000.	0.210-01
	10000.	0.988-01		10000.	0.956-01
	20000.	0.698-01		20000.	0.676-01
${}^4F_{9/2} - {}^4G_{7/2}^o$	50000.	0.442-01	${}^4F_{5/2} - {}^4G_{5/2}^o$	50000.	0.427-01
2657.3 Å	100000.	0.321-01	2635.0 Å	100000.	0.311-01
	200000.	0.264-01		200000.	0.256-01
	300000.	0.253-01		300000.	0.245-01
	10000.	0.924-01		10000.	0.901-01
	20000.	0.653-01		20000.	0.637-01
${}^4F_{9/2} - {}^4G_{9/2}^o$	50000.	0.413-01	${}^4F_{5/2} - {}^4G_{7/2}^o$	50000.	0.403-01
2558.7 Å	100000.	0.300-01	2546.4 Å	100000.	0.293-01
	200000.	0.246-01		200000.	0.241-01
	300000.	0.237-01		300000.	0.231-01
	10000.	0.859-01		10000.	0.788-01
	20000.	0.608-01		20000.	0.557-01
${}^4F_{9/2} - {}^4G_{11/2}^o$	50000.	0.384-01	${}^4F_{5/2} - {}^4F_{7/2}^o$	50000.	0.352-01
2457.8 Å	100000.	0.279-01	2373.5 Å	100000.	0.256-01
	200000.	0.229-01		200000.	0.209-01
	300000.	0.220-01		300000.	0.202-01

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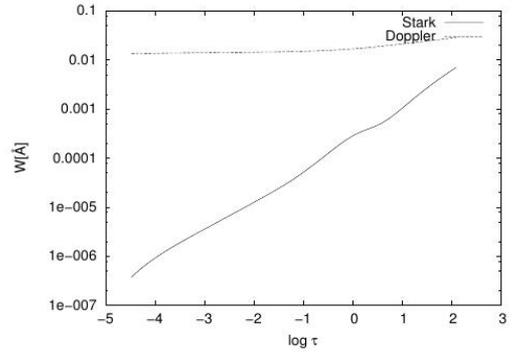


Figure 1: Thermal Doppler and Stark widths for Nb III spectral lines $4d^2 (^3F) 5s ^4F_{7/2} - 4d^2 (^3F) 5p ^4F_{7/2}^o$ ($\lambda=2415.2 \text{ \AA}$), for an A type star atmosphere model with $T_{eff} = 10,000 \text{ K}$ and $\log g = 4.5$, as a function of the Rosseland optical depth.

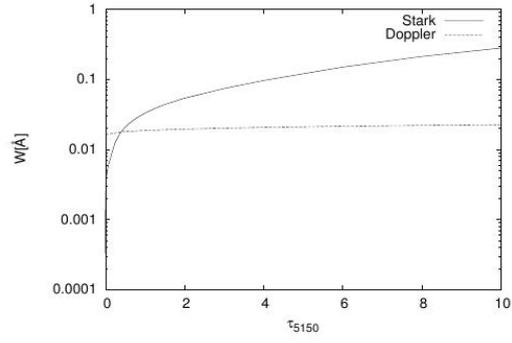


Figure 2: Thermal Doppler and Stark widths for Nb III spectral lines $4d^2 (^3F) 5s ^4F_{7/2} - 4d^2 (^3F) 5p ^4F_{7/2}^o$ ($\lambda=2415.2 \text{ \AA}$) for a DB white dwarf atmosphere model with $T_{eff} = 15,000 \text{ K}$ and $\log g = 8$, as a function of optical depth τ_{5150} .

**Tabela I, (Gayazov et al. 1998), prelazi su
odredjeni za
en. nivoa ciji je doprinos u termu 80% i vise,
pomocu PDP.**

td(A)i

5p (3F) 4G5/2 - 5d (3F) 4F3/2 priprema01

5p (3F) 4G5/2 - 5d (3F) 4F5/2 priprema02

5p (3F) 4G5/2 - 5d (3F) 4F7/2

f	i		
5p (3F) 4G5/2 - 5d (3F) 4F3/2		WL1838.0	PD1.0E+17
83% 63686.35	89% 118092.75		

5p (3F) 4G5/2 - 5d (3F) 4F5/2		WL1824.8	PD1.0E+17
83% 63686.35	85% 118487.90		

	1838.0	1824.8
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10000.	0.5990D-01	0.5922D-01
20000.	0.4236D-01	0.4187D-01
50000.	0.2679D-01	0.2648D-01
100000.	0.1933D-01	0.1913D-01
200000.	0.1746D-01	0.1729D-01
300000.	0.1756D-01	0.1741D-01



Thank you for attention!