Triply ionized Molybdenum lines in the spectra of the DA-type and the DO-type white dwarfs

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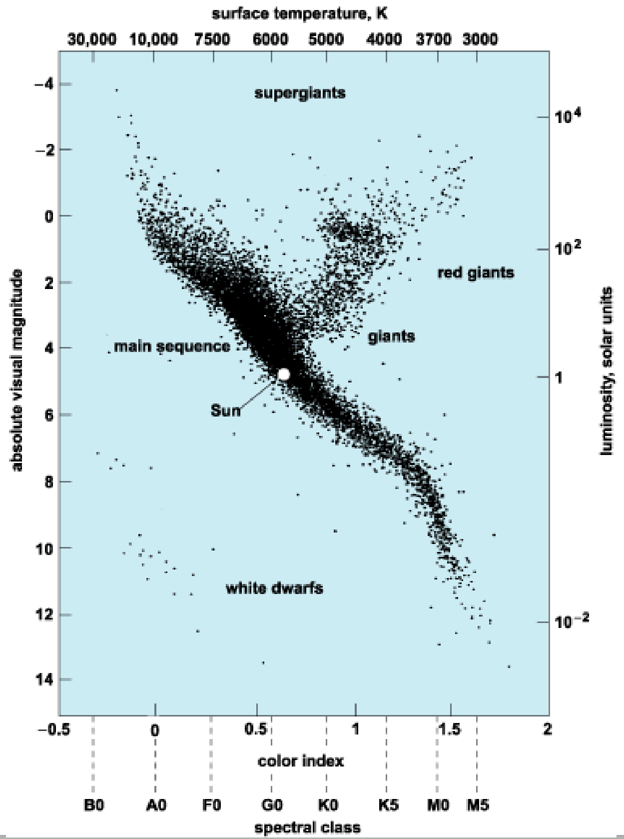
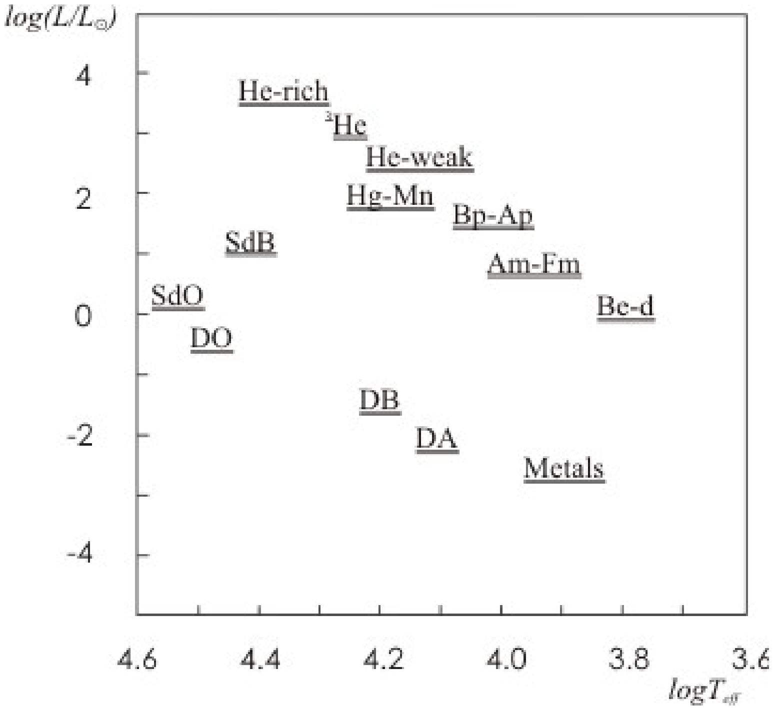
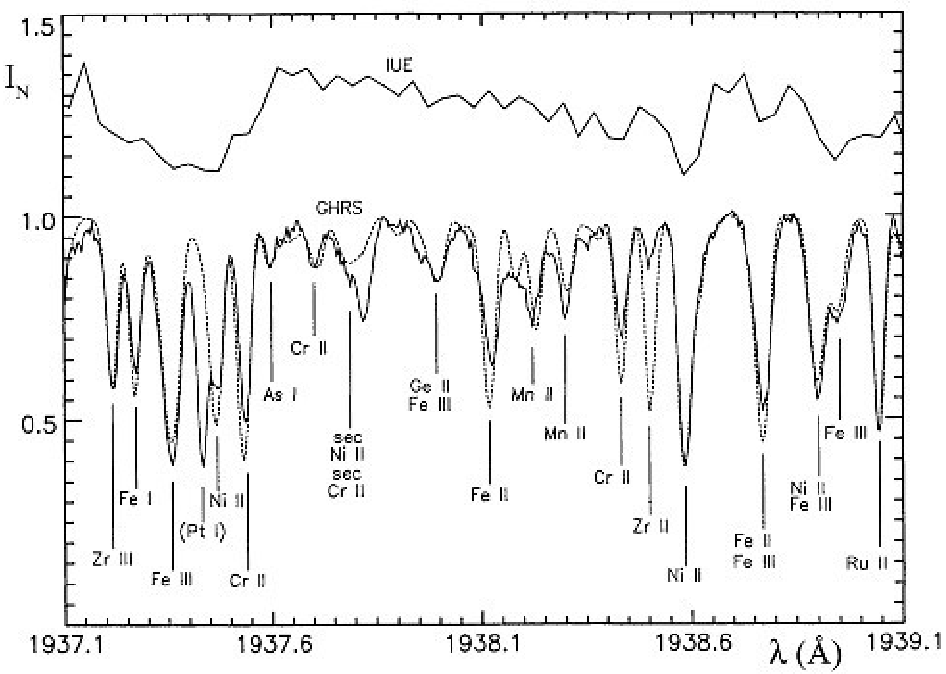
Chemically Peculiar Stars and White Dwarfs





Ultravioletni spektar zvezde χ Lupi dobijen sa GHRS i sa IUE satelitom (Leckrone at al, 1993), gde je rezolucija spektra dobijenog pomoću GHRS jednaka 0.0023nm, maksimalni odnos signal šum je 95 (Brandt et al, 1999); puna linija, posmatrani GHRS spektar; isprekidana linija, sintetizovani spektar



Theoretical Method – MSE Dimitrijević&Konjević, 1980

The simplified modified semiempirical method [12], formulated for Stark broadening of isolated spectral lines of singly and multiply charged ions in plasma is convenient for Rh II lines. According to [12], full width at half intensity maximum is:

$$w_{smse} = const\frac{\lambda^2 N}{\sqrt{T}}(0.9 - \frac{1.1}{Z})\sum_{k=i,f}\left(\frac{3n^*_{l_k}}{2Z}\right)^2 ({n^*_{l_k}}^2 - {l_k}^2 - l_k - 1) \qquad (2.1)$$

where λ is wavelength in $[m]$, N perturber density in $[m^{-3}]$, T temperature in $[K]$ and $const = 2.21577\times10^{-20}m^2K^{1/2}$ give us full width at half intensity of maximum w_{smse} in $[m]$. Here, $k = i, f$ and i is for initial atomic energy level of the considered spectral line and f for final. Here, with Z denoted residual charges if ion. For neutral $Z = 1$, and for singly ionized $Z = 2$, for doubly ionized $Z = 3$ etc. Effective principal quantum number denoted with $n^*_{l_k}$, where l_k ($k = i, f$) represent orbital angular momentum quantum number.

In the case of the Stark shift for ions, there are two different formula. If we neglect transitions with $\Delta n = 0$, where n denotes main principal number by summing all allowed transitions we get the following shift formula:

$$d_{smse}^{(1)}(\mathring{A}) \approx 1.1076 \times 10^{-8} \frac{\lambda^2(cm) N(cm^{-3})}{\sqrt{T(K)}} (0.9 - \frac{1.1}{Z}) \frac{9}{4Z^2} S1 \quad (2.2)$$

where is

$$S1 = \sum_{k=i,f} \frac{n_{l_k}^{*\ 2} \epsilon_k}{2l_k + 1} (n_{l_k}^{*\ 2} - 3l_k^{\ 2} - l_k - 1) \quad (2.3)$$

if exist all levels we can find shift by next formula:

$$d_{smse}^{(2)}(\mathring{A}) \approx 1.1076 \times 10^{-8} \frac{\lambda^2(cm) N(cm^{-3})}{\sqrt{T(K)}} (0.9 - \frac{1.1}{Z}) \frac{9}{4Z^2} S2 \quad (2.4)$$

where is

$$S2 = \sum_{k=i,f} \frac{n_{l_k}^{*\ 2} \epsilon_k}{2l_k + 1} [(l_k + 1)[n_{l_k}^{*\ 2} - (l_k + 1)^2] - l_k(n_{l_k}^{*\ 2} - l_k^2)] \quad (2.5)$$

recent considered metals and transitions

The shape of the spectral line is conditioned by natural broadening, Doppler and collision broadening.

301 Ir II ------ 31 Rh II ------ 11 Re II

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Singly Ionized Iridium Spectral Lines in the Atmosphere of Hot Stars

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The electron-impact broadening parameters of ion lines are of interest for a number of problems in astrophysical, laboratory, and technological plasma investigations. Singly ionized Iridium lines are confirmed their presence in stellar spectra of the chemically peculiar stars. Our calculations are performed using the modified semiempirical method of Dimitrijević and Konjević. Stark widths for 301 Ir II spectral lines are presented. From the calculated list of lines, the 21 strongest lines from the iridium spectrum are selected with high value of intensity ≥ 3000 to demonstrate importance of the Stark broadening mechanism for different types of stars. The analysis of the electron-impact effect on spectral line shapes are performed and obtained Stark and Doppler withds are compared.

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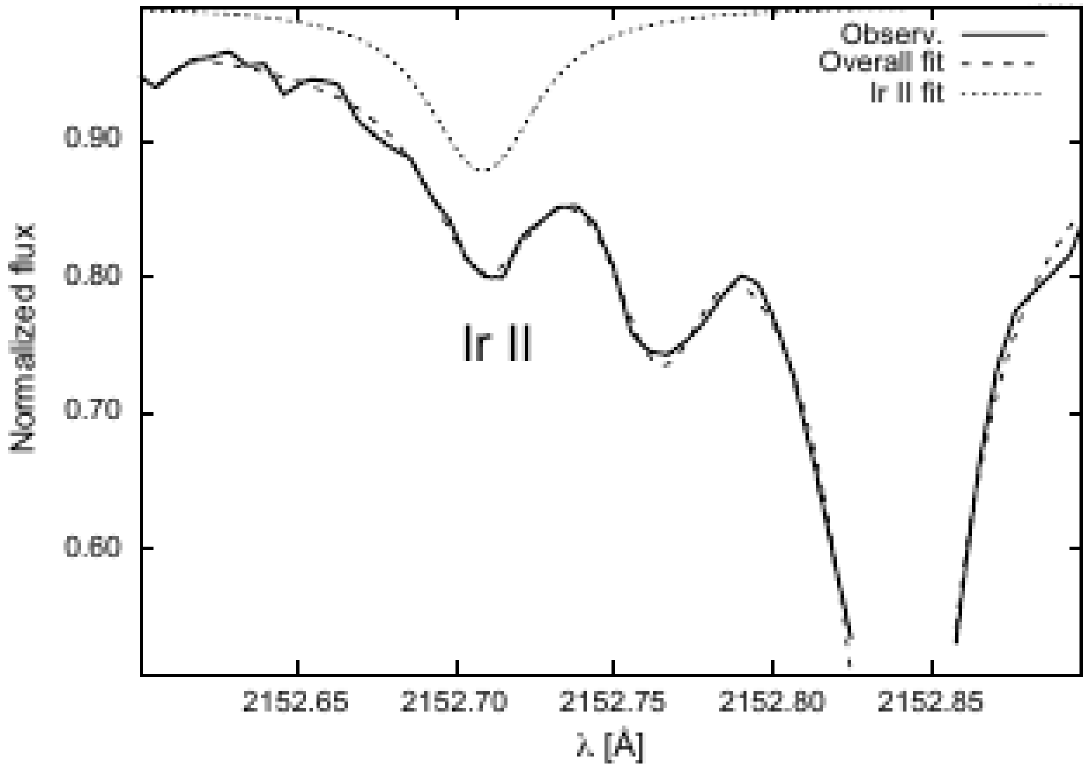
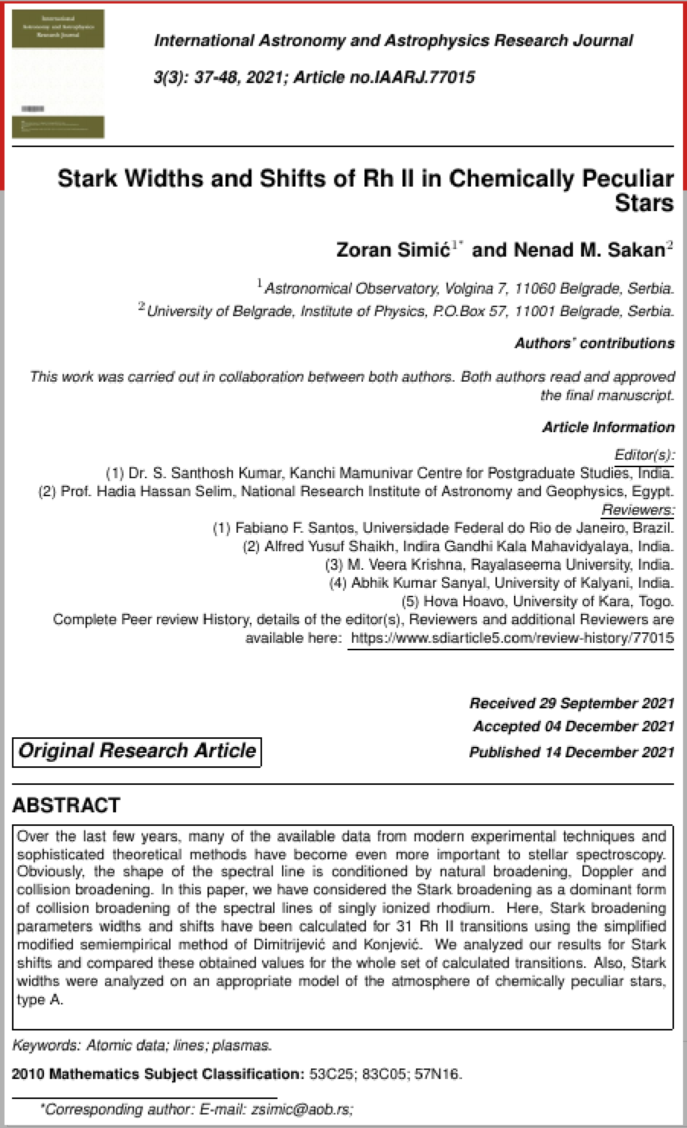
Iridium II

301 sp. Lines
Perturber density $10^{17} cm^{-3}$
Temperatura eff 10000K

21 strongest lines, intensity ≥ 3000
SYNTH and ATLAS9 code
to demonstrate importance of the Stark broadening mechanism for different types of stars

Fig. 5. From the observed spectrum of χ Lupi presented in [9], the fitting procedure is used to extracted the Ir II 2152.7 Å line parameters assuming the Voigt line profile. The solid line presents experimental observation spectra, while the long dashed line is the overall fit, and short dash line is the sought line fit.





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Stark Widths and Shifts of Rh II in Chemically Peculiar Stars

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Over the last few years, many of the available data from modern experimental techniques and sophisticated theoretical methods have become even more important to stellar spectroscopy. Obviously, the shape of the spectral line is conditioned by natural broadening, Doppler and collision broadening. In this paper, we have considered the Stark broadening as a dominant form of collision broadening of the spectral lines of singly ionized rhodium. Here, Stark broadening parameters widths and shifts have been calculated for 31 Rh II transitions using the simplified modified semiempirical method of Dimitrijević and Konjević. We analyzed our results for Stark shifts and compared these obtained values for the whole set of calculated transitions. Also, Stark widths were analyzed on an appropriate model of the atmosphere of chemically peculiar stars, type A.

Keywords: Atomic data; lines; plasmas.

2010 Mathematics Subject Classification: 53C25; 83C05; 57N16.

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Rhodium II

31 Rh II lines, widths and shifts
Pertuber density 10^{23} m^{-3}
Temperature range 10000-300000 K

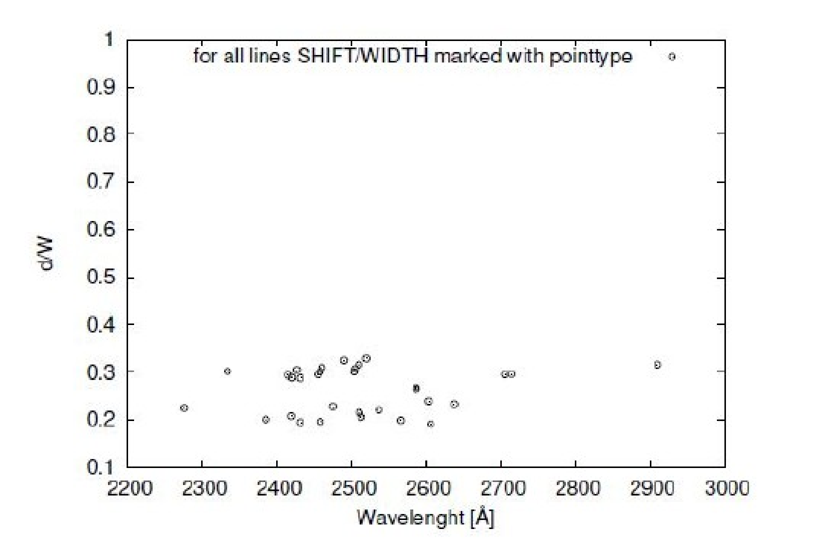
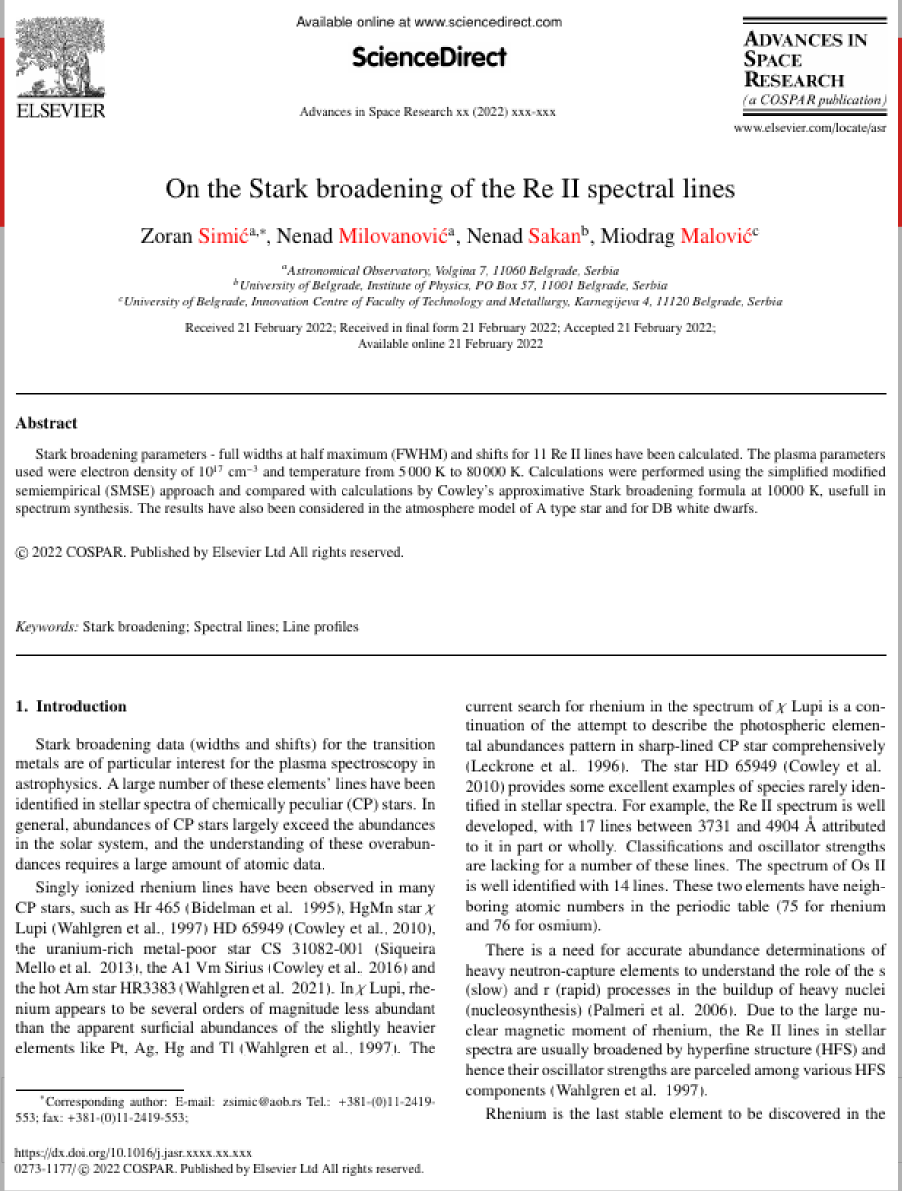


Table 1. This table presents Rh II electron-impact broadening parameters: Stark width-W and shifts-d, both in [Å] and angular units [s^{-1}] for 31 transitions, obtained by the simplified modified semiempirical method [13] for a perturber density of 10^{23} m^{-3} and temperature range from 10000 up to 300000 K

Transition λ[Å]	T[K]	W[Å]	d[Å]	W[s^{-1}]	d[s^{-1}]
5s b^3F_3 - 5p $y^5D^o_3$	10000	0.6131D-01	-0.1380D-01	0.2229D+12	-0.5018D+11
2276.2	20000	0.4335D-01	-0.9760D-02	0.1576D+12	-0.3548D+11
	50000	0.2742D-01	-0.6173D-02	0.9968D+11	-0.2244D+11
	100000	0.1939D-01	-0.4365D-02	0.7048D+11	-0.1587D+11
	200000	0.1371D-01	-0.3086D-02	0.4984D+11	-0.1122D+11
	300000	0.1119D-01	-0.2520D-02	0.4069D+11	-0.9162D+10
5s a^5F_5 - 5p $z^5G^o_6$	10000	0.4491D-01	-0.1358D-01	0.1552D+12	-0.4692D+11
2334.8	20000	0.3176D-01	-0.9602D-02	0.1097D+12	-0.3318D+11
	50000	0.2009D-01	-0.6073D-02	0.6940D+11	-0.2098D+11
	100000	0.1420D-01	-0.4294D-02	0.4908D+11	-0.1484D+11
	200000	0.1004D-01	-0.3036D-02	0.3470D+11	-0.1049D+11
	300000	0.8200D-02	-0.2479D-02	0.2833D+11	-0.8567D+10
5s b^3P_2 - 5p $w^3D^o_1$	10000	0.8034D-01	-0.1616D-01	0.2658D+12	-0.5347D+11
2386.0	20000	0.5681D-01	-0.1143D-01	0.1880D+12	-0.3781D+11
	50000	0.3593D-01	-0.7227D-02	0.1189D+12	-0.2391D+11
	100000	0.2541D-01	-0.5111D-02	0.8406D+11	-0.1691D+11
	200000	0.1797D-01	-0.3614D-02	0.5944D+11	-0.1196D+11
	300000	0.1467D-01	-0.2951D-02	0.4853D+11	-0.9763D+10
5s a^5F_3 - 5p $z^5G^o_4$	10000	0.5091D-01	-0.1500D-01	0.1643D+12	-0.4842D+11
2415.9	20000	0.3600D-01	-0.1061D-01	0.1162D+12	-0.3424D+11
	50000	0.2277D-01	-0.6710D-02	0.7348D+11	-0.2166D+11
	100000	0.1610D-01	-0.4745D-02	0.5196D+11	-0.1531D+11
	200000	0.1138D-01	-0.3355D-02	0.3674D+11	-0.1083D+11
	300000	0.9294D-02	-0.2739D-02	0.3000D+11	-0.8841D+10
5s a^3G_3 - 5p $y^3F^o_2$	10000	0.8027D-01	-0.1671D-01	0.2582D+12	-0.5374D+11
2420.2	20000	0.5676D-01	-0.1182D-01	0.1825D+12	-0.3800D+11
	50000	0.3590D-01	-0.7474D-02	0.1154D+12	-0.2404D+11
	100000	0.2538D-01	-0.5285D-02	0.8163D+11	-0.1700D+11
	200000	0.1795D-01	-0.3737D-02	0.5772D+11	-0.1202D+11
	300000	0.1466D-01	-0.3051D-02	0.4713D+11	-0.9812D+10
5s a^5F_2 - 5p $z^5G^o_3$	10000	0.5239D-01	-0.1518D-01	0.1684D+12	-0.4879D+11
2421.0	20000	0.3704D-01	-0.1073D-01	0.1190D+12	-0.3450D+11
	50000	0.2343D-01	-0.6789D-02	0.7529D+11	-0.2182D+11
	100000	0.1657D-01	-0.4801D-02	0.5324D+11	-0.1543D+11
	200000	0.1171D-01	-0.3395D-02	0.3765D+11	-0.1091D+11
	300000	0.9565D-02	-0.2772D-02	0.3074D+11	-0.8907D+10
5s a^5F_4 - 5p $z^5G^o_5$	10000	0.4923D-01	-0.1501D-01	0.1574D+12	-0.4798D+11
2427.1	20000	0.3481D-01	-0.1061D-01	0.1113D+12	-0.3393D+11
	50000	0.2202D-01	-0.6710D-02	0.7040D+11	-0.2146D+11
	100000	0.1557D-01	-0.4745D-02	0.4978D+11	-0.1517D+11
	200000	0.1101D-01	-0.3355D-02	0.3520D+11	-0.1073D+11
	300000	0.8988D-02	-0.2740D-02	0.2874D+11	-0.8760D+10

$$W(\mathring{A}) = \frac{\lambda^2}{2\pi c} W(s^{-1})$$

Rhenium II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On the Stark broadening of the Re II spectral lines

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Abstract

Stark broadening parameters - full widths at half maximum (FWHM) and shifts for 11 Re II lines have been calculated. The plasma parameters used were electron density of 10^{17} cm^{-3} and temperature from 5 000 K to 80 000 K. Calculations were performed using the simplified modified semiempirical (SMSE) approach and compared with calculations by Cowley's approximative Stark broadening formula at 10000 K, usefull in spectrum synthesis. The results have also been considered in the atmosphere model of A type star and for DB white dwarfs.

Keywords: Stark broadening; Spectral lines; Line profiles

1. Introduction

Stark broadening data (widths and shifts) for the transition metals are of particular interest for the plasma spectroscopy in astrophysics. A large number of these elements' lines have been identified in stellar spectra of chemically peculiar (CP) stars. In general, abundances of CP stars largely exceed the abundances in the solar system, and the understanding of these overabundances requires a large amount of atomic data.

Singly ionized rhenium lines have been observed in many CP stars, such as Hr 465 (Bidelman et al. 1995), HgMn star χ Lupi (Wahlgren et al., 1997) HD 65949 (Cowley et al., 2010), the uranium-rich metal-poor star CS 31082-001 (Siqueira Mello et al. 2013), the A1 Vm Sirius (Cowley et al. 2016) and the hot Am star HR3383 (Wahlgren et al. 2021). In χ Lupi, rhenium appears to be several orders of magnitude less abundant than the apparent surficial abundances of the slightly heavier elements like Pt, Ag, Hg and Tl (Wahlgren et al., 1997). The current search for rhenium in the spectrum of χ Lupi is a continuation of the attempt to describe the photospheric elemental abundances pattern in sharp-lined CP star comprehensively (Leckrone et al. 1996). The star HD 65949 (Cowley et al. 2010) provides some excellent examples of species rarely identified in stellar spectra. For example, the Re II spectrum is well developed, with 17 lines between 3731 and 4904 Å attributed to it in part or wholly. Classifications and oscillator strengths are lacking for a number of these lines. The spectrum of Os II is well identified with 14 lines. These two elements have neighboring atomic numbers in the periodic table (75 for rhenium and 76 for osmium).

There is a need for accurate abundance determinations of heavy neutron-capture elements to understand the role of the s (slow) and r (rapid) processes in the buildup of heavy nuclei (nucleosynthesis) (Palmeri et al. 2006). Due to the large nuclear magnetic moment of rhenium, the Re II lines in stellar spectra are usually broadened by hyperfine structure (HFS) and hence their oscillator strengths are parceled among various HFS components (Wahlgren et al. 1997).

Rhenium is the last stable element to be discovered in the

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0273-1177/

11 Re II sp. Lines
10^{17} cm^{-3}
(5000, 80000)K

Re II in A type stars and DB white dwarfs

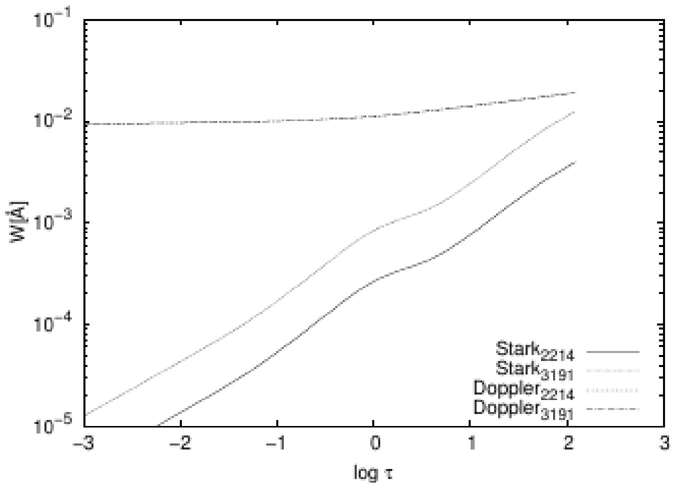


Fig. 2. Thermal Doppler and Stark widths for Re II spectral lines 6s a^7S_3 - 6p $z^7P^o_3$ (2214.9 Å) and 6s a^5P_1 - 6p $y^5P^o_2$ (3191.1 Å) in A type stars, using an atmosphere model with T_{eff} = 10 000 K and log g = 4.5 (Kuruczs, 1979) as a function of Rosseland optical depth.

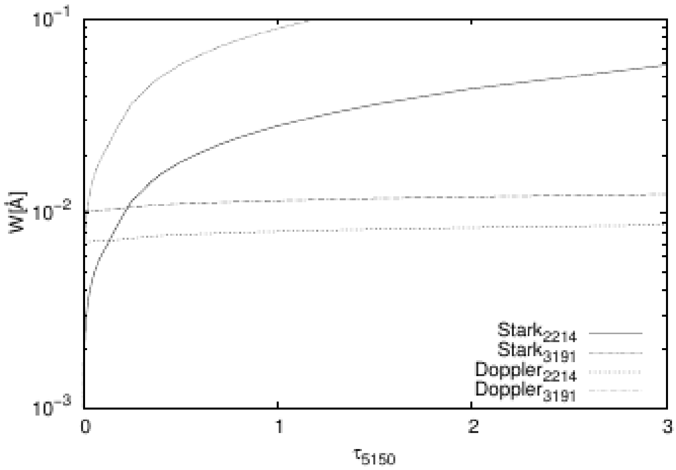


Fig. 3. Thermal Doppler and Stark widths for Re II spectral lines 6s a^7S_3 - 6p $z^7P^o_3$ (2214.9 Å) and 6s a^5P_1 - 6p $y^5P^o_2$ (3191.1 Å) in DB white dwarfs atmosphere model with T_{eff} = 15 000 K and log g = 8 (Kuruczs 1979) as a function of optical depth.

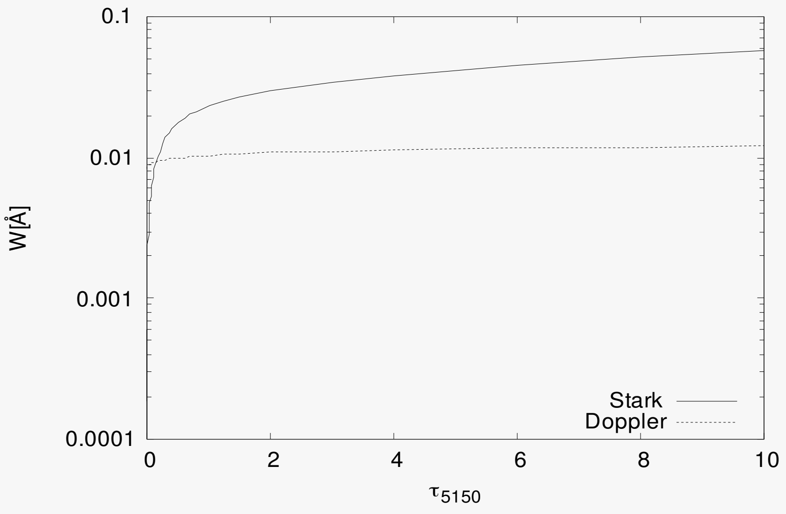
Transitions of interest for MoIV - analysis

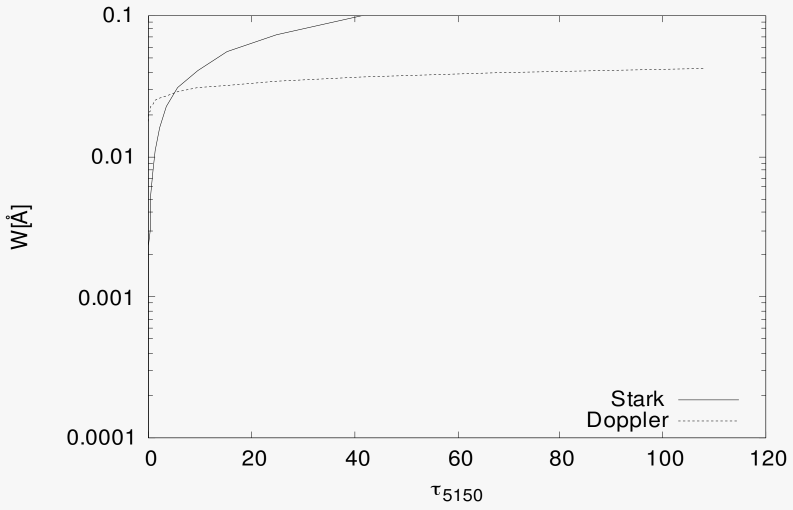
	4Do	8lines	
4d2 (3F) 5s 4F - 5p	4Fo	10lines	total 25 (18 of interest)
	4Go	7lines	distances in term are big

	2Do	3	
4d2 (3F) 5s 2F - 5p	2Fo	4,	total 9
	2Go	2	

Number of transitions 27

Mo IV line 1886 in two models DA & DO type of white dwarfs





DA type of WD

λ= 1886 Å

Teff=15000K, log g=8

DO type of WD

λ= 1886 Å

Teff=80000K, log g=6

Thank you!