

Impact broadening parameters for some transitions for heavy elements in CP stars

Zoran Simić

Astronomical Observatory, Volgina 7, 11060 Belgrade, Serbia

&

Nenad Sakan

University of Belgrade, Institute of Physics, P.O.Box 57, 11001 Belgrade, Serbia

recent considered metals and transitions

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

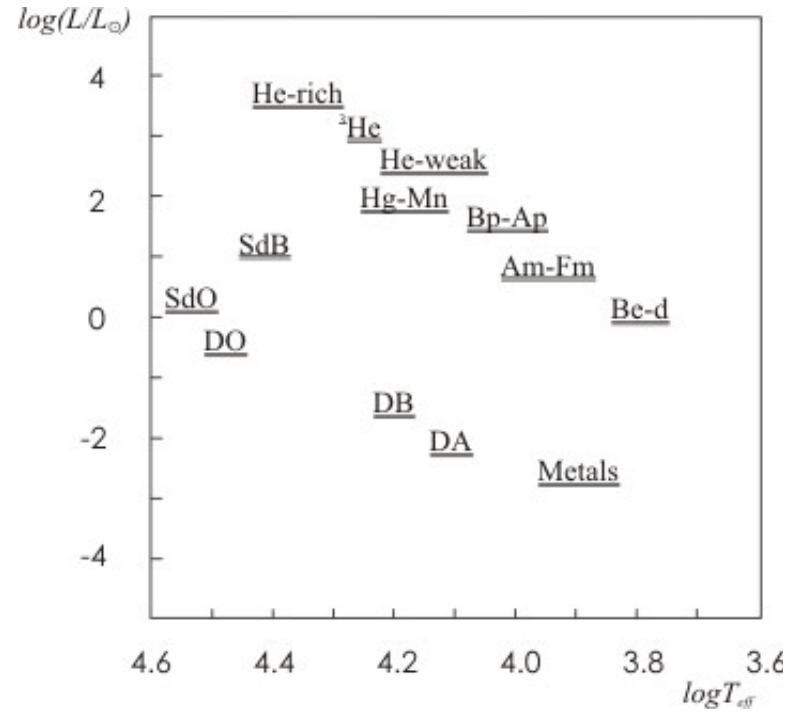
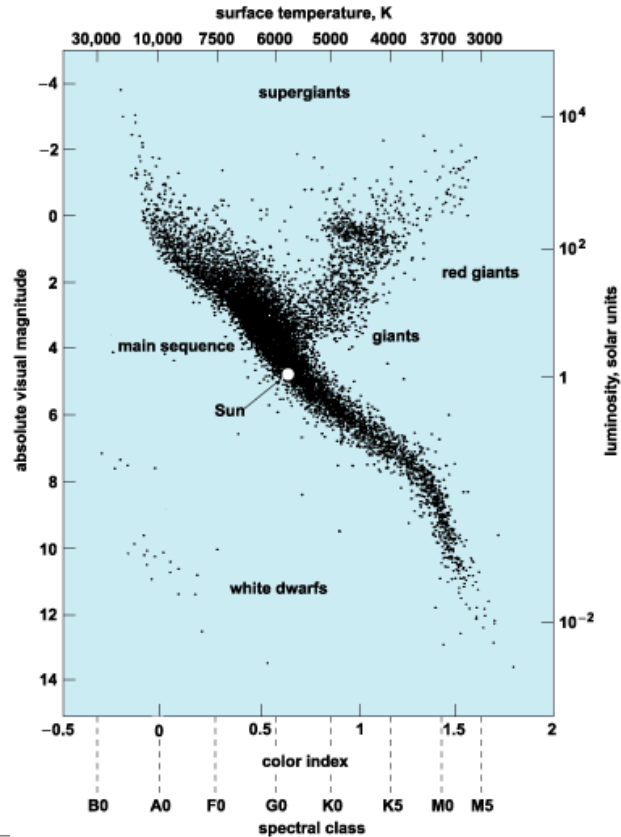
301 Ir II (172)

31 Rh II

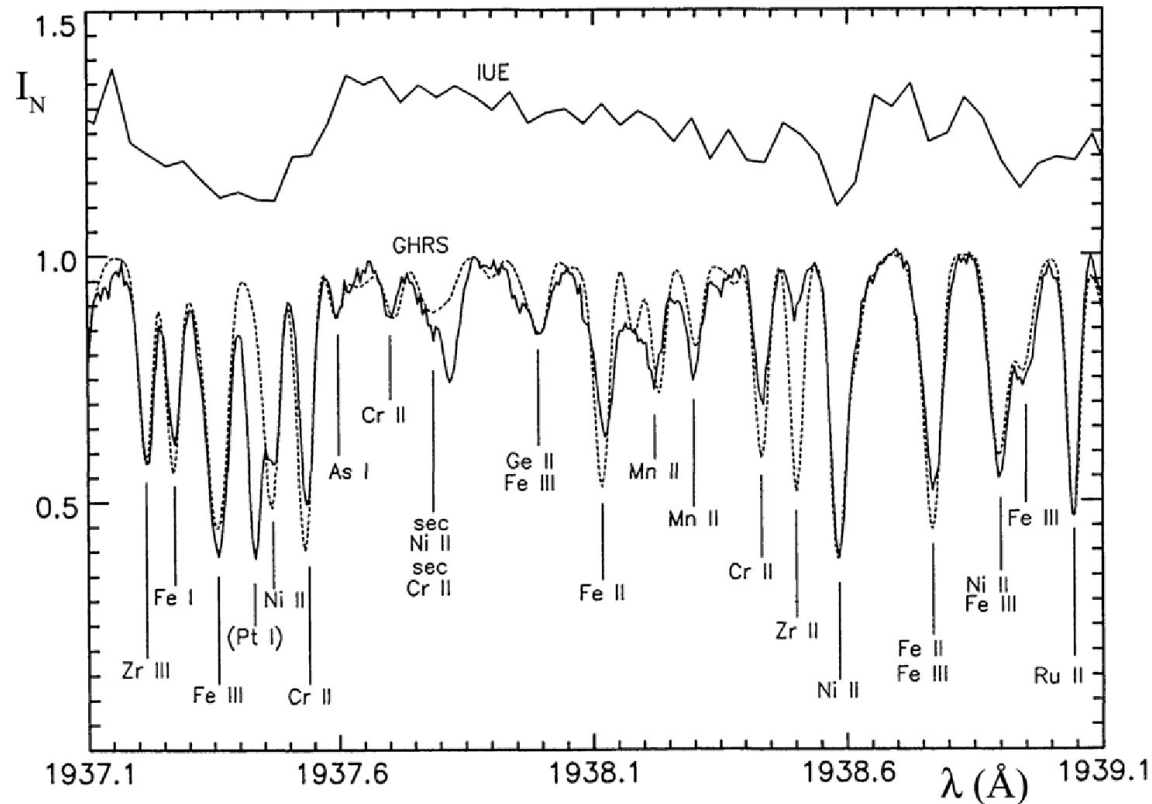
11 Re II

50 Ir II *additional data

Chemically Peculiar Stars and White Dwarfs



Ultravioletni spekter zvezde χ Lupi dobijen sa GHRs i sa IUE
satelitom (Leckrone et 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 spekter; isprekidana linija, sintetizovani spekter



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:

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

where λ is wavelength in [m], N perturber density in [m^{-3}], T temperature in [K] and $const = 2.21577 \times 10^{-20} m^2 K^{1/2}$ 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:

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

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:

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

where is

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

Singly Ionized Iridium Spectral Lines in the Atmosphere of Hot Stars

Zoran Simić^{1*}, Nenad M. Sakan², Nenad Milovanović¹
and Mihailo Martinović^{3,4}

¹Astronomical Observatory, Volgina 7, 11060 Belgrade, Serbia.

²University of Belgrade, Institute of Physics, P.O.Box 57, 11001 Belgrade, Serbia.

³Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA.

⁴LESIA, Observatoire de Paris, Meudon, France.

Authors' contributions

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

Article Information

Editor(s):

(1) Prof. Magdy Rabie Soliman Sanad, National Research Institute of Astronomy and Geophysics, Egypt.

(2) Prof. Hadia Hassan Selim, National Research Institute of Astronomy and Geophysics, Egypt.

Reviewers:

(1) Feyisso Sado Bedecha, Addis Ababa University, Jigjiga University, Ethiopia.

(2) Rahul Singh, India.

(3) Ricardo Gobato, Secretariat of State of Parana Education and Sport (SEED/PR), Laboratory of Biophysics and Molecular Modeling Genesis, Brazil.

(4) Gemechu Muleta Kumssa, Ethiopian Space Science and Technology Institute (ESSTI), Ethiopia.

(5) Dmitry Tsipenyuk, Moscow Polytechnic University, Russia.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/70329>

Received 09 May 2021

Accepted 14 July 2021

Published 19 July 2021

Original Research Article

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 widths are compared.

*Corresponding author: E-mail: zsimic@aob.rs;

Iridium II

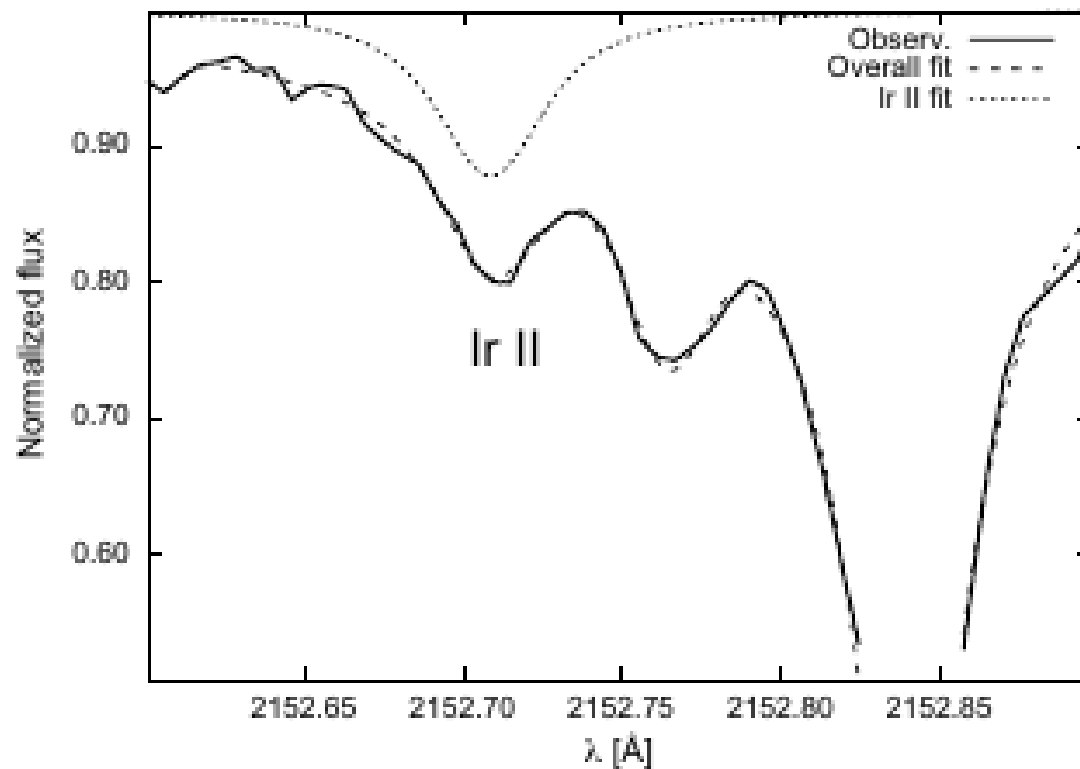
301 sp. Lines

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 extract 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.



Stark Widths and Shifts of Rh II in Chemically Peculiar Stars

Zoran Simić^{1*} and Nenad M. Sakan²

¹Astronomical Observatory, Volgina 7, 11060 Belgrade, Serbia.

²University of Belgrade, Institute of Physics, P.O.Box 57, 11001 Belgrade, Serbia.

Authors' contributions

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

Article Information

Editor(s):

- (1) Dr. S. Santhosh Kumar, Kanchi Mamunivar Centre for Postgraduate Studies, India.
- (2) Prof. Hadia Hassan Selim, National Research Institute of Astronomy and Geophysics, Egypt.

Reviewers:

- (1) Fabiano F. Santos, Universidade Federal do Rio de Janeiro, Brazil.
- (2) Alfred Yusuf Shaikh, Indira Gandhi Kala Mahavidyalaya, India.
- (3) M. Veera Krishna, Rayalaseema University, India.
- (4) Abhik Kumar Sanyal, University of Kalyani, India.
- (5) Hova Hoavo, University of Kara, Togo.

Complete Peer review History, details of the editor(s), Reviewers and additional Reviewers are available here: <https://www.sdiarticle5.com/review-history/77015>

Received 29 September 2021

Accepted 04 December 2021

Published 14 December 2021

Original Research Article

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.

*Corresponding author: E-mail: zsimic@aob.rs;

Rhodium II

31 Rh II lines, widths and shifts

Perturber density 10^{23} m^{-3}

Temperature range 10000-300000 K

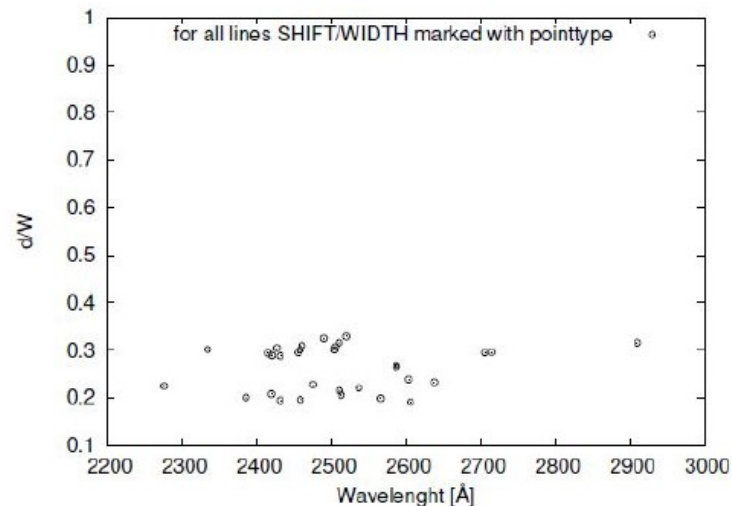


Table 1. This table presents Rh II electron-impact broadening parameters: Stark width-W and shifts-d, both in [Å] and angular units [s⁻¹] for 31 transitions, obtained by the simplified modified semiempirical method [13] for a perturber density of 10²³ m⁻³ and temperature range from 10000 up to 300000 K

Transition λ[Å]	T[K]	W[Å]	d[Å]	W[s ⁻¹]	d[s ⁻¹]
5s b ³ F ₃ - 5p y ⁵ D ₃ ^o 2276.2	10000	0.6131D-01	-0.1380D-01	0.2229D+12	-0.5018D+11
	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 ⁵ F ₅ - 5p z ⁵ G ₅ ^o 2334.8	10000	0.4491D-01	-0.1358D-01	0.1552D+12	-0.4692D+11
	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 ³ P ₂ - 5p w ³ D ₁ ^o 2386.0	10000	0.8034D-01	-0.1616D-01	0.2658D+12	-0.5347D+11
	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 ⁵ F ₃ - 5p z ⁵ G ₃ ^o 2415.9	10000	0.5091D-01	-0.1500D-01	0.1643D+12	-0.4842D+11
	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 ³ G ₃ - 5p y ³ F ₂ ^o 2420.2	10000	0.8027D-01	-0.1671D-01	0.2582D+12	-0.5374D+11
	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 ⁵ F ₂ - 5p z ⁵ G ₂ ^o 2421.0	10000	0.5239D-01	-0.1518D-01	0.1684D+12	-0.4879D+11
	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 ⁵ F ₄ - 5p z ⁵ G ₄ ^o 2427.1	10000	0.4923D-01	-0.1501D-01	0.1574D+12	-0.4798D+11
	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

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

On the Stark broadening of the Re II spectral lines

Zoran Simić^{a,*}, Nenad Milovanović^a, Nenad Sakan^b, Miodrag Malović^c

^aAstronomical Observatory, Volgina 7, 11060 Belgrade, Serbia

^bUniversity of Belgrade, Institute of Physics, PO Box 57, 11001 Belgrade, Serbia

^cUniversity of Belgrade, Innovation Centre of Faculty of Technology and Metallurgy, Karnegijeva 4, 11120 Belgrade, Serbia

Received 21 February 2022; Received in final form 21 February 2022; Accepted 21 February 2022;

Available online 21 February 2022

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 5000 K to 80000 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, useful in spectrum synthesis. The results have also been considered in the atmosphere model of A type star and for DB white dwarfs.

© 2022 COSPAR. Published by Elsevier Ltd All rights reserved.

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

Rhenium II

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

*Corresponding author. E-mail: zsimic@aob.rs Tel.: +381-(0)11-2419-553; fax: +381-(0)11-2419-553;

Re II in A type stars and DB white dwarfs

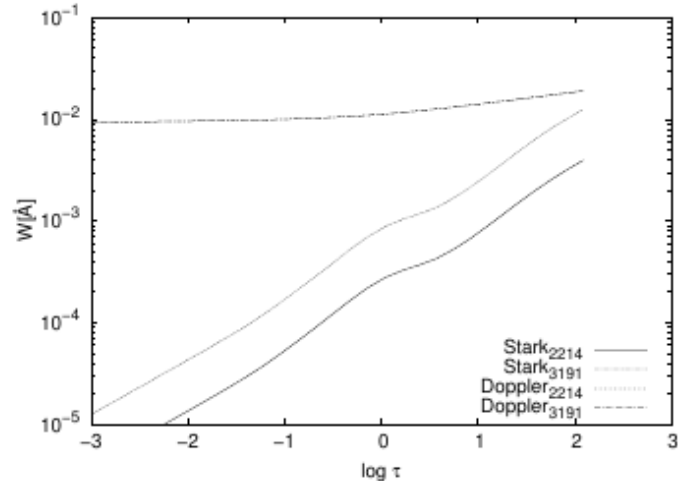


Fig. 2. Thermal Doppler and Stark widths for Re II spectral lines $6s\ a^7S_3 - 6p\ z^7P_3^o$ (2214.9 Å) and $6s\ a^5P_1 - 6p\ y^5P_2^o$ (3191.1 Å) in A type stars, using an atmosphere model with $T_{eff} = 10000\ K$ and $\log g = 4.5$ (Kurucz, 1979) as a function of Rosseland optical depth.

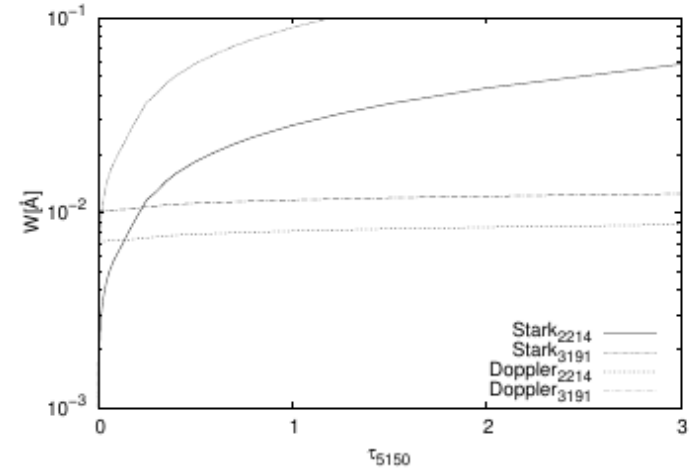


Fig. 3. Thermal Doppler and Stark widths for Re II spectral lines $6s\ a^7S_3 - 6p\ z^7P_3^o$ (2214.9 Å) and $6s\ a^5P_1 - 6p\ y^5P_2^o$ (3191.1 Å) in DB white dwarfs atmosphere model with $T_{eff} = 15000\ K$ and $\log g = 8$ (Kurucz 1979) as a function of optical depth.

On the Stark broadening parameters of Ir II spectral lines

Z. Simić¹ and N. Sakan²

¹ *Astronomical Observatory, Volgina 7, 11060 Belgrade, Serbia,
(E-mail: zsimic@aob.rs)*

² *University of Belgrade, Institute of Physics, PO Box 57,
11001 Belgrade, Serbia*

Received: July 1, 2022; Accepted: September 12, 2022

Abstract. The presence of singly ionized Iridium lines in spectra of chemically peculiar stars (CP stars) is experimentally confirmed recently. Stark widths for additional 50 Ir II spectral lines are calculated using the modified semi-empirical method of Dimitrijević and Konjević. The calculations of Stark widths (FWHM) for electron-impact broadening, have been performed for a perturber density of 10^{17} cm^{-3} and for a temperature value of 10000K. In order to have a easier to monitor and observe atomic data for spectroscopy the transitions in our table follows the list of spectral lines from the NIST database.

Within the frame of the presented work a additional data for 50 more Ir II spectral lines are added to the previously calculated data of 301 lines presented earlier (Simić et al. 2021.). The enhanced dataset is applicable to the describing of CP stars spectra and is step forward towards the completing of dataset for known CP stars atmosphere composition.

Key words: Atomic data – Spectral lines – CP stars

1. Introduction

In chemically peculiar (CP) stars, there is a great need for data on the precise abundance of heavy elements since this is a key parameter for the visibility of spectral lines. In our previous study of Stark widths of single ionized iridium in the atmospheres of CP stars, Simić et al. (2021), we included a total of 301 spectral lines from the spectrum of this element. Here, in this paper, we continue the started research and expand the previous data set by 50 new values for the widths for single ionized iridium.

Our knowledge of the atomic structure and spectrum of Ir II is still insufficient but is in ongoing development. It depends on laboratory measurements and theoretical approximations to the real picture of the atomic structure of iridium and its ionized states. It is well known that accurate stellar abundances depend heavily upon radiative parameters and hyperfine structure data Xu et al. (2007).

Iridium II additional data

Thank you!