Stark Widths and Shifts of Rh II in Chemically Peculiar Stars

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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.

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1 INTRODUCTION

Rhodium is one of the of the six platinum group metals: platinum, palladium, rhodium, osmium, iridium and ruthenium. It is also classified as a noble metal, meaning that it does not react to oxygen easily, acts as a fantastic catalyst and is resistant to corrosion and oxidation. Stark broadening parameters, line width and shift, especially are needed in astrophysics, due to constantly increasing resolution of satellite borne spectrographs, and large telescopes. This data on trace elements, which were previously insignificant, now have increasing importance.

In [1] it is reported a few strong Rh I an Pd I in spectra of γ Equ as one of the example of cool Ap star belonging to chemically peculiar (CP) stars. Some atomic species have stronger lines in the ultraviolet than in the photographic region, which is why they can only be seen in the UV region, for example Co II. This star is also known as sharpest-lined Ap star [2]. A line identification study of $\lambda\lambda$ 3086-3807 confirms the previously stated, see [3]

Neutral rhodium Rh I is better known in the literature than its higher ionization states. Today, both singly and doubly ionized rhodium were detected in stellar spectra. Several singly ionized rhodium Rh II, have been identified in different astrophysical spectra such as the Solar spectrum [4] and the spectra of the HgMn type star χ Lupi [5], the super-rich mercury star HD65949 [6], the HgMn HD175640 [7] and the peculiar Przybilski's star HD101065 [8]. Some of these stars show the presence of singly ionized rhodium because its spectral lines at different wavelengths observed λ = 3093.5, 3162.2, 3187.9, 3207.3, 3307.4 and 3477.8, these 6 lines were identified as radiative transitions [9].

Authors from [9] reported oscillatory strengths for transitions of astrophysical interest to singly ionized rhodium. Seventeen radiative lifetimes of singly ionized rhodium have been measured with time-resolved laser-induced fluoroscence techique and combine with theoretical branching fractions calculated using a relativistic Hartee-Fock model including core-polarization. As a final result, a set of 113 Rh II transitions in the spectral range 1530-4180 is published in [9].

New experimentally determined branching fractions and oscillator strengths (log gf) for lines originating from 17 levels belonging to 5 terms of the first excited odd configuration $4d^7(^4D)5p$ in Rh II are given in [10]. Spectra of singly ionized rhodium Rh II have been recorded with a Fourier transform spectrometer between (2200-4000 Å) in energy range 25000 and 45000 cm^{-1}. In this region, 49 lines have been identified and measured. By combining the branching fractions obtained from the spectra with previously measured lifetimes, log gf values are reported in [10]).

Rhodium atoms have 45 electrons and the shell structure is 2, 8, 18, 16, 1. The ground state electronic configuration of neutral Rhodium atom is [Kr] $4d^8 5s^1$ and the term symbol is $^4F_{9/2}$, which follows noble gas [Kr]. It has one stable isotope and 19 short-lived isotopes and isomers [9]. Rhodium is a very important element for stellar nucleosynthesis obtained from the r- and s-processes. One example in ultra metal-poor star CS 22892-052, indicated two different r-processes, where are the new observed data of the lighter n-capture elements in the $40<Z<56$ domain (Nb, Ru, Rh, Pd, Ag and Cd). This stellar r-process patterns are similar to the solar system r-process abundance distribution [11].

For our calculations of Stark broadening parameters we used simplified modified semiempirical method [12] based on [13] since a set of atomic data, needed for more accurate semiclassical perturbation calculations [14, 15] does not exist. There is no other experimental and theoretical data for Stark widths and shifts except our set of calculated values.

2 THEORETICAL METHOD

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:

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

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:

$$d^{(1)}_{smse}(\text{Å})\approx1.1076\times10^{-8}\frac{\lambda^2(cm)N(cm^{-3})}{\sqrt{T(K)}}(0.9 - \frac{1.1}{Z})\frac{9}{4Z^2}S1 \quad (2.2)$$

where is

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

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

$$d^{(2)}_{smse}(\text{Å})\approx1.1076\times10^{-8}\frac{\lambda^2(cm)N(cm^{-3})}{\sqrt{T(K)}}(0.9 - \frac{1.1}{Z})\frac{9}{4Z^2}S2 \quad (2.4)$$

where is

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

3 RESULTS

In our previous study of singly ionized iridium ion [16] we noted that it is possible to apply simplified modified semiempirical method [12] when the conditions are satisfied. Because of this reason we take available 31 lines of Rh II for calculations of Stark broadening parameters, widths and shifts. Our results for Rh II spectral lines are presented in Table 1. For calculations we used an electron density of 10^{23} m^{-3} and temperatures from 10000 up to 300000 Kelvins. Energy levels for calculations have been taken from [17].

Here, we noted that wavelengths given in Table 1 are calculated ones, and consequently different from experimental ones. The transformation of Stark width in Å to the width expressed in angular frequency units may be performed using the following formula:

$$W(\mathring{A}) = \frac{\lambda^2}{2\pi c}W(s^{-1}) \quad (3.1)$$

where c is the speed of light. If the width or shift should be corrected for the difference between calculated and experimental wavelength, this can be performed with next expression:

$$W' = (\lambda_{exp}/\lambda_{th})^2W \quad (3.2)$$

and for the shift the same formalism in the appropriate designation. With $W^{'}$ is denoted the corrected width, λ_{exp} is the experimental, λ_{th} the calculated wavelength and W the width from Table 1.

We analyzed our results for a complete set of calculated lines of single ionized rhodium. In Section 2, we described a method for obtaining Stark widths and shifts given by the indicated formulas. If we make the ratio d/W we can see that it does not depend on the temperature or the wavelength or of the perturber density. This is interesting because such a ratio is constant for each line separately when varying these parameters, here specifically for the temperature. This ratio depends only on quantum numbers and optical charge, which can be seen if we derive the quotient shift and line width.

For example, for the 2490.8 Å line, this ratio is 0.325 and it is the same for any temperature from 10000 to 300000 Kelvins. Also, the minimum value of the ratio has line 2606.5 Å with value 0.191, and the maximum for line 2520.5 Å with value 0.329. For all calculations in a given wavelength range of interest, these ratios are between 19.1% and 32.9% of the width of a single line, which can be seen in Fig. 1.

The growing need for the spectral line data for the concerning neutral and lowly ionized heavy atoms $Z \geq 37$ is of enlarged interest in describing a chemically peculiar star atmosphere. The Rh II spectrum has been intensively researched for the last decade and is used in experimental and technological terms. A look at NIST spectral database reveals that there is a need of not only for the characterizing the spectral line properties but also the characterization of the energy levels, please take a look at 2477.54 Å, 2504.29 Å, and 3964.54 Å lines for instance. The decay times and related oscillator strengths are investigated by the means of the laser induced fluorescent methods. In the [18], two wavelength methods are used. Two Nd:YAG second harmonic lasers are used, one for breakdown on the Rh surface in a vacuum chamber and the second pulse is exiting the desired level. The time domain resolved decay is measured, the results are used for determining both oscillator strengths and branching factors in [19]. From all previous studies it is obvious that the Rh II spectral characteristics are not only of interest but present open fields for further research in both experimental and theoretical aspects of research.

All of the presented works are comparing their results with adequate pseudo-relativistic Hartree-Fock models. Having that in mind, it is our belief that the set of data concerning a Stark broadening parameters width and shift for the known spectral line is of interest for both solar models as well as experimental usage. The lack of detailed knowledge of energy levels for Rh II led us to usage of simplified rather than detailed MSE method.

Here, we considered the Stark broadening effect for Rh II spectral lines in A type star, as we considered in our previos papers [20, 21, 22]. In Table 1 is placed spectral line of Rh II with wavelength 2511.1 Å as 5s b^{3}F$_4$ - 5p z^{3}F$^o_4$ transition with a relative intensity of 300 [23]. We make a comparison of thermal Doppler and Stark widths for Rh II spectral line 5s b^{3}F$_4$ - 5p z^{3}F$^o_4$ (2511.1 Å) in A type stars, a model atmosphere with T_{eff} = 10000 K and log g = 4.5 [24], in Fig. 2. X axis is written with logτ and indicates Rosseland optical depth scale. This chosen model is very similar to the models of A type stars, where rhodium was detected in their spectrum, which we wrote about in the introduction of this paper. In the deeper layers of the atmosphere, the Stark effect is below the thermal Doppler, but as we go towards the surface layers, it grows and becomes dominant above the optical depth whose value is 2.5, see Fig. 2. Although in deeper atmospheric layers Stark broadening is less significant compared to Doppler one, and it has an effect on the wings of the spectral line and is still dominant. This fact is supported by the growing abundance of this element in the atmosphere of the star. In Fig. 2 we can see distribution of width for Stark and Doppler one in marked temperature range, from 10000 to 40000 Kelvins, for the same model of A type star with T_{eff} = 10000 K and log g = 4.5 [24].

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 $y^5D_2^o$	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 $z^5G_6^o$	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 $w^3D_1^o$	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 $z^5G_4^o$	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 $y^3F_2^o$	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 $z^5G_3^o$	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 $z^5G_5^o$	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

Table 1: Continued.

Transition λ[Å]	T[K]	W[Å]	d[Å]	W[s^{-1}]	d[s^{-1}]
5s b^1G_4 - 5p $x^3G^o_3$	10000	0.8828D-01	-0.1716D-01	0.2812D+12	-0.5472D+11
2431.8	20000	0.6242D-01	-0.1215D-01	0.1988D+12	-0.3869D+11
	50000	0.3948D-01	-0.7683D-02	0.1258D+12	-0.2447D+11
	100000	0.2792D-01	-0.5433D-02	0.8892D+11	-0.1730D+11
	200000	0.1974D-01	-0.3842D-02	0.6288D+11	-0.1224D+11
	300000	0.1612D-01	-0.3137D-02	0.5134D+11	-0.9991D+10
5s a^5F_1 - 5p $z^5G^o_2$	10000	0.5352D-01	-0.1540D-01	0.1704D+12	-0.4905D+11
2431.9	20000	0.3784D-01	-0.1089D-01	0.1205D+12	-0.3469D+11
	50000	0.2393D-01	-0.6888D-02	0.7623D+11	-0.2194D+11
	100000	0.1692D-01	-0.4870D-02	0.5390D+11	-0.1551D+11
	200000	0.1197D-01	-0.3444D-02	0.3811D+11	-0.1097D+11
	300000	0.9771D-02	-0.2812D-02	0.3112D+11	-0.8956D+10
5s a^5F_2 - 5p $z^5D^o_2$	10000	0.5319D-01	-0.1567D-01	0.1661D+12	-0.4896D+11
2455.7	20000	0.3761D-01	-0.1108D-01	0.1175D+12	-0.3462D+11
	50000	0.2379D-01	-0.7009D-02	0.7430D+11	-0.2189D+11
	100000	0.1682D-01	-0.4956D-02	0.5254D+11	-0.1548D+11
	200000	0.1189D-01	-0.3505D-02	0.3715D+11	-0.1095D+11
	300000	0.9712D-02	-0.2862D-02	0.3033D+11	-0.8938D+10
5s a^3D_3 - 5p $x^3G^o_3$	10000	0.9057D-01	-0.1772D-01	0.2822D+12	-0.5521D+11
2458.9	20000	0.6404D-01	-0.1253D-01	0.1995D+12	-0.3904D+11
	50000	0.4050D-01	-0.7925D-02	0.1262D+12	-0.2469D+11
	100000	0.2864D-01	-0.5604D-02	0.8923D+11	-0.1746D+11
	200000	0.2025D-01	-0.3962D-02	0.6309D+11	-0.1234D+11
	300000	0.1654D-01	-0.3235D-02	0.5151D+11	-0.1008D+11
5s a^5F_3 - 5p $z^5D^o_3$	10000	0.5188D-01	-0.1561D-01	0.1616D+12	-0.4862D+11
2458.9	20000	0.3669D-01	-0.1104D-01	0.1143D+12	-0.3438D+11
	50000	0.2320D-01	-0.6980D-02	0.7229D+11	-0.2175D+11
	100000	0.1641D-01	-0.4936D-02	0.5112D+11	-0.1538D+11
	200000	0.1160D-01	-0.3490D-02	0.3614D+11	-0.1087D+11
	300000	0.9473D-02	-0.2850D-02	0.2951D+11	-0.8878D+10
5s a^5F_4 - 5p $z^5D^o_4$	10000	0.4998D-01	-0.1547D-01	0.1554D+12	-0.4813D+11
2461.0	20000	0.3534D-01	-0.1094D-01	0.1099D+12	-0.3403D+1
	50000	0.2235D-01	-0.6920D-02	0.6952D+11	-0.2152D+11
	100000	0.1581D-01	-0.4893D-02	0.4916D+11	-0.1522D+11
	200000	0.1118D-01	-0.3460D-02	0.3476D+11	-0.1076D+11
	300000	0.9125D-02	-0.2825D-02	0.2838D+11	-0.8786D+10
5s a^3G_5 - 5p $z^3H^o_6$	10000	0.7639D-01	-0.1742D-01	0.2348D+12	-0.5354D+11
2475.6	20000	0.5402D-01	-0.1232D-01	0.1660D+12	-0.3786D+11
	50000	0.3416D-01	-0.7790D-02	0.1050D+12	-0.2394D+11
	100000	0.2416D-01	-0.5508D-02	0.7425D+11	-0.1693D+11
	200000	0.1708D-01	-0.3895D-02	0.5250D+11	-0.1197D+11
	300000	0.1395D-01	-0.3180D-02	0.4287D+11	-0.9775D+10

Table 1: Continued.

Transition λ[Å]	T[K]	W[Å]	d[Å]	W[s^{-1}]	d[s^{-1}]
5s a^5F_5 - 5p $z^5F^o_5$ 2490.8	10000	0.4818D-01	-0.1567D-01	0.1463D+12	-0.4756D+11
	20000	0.3407D-01	-0.1108D-01	0.1034D+12	-0.3363D+11
	50000	0.2155D-01	-0.7006D-02	0.6542D+11	-0.2127D+11
	100000	0.1524D-01	-0.4954D-02	0.4626D+11	-0.1504D+11
	200000	0.1077D-01	-0.3503D-02	0.3271D+11	-0.1064D+11
	300000	0.8796D-02	-0.2860D-02	0.2671D+11	-0.8684D+10
5s a^5F_2 - 5p $z^5F^o_1$ 2503.9	10000	0.5434D-01	-0.1637D-01	0.1633D+12	-0.4918D+11
	20000	0.3843D-01	-0.1157D-01	0.1154D+12	-0.3477D+11
	50000	0.2430D-01	-0.7320D-02	0.7301D+11	-0.2199D+11
	100000	0.1718D-01	-0.5176D-02	0.5163D+11	-0.1555D+11
	200000	0.1215D-01	-0.3660D-02	0.3651D+11	-0.1100D+11
	300000	0.9921D-02	-0.2988D-02	0.2981D+11	-0.8978D+10
5s a^5F_3 - 5p $z^5F^o_2$ 2505.1	10000	0.5297D-01	-0.1627D-01	0.1590D+12	-0.4882D+11
	20000	0.3745D-01	-0.1150D-01	0.1124D+12	-0.3452D+11
	50000	0.2369D-01	-0.7274D-02	0.7110D+11	-0.2183D+11
	100000	0.1675D-01	-0.5144D-02	0.5027D+11	-0.1544D+11
	200000	0.1184D-01	-0.3637D-02	0.3555D+11	-0.1092D+11
	300000	0.9670D-02	-0.2970D-02	0.2903D+11	-0.8914D+10
5s a^5F_4 - 5p $z^5F^o_3$ 2510.7	10000	0.5111D-01	-0.1617D-01	0.1527D+12	-0.4832D+11
	20000	0.3614D-01	-0.1143D-01	0.1080D+12	-0.3417D+11
	50000	0.2286D-01	-0.7232D-02	0.6831D+11	-0.2161D+11
	100000	0.1616D-01	-0.5114D-02	0.4830D+11	-0.1528D+11
	200000	0.1143D-01	-0.3616D-02	0.3415D+11	-0.1081D+11
	300000	0.9332D-02	-0.2952D-02	0.2789D+11	-0.8822D+10
5s b^3P_1 - 5p $y^3P^o_1$ 2511.1	10000	0.8562D-01	-0.1842D-01	0.2558D+12	-0.5502D+11
	20000	0.6054D-01	-0.1302D-01	0.1809D+12	-0.3890D+11
	50000	0.3829D-01	-0.8236D-02	0.1144D+12	-0.2460D+11
	100000	0.2708D-01	-0.5824D-02	0.8088D+11	-0.1740D+11
	200000	0.1915D-01	-0.4118D-02	0.5719D+11	-0.1230D+11
	300000	0.1563D-01	-0.3362D-02	0.4670D+11	-0.1004D+11
5s c^3P_2 - 5p $w^3D^o_1$ 2513.4	10000	0.9061D-01	-0.1866D-01	0.2702D+12	-0.5565D+11
	20000	0.6407D-01	-0.1320D-01	0.1911D+12	-0.3935D+11
	50000	0.4052D-01	-0.8347D-02	0.1208D+12	-0.2489D+11
	100000	0.2865D-01	-0.5902D-02	0.8544D+11	-0.1760D+11
	200000	0.2026D-01	-0.4173D-02	0.6042D+11	-0.1244D+11
	300000	0.1654D-01	-0.3407D-02	0.4933D+11	-0.1016D+11
5s a^5F_5 - 5p $z^5F^o_4$ 2520.5	10000	0.4884D-01	-0.1608D-01	0.1448D+12	-0.4767D+11
	20000	0.3453D-01	-0.1137D-01	0.1024D+12	-0.3371D+11
	50000	0.2184D-01	-0.7190D-02	0.6476D+11	-0.2132D+11
	100000	0.1544D-01	-0.5084D-02	0.4579D+11	-0.1507D+11
	200000	0.1092D-01	-0.3595D-02	0.3238D+11	-0.1066D+11
	300000	0.8916D-02	-0.2935D-02	0.2644D+11	-0.8703D+10

Table 1: Continued.

Transition λ[Å]	T[K]	W[Å]	d[Å]	W[s^{-1}]	d[s^{-1}]
5s b^3P_2 - 5p $z^3P^o_1$	10000	0.8510D-01	-0.1882D-01	0.2490D+12	-0.5508D+11
2537.1	20000	0.6017D-01	-0.1331D-01	0.1761D+12	-0.3895D+11
	50000	0.3806D-01	-0.8417D-02	0.1114D+12	-0.2463D+11
	100000	0.2691D-01	-0.5952D-02	0.7875D+11	-0.1742D+11
	200000	0.1903D-01	-0.4209D-02	0.5568D+11	-0.1232D+11
	300000	0.1554D-01	-0.3436D-02	0.4547D+11	-0.1006D+11
5s a^3D_1 - 5p $x^3D^o_1$	10000	0.1001D+00	-0.1998D-01	0.2863D+12	-0.5711D+11
2566.9	20000	0.7082D-01	-0.1412D-01	0.2024D+12	-0.4038D+11
	50000	0.4479D-01	-0.8933D-02	0.1280D+12	-0.2554D+11
	100000	0.3167D-01	-0.6317D-02	0.9054D+11	-0.1806D+11
	200000	0.2239D-01	-0.4467D-02	0.6402D+11	-0.1277D+11
	300000	0.1828D-01	-0.3647D-02	0.5227D+11	-0.1043D+11
5s b^3F_3 - 5p $z^3D^o_2$	10000	0.6963D-01	-0.1867D-01	0.1959D+12	-0.5254D+11
2587.2	20000	0.4923D-01	-0.1320D-01	0.1385D+12	-0.3715D+11
	50000	0.3114D-01	-0.8349D-02	0.8762D+11	-0.2349D+11
	100000	0.2202D-01	-0.5904D-02	0.6196D+11	-0.1661D+11
	200000	0.1557D-01	-0.4175D-02	0.4381D+11	-0.1175D+11
	300000	0.1271D-01	-0.3409D-02	0.3577D+11	-0.9592D+10
5s a^5P_2 - 5p $z^3D^o_1$	10000	0.7117D-01	-0.1878D-01	0.2003D+12	-0.5284D+11
2587.3	20000	0.5033D-01	-0.1328D-01	0.1416D+12	-0.3737D+11
	50000	0.3183D-01	-0.8399D-02	0.8956D+11	-0.2363D+11
	100000	0.2251D-01	-0.5939D-02	0.6333D+11	-0.1671D+11
	200000	0.1591D-01	-0.4199D-02	0.4478D+11	-0.1182D+11
	300000	0.1299D-01	-0.3429D-02	0.3656D+11	-0.9648D+10
5s a^3G_4 - 5p $y^5D^o_4$	10000	0.8277D-01	-0.1977D-01	0.2300D+12	-0.5494D+11
2603.3	20000	0.5853D-01	-0.1398D-01	0.1627D+12	-0.3885D+11
	50000	0.3701D-01	-0.8840D-02	0.1029D+12	-0.2457D+11
	100000	0.2617D-01	-0.6251D-02	0.7275D+11	-0.1737D+11
	200000	0.1851D-01	-0.4420D-02	0.5144D+11	-0.1229D+11
	300000	0.1511D-01	-0.3609D-02	0.4200D+11	-0.1003D+11
5s a^1H_5 - 5p $y^3H^o_5$	10000	0.1104D+00	-0.2108D-01	0.3060D+12	-0.5845D+11
2606.5	20000	0.7803D-01	-0.1491D-01	0.2164D+12	-0.4133D+11
	50000	0.4935D-01	-0.9428D-02	0.1368D+12	-0.2614D+11
	100000	0.3490D-01	-0.6666D-02	0.9676D+11	-0.1848D+11
	200000	0.2468D-01	-0.4714D-02	0.6842D+11	-0.1307D+11
	300000	0.2015D-01	-0.3849D-02	0.5586D+11	-0.1067D+11
5s b^3P_2 - 5p $z^3P^o_2$	10000	0.8862D-01	-0.2068D-01	0.2397D+12	-0.5594D+11
2638.8	20000	0.6266D-01	-0.1462D-01	0.1695D+12	-0.3956D+11
	50000	0.3963D-01	-0.9249D-02	0.1072D+12	-0.2502D+11
	100000	0.2802D-01	-0.6540D-02	0.7581D+11	-0.1769D+11
	200000	0.1982D-01	-0.4624D-02	0.5360D+11	-0.1251D+11
	300000	0.1618D-01	-0.3776D-02	0.4377D+11	-0.1021D+11

Table 1: Continued.

Transition λ[Å]	T[K]	W[Å]	d[Å]	W[s^{-1}]	d[s^{-1}]
5s b^3F_4 - 5p $z^3F^o_4$ 2705.6	10000	0.6871D-01	-0.2027D-01	0.1768D+12	-0.5215D+11
	20000	0.4859D-01	-0.1433D-01	0.1250D+12	-0.3688D+11
	50000	0.3073D-01	-0.9064D-02	0.7907D+11	-0.2332D+11
	100000	0.2173D-01	-0.6409D-02	0.5591D+11	-0.1649D+11
	200000	0.1536D-01	-0.4532D-02	0.3954D+11	-0.1166D+11
	300000	0.1255D-01	-0.3700D-02	0.3228D+11	-0.9522D+10
5s b^3F_4 - 5p $z^3G^o_5$ 2715.3	10000	0.6901D-01	-0.2043D-01	0.1763D+12	-0.5219D+11
	20000	0.4880D-01	-0.1445D-01	0.1247D+12	-0.3691D+11
	50000	0.3086D-01	-0.9136D-02	0.7885D+11	-0.2334D+11
	100000	0.2182D-01	-0.6460D-02	0.5575D+11	-0.1650D+11
	200000	0.1543D-01	-0.4568D-02	0.3942D+11	-0.1167D+11
	300000	0.1260D-01	-0.3730D-02	0.3219D+11	-0.9529D+10
5s b^3F_4 - 5p $z^5G^o_5$ 2910.1	10000	0.7518D-01	-0.2378D-01	0.1672D+12	-0.5288D+11
	20000	0.5316D-01	-0.1681D-01	0.1182D+12	-0.3739D+11
	50000	0.3362D-01	-0.1063D-01	0.7478D+11	-0.2365D+11
	100000	0.2377D-01	-0.7519D-02	0.5288D+11	-0.1672D+11
	200000	0.1681D-01	-0.5316D-02	0.3739D+11	-0.1183D+11
	300000	0.1373D-01	-0.4341D-02	0.3063D+11	-0.9655D+10

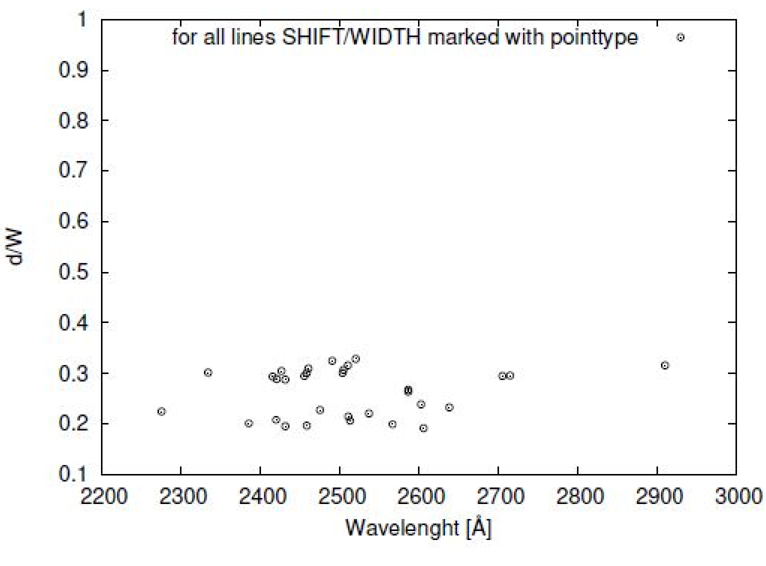

Fig. 1. Ratio of calculated Stark shifts and widths for all spectral lines for singly ionized rhodium

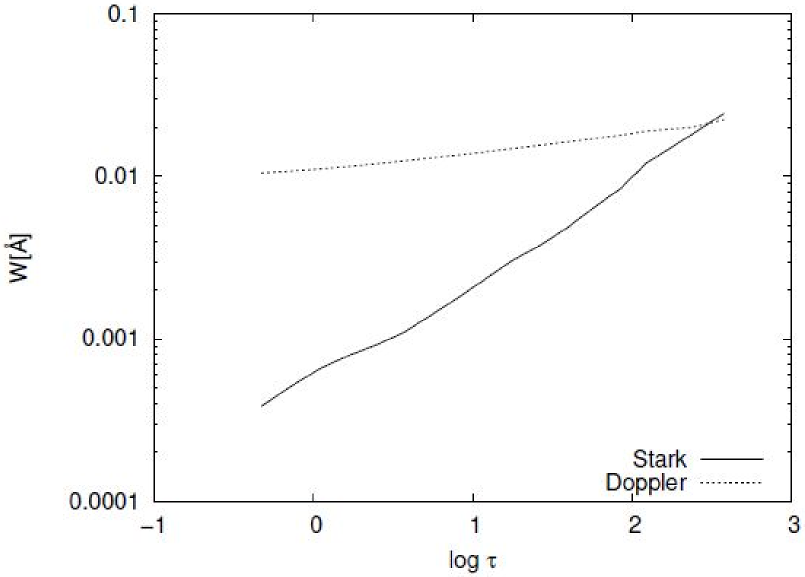

Fig. 2. Stark widths for Rh II spectral lines 5s b^{3}F$_4$ - 5p z^{3}F$^o_4$ (λ=2511.1 Å), for an A type star atmosphere model with T_{eff} = 10,000 K and log g = 4.5, as a function of the Rosseland optical depth

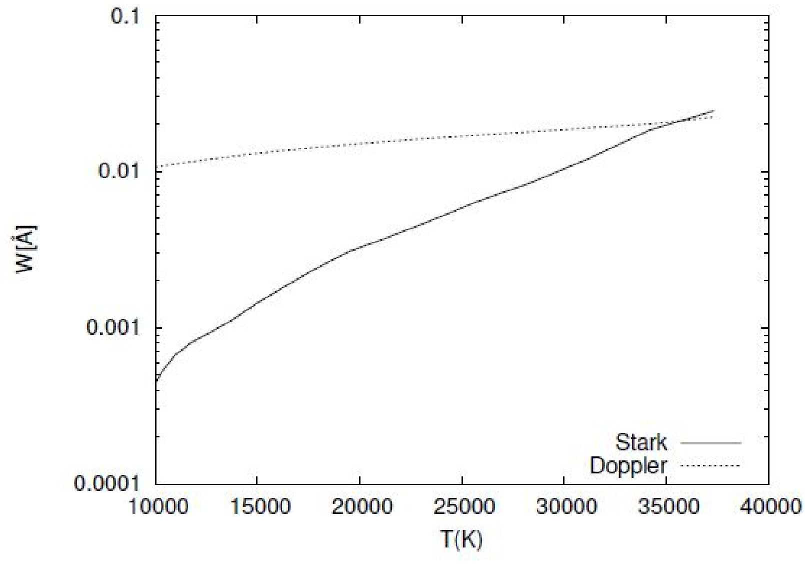

Fig. 3. Stark widths for Rh II spectral lines 5s b^{3}F$_4$ - 5p z^{3}F$^o_4$ (λ=2511.1 Å), for an A type star atmosphere model with T_{eff} = 10,000 K and log g = 4.5, as a function of the temperature

One can see from our results it follows that in atmospheres of A type stars exist layers where Stark broadening effect should be taken into account for modeling and investigation stellar plasmas.

4 CONCLUSION

We have performed a simplified MSE method for calculation of Stark broadening parameters for 31 transitions in Rh II. Stark broadening parameters widths and shifts have been calculated.

We can see that Stark broadening is more important or comparable to Doppler broadening for important layers and that its significance increases with the increase of the optical depth. One should note that even when the Doppler width is larger than Stark width, due to the differences between Gaussian and Lorentzian profiles, Stark broadening may be important in line wings.

The principal pressure broadening mechanism for A type stars is Stark broadening, so this data are usefull for determination of abundances, radiative transfer calculations, stellar opacity calculations, modelling of stellar atmospheres and stellar spectra analysis and synthezis.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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