Case studies on recent Stark broadening calculations and STARK-B database development in the framework of the European project VAMDC (Virtual Atomic and Molecular Data Center)

S Sahal-Bréchot
Paris Observatory, CNRS-UMR 8112 and University Pierre et Marie Curie, LERMA, 5 Place Jules Janssen, 92190 Meudon, France
E-mail: Sylvie.sahal-brechot@obspm.fr

Abstract. Stark broadening theories and calculations have been extensively developed for about 50 years. The theory can now be considered as mature for many applications, especially for accurate spectroscopic diagnostics and modelling. In astrophysics, with the increasing sensitivity of observations and spectral resolution, in all domains of wavelengths from far UV to infrared, it has become possible to develop realistic models of interiors and atmospheres of stars and interpret their evolution and the creation of elements through nuclear reactions. For hot stars, especially white dwarfs, Stark broadening is the dominant collisional line broadening process. This requires the knowledge of numerous profiles, especially for trace elements, which are used as useful probes for modern spectroscopic diagnostics. Hence, calculations based on a simple but enough accurate and fast method, are necessary for obtaining numerous results. Ab initio calculations are a growing domain of development. Nowadays, the access to such data via an on line database becomes crucial. This is the object of STARK-B, which is a collaborative project between the Paris Observatory and the Astronomical Observatory of Belgrade. It is a database of calculated widths and shifts of isolated lines of atoms and ions due to electron and ion collisions. It is devoted to modelling and spectroscopic diagnostics of stellar atmospheres and envelopes. In addition, it is relevant to laboratory plasmas, laser equipments and technological plasmas. It is a part of VAMDC (Virtual Atomic and Molecular Data Centre), which is an European Union funded collaboration between groups involved in the generation and use of atomic and molecular data.

1. Introduction
Atomic physics in plasmas has been a basic tool in Astrophysics for many years. In addition, a number of its developments have been stimulated not only by the advances in Astrophysics, but also by the needs in laboratory and technological plasmas (tokamaks, laser produced plasmas...). We will focus to astrophysical plasmas needs in the present paper. A major interest consists in the understanding of the evolution of the Universe, of the birth, growing, evolution and death of stars, which eject their material into the interstellar medium at the end of their life. The Big Bang explosion was responsible for the production of very light elements hydrogen and helium (and also lithium for a little part) and next the first generation of stars was born. These stars were extremely metal-poor. Then other elements (the
“metals”) were synthesized inside stars, and later on ejected back into the interstellar medium. The molecular regions are the nurseries at the source of birth of the new stars. Then the next generations of stars are the result of seeds from the previous ones, and so on. And the “metallicity” of the new generation increases.

Fusion reactions synthesize the elements up to iron. Heavier elements, such as platinum or gold, cannot be formed in such a manner, and are created by neutron-capture reaction: this is due to the fact that for heavy elements the high number of protons prevents nuclear reactions between charged particles.

Thus, to be more specific and to make this scenario scientifically precise with a quantitative modelling, it is necessary to accurately describe the stellar evolution, and the formation of elements, which are closely connected. Low-mass stars, such as the sun, have a long lifetime (billions of years) and end as planetary nebulae and then white dwarfs. More massive stars evolve at a faster rate and live only millions of years. They end their life in a gigantic supernova explosion, and the remnant is a neutron star (a pulsar). To make progress in these developments chemical abundances are crucial parameters to be determined. This needs an accurate interpretation of the detailed line spectra of the stellar objects. This also needs a quantitative modelling of stellar interiors and to calculate accurate radiative opacities in stellar envelopes.

In fact, thanks to the fantastic developments of the spectral resolution, of the sensitivity (high S/N) of the recent past years, and to large ground-based telescopes and space-born missions which allow to observe in all ranges of wavelengths (from γ to radio), this has become possible. Therefore an accurate analysis of very weak lines has been more and more possible. In particular the analysis of the spectra of the heavy elements which are only traces, will give the necessary information for understanding their creation through neutron capture. In another domain, interpretation of the spectra of white dwarfs, which are very faint, allows to understand the evolution of these very old stars, which are close to death.

For interpreting the spectra, identification of lines, and atomic parameters responsible for the intensity and line profiles of the lines are required. Apart oscillator strengths and excitation impact cross-sections when LTE is not fulfilled, line broadening parameters due to interactions (collisions) with the particles of the medium are required. For moderately hot (A-stars) to very hot (B and O) stars, “Stark” broadening is the main pressure broadening mechanism. It has to be known with accuracy. Nowadays collisional broadening data are needed, not only for strong lines of abundant elements (H, He, C, N, O, Ne) as in the past, but also for weak lines of abundant elements, and in addition for elements of lower abundance (the Iron-peak), and then, that is more recent, the heavy elements of very low abundance which follow on the Mendeleev table which are always very weak. Even some radioactive elements, such as thorium and uranium have been recently discovered in low-metallicity stars (stars of the first or second generation), and are used for chronometric age determination.

Section 2 will precise the physical conditions where Stark broadening plays a role in astrophysical plasmas. Section 3 will be devoted to a very brief review of the standard impact Stark broadening theory. In section 4 we will present some examples of astrophysical applications and recent results showing the new interest for weak lines.

In addition, the development of powerful computers also stimulates the development of atomic data on a large scale. The modelling of stellar atmospheres and of the stellar interiors needs extensive sets of atomic data, including collisional broadening and especially Stark broadening. For example, the PHOENIX computer code [1] developed for stellar modelling includes a database containing more than 10^7 atomic and ionic spectral lines. The access to these atomic data via on line databases becomes essential. In section 5 we will present the STARK-B database, which is a database of calculated widths and shifts of isolated lines of atoms and ions due to electron and ion collisions. This database is devoted to modelling and spectroscopic diagnostics of stellar atmospheres and envelopes. In addition, it is relevant to laboratory plasmas, laser equipments and technological plasmas. It is a collaborative project between the Paris Observatory and the Astronomical Observatory of Belgrade and has been
opened online since the end of 2008, though not complete and currently under development, particularly in the framework of VAMDC (Virtual Atomic and Molecular Data Center).

2. Physical conditions for Stark broadening importance in astrophysical plasmas

Pressure broadening of spectral lines arises when an atom, ion, or molecule which emits or absorbs light in a gas or a plasma, is perturbed by its interactions with the other particles of the medium. Interpretation of this phenomena is currently used for modelling of the medium and for spectroscopic diagnostics, since the broadening of the lines depends on the temperature and density of the medium. In astrophysics, the physical conditions are very various, and collisional broadening with charged particles appears to be important in many domains. For example, in the very low dense interstellar ionized regions where the temperature is around $10^4$ K and the electron density of about $10^{24}$ cm$^{-3}$ (the so-called H II regions), the radiorecombination lines of H and C II [1] arising from Rydberg levels (n-n±1 lines) are broadened by interactions with electrons and protons. On an opposite extreme domain of temperatures and densities (about $10^6$ - $10^7$ K, and electron densities of about $10^{24}$ cm$^{-3}$), the interiors of stars, which cannot be observed but are mirrored via asterosismology, can be modelled and electron collisional broadening of abundant ions plays an important role for the radiative opacities. In the very dense and hot atmospheres of neutron stars, the physical conditions are typical of those of stellar interiors, and highly-ionized atoms such as H and He-like Fe have been observed in X rays and the measured line strengths of lines indicate that the lines are significantly broadened by the Stark effect [2], and this should provide an opportunity to determine both the mass and the radius of these exotic objects.

On less extreme conditions of temperatures ($10^4$ to a few $10^4$ K) and densities ($10^{13}$ to $10^{15}$ cm$^{-3}$), Stark broadening is efficient for modelling and analyzing spectra of moderately hot (A), hot (B) and very hot (O) types of stars. It is dominant in comparison with the thermal Doppler effect in deep layers of the stellar atmosphere. In white dwarfs, collisional broadening and especially Stark broadening is dominant in all layers of the atmosphere (temperatures in the region of $10^4$ K, electronic densities of the order of $10^{18}$-$10^{19}$ cm$^{-3}$) Even in stars like sun, and especially in the chromosphere which lays above the photosphere, Stark broadening is operative for lines arising from high excited levels, and especially for hydrogen lines. For interpretation of these spectra, the standard theory of Stark impact broadening of isolated lines is convenient.

3. The standard theory of Stark impact broadening of isolated lines

Following the founding work by Baranger [3] [4] [5], the theory and calculation of collisional line broadening in the impact approximation for electron and ion interactions underwent a great expansion in the sixties and the seventies, and experiments as well.

3.1. The impact approximation

The impact approximation forms the base for the theory: the interactions are separated in time. In other words, the studied radiating atom interacts with one perturber one at a time. Consequently the duration of an interaction must be much smaller than the mean time interval between two collisions, which is of the order of the inverse of the collisional line width. The effect of perturbers are independent and are additive.

The radiation field is weak, so the dressed atom theory is not necessary. It is a general case in astrophysics.

3.2. The complete collision approximation

In addition the collision is assumed to be complete. This means that the atom has no time to emit or absorb a photon during the collision process. This is valid if the duration of an interaction is much smaller than the interval between two successive emissions (or absorptions) of photons, which is of the order of the inverse of the detuning, when larger than the line width.
Consequently radiative and collision processes are decoupled and the impact broadening theory becomes an application of the theory of collisions between an atom (or ion) and interacting particles.

3.3. The case of “isolated lines”
We will be interested in “isolated lines” and exclude the case of “overlapping lines” [4], in the following. This means that the levels next to the upper or lower level of the studied transition and likely to modify the broadening by introducing optical coherences do not overlap with them. So we will consider neither hydrogen and hydrogenic ionic lines in the present paper, nor some specific helium lines and some lines arising from Rydberg levels.

3.4. The result is a Lorentz profile
Therefore the profile of the $i$-$f$ line emitted or absorbed between the $i$ and $f$ levels studied is Lorentzian with a full width at half maximum $W$ (in angular frequency units) and a shift $d$ [5]. $W$ can be expressed in terms of inelastic cross-sections and elastic processes as

$$W = \frac{N}{\pi} v f(v) \left( \sum_{i \neq f} \sigma_{ii'}(v) + \sum_{f \neq f'} \sigma_{ff'}(v) + \sigma_{el}(v) \right),$$

where $N$ is the density of the colliding perturbers, $f(v)$ the Maxwell distribution of the relative atom-perturber velocity $v$, $\sigma_{ii'}$ and $\sigma_{ff'}$ the inelastic cross-sections between the initial level $i$ (resp. $f$ final level) and the perturbing levels $i'$ (resp. $f'$) of the $i$-$f$ transition. $\sigma_{el}(v)$ represents the contribution of elastic collisions and include Feshbach resonances when ion-electron collisions are studied. The shift is not given in the present paper, we refer to [5] for its quantum expression.

3.5. Orders of magnitude of the effect of electron collisions compared to the one due to ion collisions
For isolated lines, the widths and shifts due to electron collisions are generally the times higher than the widths and shifts due to ion collisions. This is due to the fact that inelastic collisions with positive ions are generally negligible, owing to the mass effect which decreases the relative velocity, and in addition, if the radiator is an ion, the Coulomb repulsion acts. This can be not the case when the perturbing levels are very close to the levels of the studied transition. This can also be not the case at very high temperatures, and especially for ion radiators when the Coulomb repulsion becomes weak. An example can be found in [6] for Cr I lines widths at very high temperatures.

3.6. Effect of fine structure and hyperfine structure on the widths and shifts
The following remark holds in LS coupling. For electronic collisions, the collision time (of the order of $\rho_{op}/v$, where $\rho_{op}$ is a typical impact parameter) is very much smaller than the fine structure splitting. So the electronic spin has no time to rotate during the collision and can be ignored. Thus all the fine structure components have the same widths and shifts, which are equal to those of the multiplet. This is a fortiori the same for the hyperfine components. So our calculations have most often been performed for multiplets only. This remark does not apply for heavy atoms where departures from LS coupling can be important.

3.7. The calculation of the cross-sections, and then widths and shifts
3.7.1. The Semi-Classical Perturbation (SCP) approach. The calculation of the cross-sections is a major quantum mechanical problem. For most astrophysical purposes, the semi-classical-perturbation treatment is adapted and gives results with a sufficient accuracy (about 20%). The method is accurate if the perturbing levels are not too far from the levels of the studied line. The formalism has been developed and discussed in detail by [7] [8] and a very fast computer code has been created. Classical straight rectilinear paths for neutral radiators, and hyperbolic paths are introduced for ion-electron et ion-ion collisions. Then the $S$-matrix is obtained within the second order perturbation theory. The needed cross-sections are obtained through an integration over the impact parameter of the transition probabilities. The needed cut-offs are determined in order to maintain the unitarity of the scattering $S$-
matrix for low impact parameters, and Debye screening is taken into account. This formalism, as well as the computer code, have been updated and optimized several times: [9] for complex atoms, [10] for the inclusion of Feshbach resonances in the elastic ion-electron cross-sections, [11] and further papers, and [12] for transitions arising from very complex configurations.

3.7.2. The atomic structure. It is the first ingredient of the calculations.

In the quantum picture, the wavefunctions enter the calculation of the S-matrix.

In the semiclassical picture, oscillator strengths and needed energy levels enter the expressions of the inelastic cross-sections.

— In the past, the Coulomb approximation with quantum defect (the Bates and Damgaard approximation [13]) was used, together with measured or calculated energy levels. Now we use modern ab initio methods (cf. the review by Ben Nessib (2009) [14]. The computer codes or the data can be downloaded on line. Thus the calculations of widths and shifts can be made from the beginning to the end without any additional external input or experimental adjustment. The chosen atomic structure package enters our computer semi-classical code and that allows, when these methods are applicable, to obtain widths and shifts for one-two hundred of lines.

— TOPbase, the Opacity Project atomic database, contains accurately calculated energy levels, f-values and photoionisation cross sections for astrophysically abundant neutral atoms and ions. They have been computed in the close-coupling scattering theory by means of the R-matrix method with innovative asymptotic techniques [15] [16]. L-S coupling is assumed. So the use of TOPbase is especially adapted to light and low and moderately ionized atoms and ions.

— The Cowan code, originally written by Cowan [17] is an atomic structure package consisting of a set of computer programs for calculation of energy levels, radiative transition wavelengths and probabilities, electron impact excitation and photoionization cross sections etc. The Hartree-Fock-Slater multi-configuration expansion method with statistical exchange is the normal option since it is most computationally efficient. The relativistic corrections are treated by perturbations. So the method is especially suited to moderately heavy atoms which are little and moderately ionized.

— SUPERSTRUCTURE (SST) [18] is well suited for computation of large quantities of atomic data for highly charged ions. The wave functions are determined by diagonalization of the nonrelativistic Hamiltonian using orbitals calculated in a scaled Thomas-Fermi-Dirac-Amaldi potential. Relativistic corrections are introduced according to the Breit-Pauli approach. Atomic data are obtained in intermediate coupling.

3.7.3. The quantum code in intermediate coupling for Stark broadening calculations. The combination of SST with the S-matrix calculated with the Distorted Wave approximation (DW) code of Eissner [19] and the code of Saraph JAJOM [20] have permitted to create a quantum code for electron-impact widths of ions [21] based on the quantum formalism of impact Stark broadening in intermediate coupling [22]. This quantum method has been compared to experimental results of some Be-like and Li-like ions with success [21] [23] but has not still been applied to astrophysics needs. It should be especially useful for UV and XUV resonance lines of highly ionized atoms when the semiclassical method cannot give accurate results, owing to the large distance of the levels of the studied transition with the perturbing levels. On the example of stellar interiors, the electron density is high enough that electron impact is the most important source of line broadening and contributes significantly to the radiative accelerations needed for evolutionary models and opacity calculations [24], whereas many data are currently missing. However, the quantum method, though in principle more accurate than the semi-classical one, is cumbersome to undertake. It can be usefully applied to particular lines, provided that the levels be not too excited: for excited levels the number of necessary configurations become excessive and the computer code cannot converge in the current state of the art. So numerous astrophysical applications are currently achieved within the semi-classical perturbation (SCP) theory.
3.7.4. The Modified Semi-Empirical Method (MSE). A number of applications were also achieved with the Modified Semi-Empirical (MSE) method [25] [26] [27] and other papers cited in [28]. It is less accurate, though more simpler to use due to the considerably smaller set of atomic data needed in comparison with the SCP theory [28]. It can effectively replace the SCP method when this one cannot be used due to a lack of atomic data.

3.8. Systematic trends and regularities
Systematic trends for energy levels and oscillator strengths in the Coulomb approximation are well known. Asymptotic behaviours of the cross sections at very small or very high incident energy are also well known. Systematic trends and regularities as a function of temperature, density, quantum numbers, have been found for Stark broadening widths and shifts. This has been an active subject of research since many years, cf. [29] and references therein. This topic has a growing interest with the calculations of widths and shifts at a large scale for many temperatures and densities, especially for the use of databases. Cf. the recent example [30], that concerns the behaviour of the widths and shifts of Ne I, 1837.8 nm as a function of temperature. Many other examples can be found in papers concerned with Stark broadening, it is not possible to enumerate them here.

4. Astrophysical applications within the SCP and MSE theories
During the recent past years, the work of the French-Serbian-Tunisian team was focused toward calculations of numerous Stark widths and shifts of astrophysical interest. On the atomic physics side, a special effort was turned towards ab initio calculations. On the astrophysical side, recent calculations have been performed for trace elements, for line stratification and for lines of white dwarfs. A very few selected examples chosen among a great number of published results are given below.

4.1. Trace elements and abundance determinations
About 50% of the element abundances beyond iron are produced via slow neutron capture nucleosynthesis (s-process) [31], which starts at iron-peak seed, synthesizing the elements between iron and bismuth. The three isotopes of tellurium Te-122, 123 and 124 provide a unique opportunity to investigate s-process. The SCP method was used to calculate the Stark broadening parameters for 4 Te I multiplets [32] within the ultraviolet, visible and infrared wavelength range, in the range of temperatures and densities for A and B type stars and DA, DB and cool DO white dwarfs where Stark broadening is of interest. Such temperatures may be of interest also for the modelling of subphotospheric layers even in cooler stars. If Doppler broadening dominates the line centre, Stark broadening may influence line wings in the upper layers of the atmosphere. Yet the Stark broadening mechanism is absolutely dominant in comparison with the thermal Doppler mechanism in deeper layers of the stellar atmosphere. The importance of taking into account accurate Stark broadening data for modelling and analyzing of neutral tellurium spectra confirms previous findings for a number of trace elements in chemically peculiar stellar spectra. Other examples are given and discussed in [28]: Cr II [33], Ge I [35], Ga I [34], Cd I [36], Cr I [33], and others. In particular, neglecting the Stark broadening mechanism introduces an error of between 10% and 45% in the equivalent widths and corresponding errors in the abundances for the Nd II lines in A type stars.

4.2. Chemical stratification
Accurate Stark broadening data are also crucial for studying chemical stratification by fitting the calculated and observed spectra. The following concerns new Stark broadening calculations made with the SCP method, most with the Bates and Damgaard approximation [13] for the oscillator strengths. For Si I lines, it is interesting to note that the electron impact is dominant, but collisions with proton and He II impacts are also important for broadening of the lines [37]. From the comparison of our calculations with the observations it was found that Stark broadening and inclusion of stratification can explain asymmetry of the Si I 6142.48 Å and 6155.13 Å lines in the atmosphere of a rapidly
oscillating roAp star, where these lines are asymmetrical and shifted. The obtained results are the first calculated data for the considered lines. In fact, the Stark broadening effect can explain the asymmetry as well as the shift of these lines in many stars including the Sun. In hotter Ap stars, besides Stark broadening, the stratification plays a very important role in producing line asymmetry. The sensitivity of the line asymmetry to changes in the abundance variation through the stellar atmosphere can be used for such spectroscopic diagnostics. Chromium is one of the most anomalous elements in Ap stars. Cr I lines from 4p−4d transitions are known to have fairly large Stark damping. When interpreting observations of a Cr-rich Ap star, it was shown [33] that Stark broadening is important to synthesize the profiles. In addition, the SCP calculations showed that the contribution of proton and He II collisions to the line width and shift is significant and comparable, and is sometimes even larger than electron-impact contribution depending of the electron temperature. Moreover, not only the Stark line width, but also the Stark shift may contribute to the blue as well as to the red asymmetry of the same line depending on the electron-, proton-, and He II density in stellar atmosphere. In addition, although they belong to the same multiplet, the widths and shifts of the different lines can be quite different.

Recent abundance and stratification analysis [38] based on Cr II lines in the spectrum of the Ap star HD 133792 was revisited in [39], by using new SCP Stark broadening data for synthetic spectrum calculations. These new theoretical results agree with the scarce experimental results and provide an accurate fit to the line profiles observed in Ap stars. In conclusion, accurate Stark broadening are essential to take into account for the study of abundance stratification, not only for the Cr I abundance, but also for all trace elements, especially in hot stars.

Other examples concerning Cu III, Se III, Au II, Co III, Nd II, etc. can be found in [32].

4.3. White dwarfs
White dwarfs are denser and sometimes hotter than stars of the principal sequence. The electronic density lies between \(10^{17}\) and a few \(10^{19}\) cm\(^{-3}\), the temperature is about \(10^4\) to a few \(10^4\) K, so Stark broadening is the dominant mechanism, and often more important than the Doppler profile in the line centre.

4.3.1. Stark width compared to the Doppler width. For example, the influence of Stark broadening on 6 Cu III, 6 Zn III and 3 Se III spectral lines in DB white dwarf atmospheres was investigated [40]. MSE Stark broadening calculations were achieved because the SCP approach could not be applied due to the lack of reliable atomic data. As an illustration of the relative order of magnitude of the different causes of broadening, it was shown that the Stark width of the Se III 3815.5 Å line is larger than the Doppler one by up to two orders of magnitude within the range of optical depths considered for the plasma conditions in the DB white dwarf atmospheres. A detailed investigation of Stark broadening of 84 UV spectral lines of Cd III was performed by the MSE approach. It was applied to F0–B0 type stars and DA and DB white dwarfs [41]. As for A type stars, this work shows that the neglect of Stark broadening introduces an error of between 10% and 45% in the equivalent widths and corresponding errors in the abundances of white dwarfs.

4.3.2. Ionized manganese lines and effect of the hyperfine splitting. Ionized manganese lines are of interest for the analysis and modelling of stellar spectra as for example for HgMn stars and DB white dwarfs. SCP calculations and oscillator strengths with the Bates and Damgaard [13] approximation, due to the lack of reliable atomic data, were performed [42] and compared to recent experiments [43]. The importance of taking into account the different hyperfine structure components by summing their respective profile intensities was emphasized. They indeed have the same width and shift equal to that of the fine structure line. This falls within the same reasoning [44] [45] where the importance of adding the different fine structure lines of the Hz line of hydrogen and Lyman hydrogenic ionic lines broadened by electrons and ions collisions was shown. In spite of that, a large disagreement (up to a factor 2) remains between the Mn II SCP calculations and the experiments.
Considering that the experiments are reliable, and that the Bates and Damgaard approximation may be insufficient for heavy atoms, this may show the importance of having a reliable atomic structure for Stark broadening calculations of heavy atoms.

The obtained results were used [46] for the investigation of the influence of Stark broadening on Mn II spectral line profiles in Ap stars and also in DB white dwarfs. It was again demonstrated that Stark broadening is an essential mechanism to take into account for the analysis of DB white dwarf spectra.

4.3.3. C II lines in white dwarfs with carbon atmosphere. A new type of white dwarfs has recently been discovered [46] [47]. The surface composition of these stars is mostly composed of carbon. There is hardly neither hydrogen nor helium in the atmosphere. In order to understand the origin and evolution of this new type of stars, the determination of gravity is essential, and it is necessary to develop a new generation of accurate models. Thus it is crucial to take into account accurate Stark broadening for modelling the atmosphere. In fact there is a lack of Stark broadening data for C II. Using SCP approach and the online TOPbase R-matrix atomic structure, ab initio Stark broadening parameters for 148 C II multiplets have been obtained. More details on the calculations are discussed in [49].

4.4. Ab initio calculations for stellar spectra modelling
The Cowan code coupled to the MSE approach was applied [50] to new Stark broadening calculations of several multiplets of S II, S III and S IV and demonstrated the interest of ab initio calculations. Then method grew up and was coupled to the SCP approach and permitted to obtain data for several hundreds of lines with an accurate atomic structure in a reasonable time of computation. Besides R-matrix and TOPBase currently applied to C II lines, the SST package was used in several papers in view of stellar modelling applications: Si VI [51] especially for DO white dwarfs atmospheres, Ne V [52], Si V [53].

5. The STARK-B database
Nowadays, the access to numerous data via an online database becomes crucial. Numerical and bibliographic Databases in Atomic and Molecular Physics are essential for both the modelling of various astrophysical media and the interpretation of astrophysical spectra provided by ground or space-based telescopes.

In this context, we are currently developing the STARK-B database [54] of calculated widths and shifts of isolated lines of atoms and ions due to electron and ion collisions in the impact approximation. It is planned to include the results of calculations made by Dimitrijević, Sahal-Bréchot, and co-workers, and contained in more than 120 publications. It is a collaborative project between the Astronomical Observatory of Belgrade and the Paris Observatory. The database is currently developed in Paris, and a mirror is planned in Belgrade. It is devoted to modelling and spectroscopic diagnostics of stellar atmospheres and envelopes. In addition, it is relevant to laboratory plasmas, laser equipments and technological plasmas. Hence, the domain of temperatures and densities covered by the tables is wide and depends on the ionization degree of the considered ion. The data are gradually implemented and the database is already on line though not yet complete.

A graphical interface is provided. First, the user clicks on the element in the Mendeleev periodic table and then on the ionization degree of interest. Next, with a few clicks, the user chooses the colliding perturber(s), the perturber density, the transition(s) by quantum numbers and the plasma temperature(s). Then a table displaying the widths and shifts is generated. Bibliographic references are given and linked to the publications via the SAO/NASA ADS Physics Abstract Service [55] and/or within DOI. They can be freely downloaded if the access is not restricted. The widths and shifts data can be downloaded in ASCII. A request by domain of wavelengths instead by transitions is planned. The implementation of remaining data is in progress. The further developments especially concern the compatibility of the output with the VO (Virtual Observatory) standards, which will be defined by VAMDC.
In fact, STARK-B is a part of VAMDC (Virtual Atomic and Molecular Data Centre) [56]. VAMDC is an European Union funded collaboration between groups involved in the generation and use of atomic and molecular data which was created in summer 2009 for three years. In fact, the free exchange of atomic and molecular data requires the definition both of standards which model the data structure and of tools that implement these standards and that help to carry out science using these data. VAMDC aims to build a secure, documented, flexible and interoperable e-science environment-based interface to existing atomic and molecular data. In particular, there is a collaborative project of standardisation of lists of lines within the IVOA (International Virtual Observatory Alliance) [57] consortium as well as a wider collaborative project of standardisation concerning many more processes of atomic and molecular data. Paris Observatory is a major partner in development of both standards and tools. All that is commented and described in more details in [58] [59].

6. Conclusion
The development of space born spectroscopy, building of giant telescopes of the new generation and increase of accuracy of computer codes for modelling of stellar atmospheres has opened up a new era for developing theoretical and experimental Stark broadening data with application to stellar spectra and stellar interiors modelling. Due to lack of space, the numerous applications to laboratory and technological plasmas have not been mentioned in the present paper. All these applications also shows the need to perform new accurate calculations for heavy atoms and ions. Ab initio methods, with sophisticated atomic structure packages coupled to the semi-classical perturbation method for Stark broadening calculations should be the best at present. The continuation of the development and service of a powerful and constantly updated online database is also indispensable.

7. Acknowledgments
A part of this work has been supported by VAMDC. VAMDC is funded under the “Combination of Collaborative Projects and Coordination and Support Actions” Funding Scheme of The Seventh Framework Program. Call topic: INFRA-2008-1.2.2 Scientific Data Infrastructure. Grant Agreement number: 239108

8. References
[1] Bildsten S, Chang P and Paerels P 2003 *Astrophys. J.* **591** L29
[2] Rovenskaya N I 2004 *Astrophys. Space Sci.* **291** 113
[3] Baranger M 1958a *Phys. Rev.* **111** 481
[4] Baranger M 1958b *Phys. Rev.* **111** 494
[5] Baranger M 1958c *Phys. Rev.* **112** 855
[6] Dimitrijević M S, Ryabchikova T, Popović L Č, Shulyak D and Khan S 2005 *A&A* **435** 1191
[7] Sahal-Bréchot S 1969a *A&A* **1** 91
[8] Sahal-Bréchot S 1969b *A&A* **2** 322
[9] Sahal-Bréchot S 1974 *A&A* **35** 321
[10] Fleurier C, Sahal-Bréchot S and Chapelle J 1977 *JQSRT* **17** 595
[11] Dimitrijević M S and Sahal-Bréchot S 1984 *JQSRT* **31** 301
[12] Mahmoudi W F, Ben Nessib N and Sahal-Bréchot S 2008 *EPJD* **47** 7
[13] Bates D R Damgaard A 1949 *Trans. Roy. Soc. Lond. Ser. A* **242** 101
[14] Ben Nessib N 2009 *New Astron. Rev.* **53**, 255
[15] Cunto W, Mendoza C, Ochsenbein F and Zeippen CJ 1993 *A&A* **275** L5
[16] http://cdsweb.u-strasbg.fr/topbase/topbase.html
[17] Cowan RD 1981 *The Theory of Atomic Structure and Spectra* (Berkeley, CA: University of California Press)
[18] Eissner W Jones M and Nussbaumer H 1974 *Comput. Phys. Commun.* **8** 270
[19] Eissner W 1998 *Comput. Phys. Commun.* **114** 295
[20] Saraph H E 1978 *Comput. Phys. Commun.* **15** 247
[21] Elabidi H, Ben Nessib N, Cornille M, Dubau J and Sahal-Bréchot S 2008 J. Phys. B 41 025702
[22] Elabidi H, Ben Nessib N and Sahal-Bréchot S 2004 J. Phys. B 37, 63
[23] Elabidi H, Sahal-Bréchot S and Ben Nessib N 2009 EPJD 54 51
[24] Alecian G, Michaud G and Tully J 1993 Ap. J. 411 882
[25] Dimitrijević M S and Konjević J 1980 JQSRT 24 451
[26] Dimitrijević M S 1982 A&A 112 251
[27] Dimitrijević M S and Krššak V 1986 A&A 165 269
[28] Dimitrijević M S 2003 A&A Trans. 22 389
[29] Pučić J, Dojčinović I P, Nikolć M, Šćepanović M, Obradović B M and Kuraica M M 2008 ApJ 680 803
[30] Chrtsova M, Dimitrijević M S, Simić Z and Sahal-Bréchot S 2010 J. Phys. Conf. 207 012025
[31] Reifarth R 2010 J. Phys. Conf. Ser. 202 012022
[32] Simić Z, Dimitrijević M S and Kovačević A 2009 New. Astr. Rev. 53 246
[33] Dimitrijević M S, Ryabchikova T, Simić Z, Popović L Č and Dačić M S 2007 A&A 469 681
[34] Dimitrijević M S, Dačić M, Cvetković Z and Simić Z 2004 A&A 425 1147
[35] Dimitrijević M S, Jovanović P and Simić Z 2003 A&A 410 735
[36] Simić Z, Dimitrijević M S, Milovanović N and Sahal-Bréchot S 2005 A&A 441 391
[37] Dimitrijević M S, Ryabchikova T, Popović L Č, Shulyak D and Tsymbal V 2003 A&A 404 1099
[38] Kochukhov O, Tsymbal V, Ryabchikova T, Makaganyk V, and Bagnulo S 2006 A&A 460 831
[39] Dimitrijević M S, Ryabchikova T, Simić Z, Popović L Č and Dačić M S 2007 A&A 469 681
[40] Simić Z, Dimitrijević M S, Popović L Č and Dačić M 2006 New Astron. 12 187
[41] Milovanović N, Dimitrijević M S, Popović L Č, and Simić Z 2004 A&A 417 375
[42] Popović L Č, Dimitrijević M S, Simić Z, Dačić M, Sahal-Bréchot S and Kovačević A 2008 New Astron. 13 85
[43] Djeniže S, Bukvić S, Srećković A and Nikolić Z 2006 NewAstron. 11 256
[44] Stehlé C and Feautrier N 1985 J. Phys. B: At. Mol. Phys. 18 1297
[45] Stehlé C 1985 J. Phys. B: At. Mol. Phys. 18 L43
[46] Simić Z, Dimitrijević M S, Popović L Č, Dačić M, Kovačević A and Sahal-Bréchot S 2008 Contrib. Astr. Obs. Skal. 38 451
[47] Dufour P, Liebert J, Fontaine G and Behara N 2007 Nature 450 522
[48] Dufour P, Fontaine G, Liebert J, Schmidt G D and Behara N 2008 Astrophys. J. 683, 978
[49] Larbi-Terzi N, Sahal-Bréchot S, Ben Nessib N and Dimitrijević M S 2010 Stark broadening parameters for white dwarf atmospheres research (JPCS preprint SPIG 25th)
[50] Milovanović N and Dimitrijević M S 2007 Cowan Code and Stark Broadening of Spectral Lines of S II, S III and S IV Spectral Line Shapes in Astrophysics: VI Serbian Conference on Spectral Line Shapes in Astrophysics (Sremski Karlovci, Serbia, 11-15 June 2007) AIP Conf. Proc. vol 938, pp. 258-261
[51] Hamdi R, Ben Nessib N, Milovanović N, Popović L Č, Dimitrijević M S and Sahal-Bréchot S 2008 MNRAS 387 871
[52] Hamdi R, Ben Nessib N, Dimitrijević M S and Sahal-Bréchot S 2007 ApJS 170 243
[53] Ben Nessib N, Dimitrijević M S and Sahal-Bréchot S 2004 A&A 423 397
[54] http://stark-b.obspm.fr
[55] http://www.adsabs.harvard.edu/
[56] http://www.vamdc.eu
[57] http://www.ivoa.net/
[58] Dimitrijević M S, Sahal-Bréchot S, Kovačević A, Jevremović D, Popović L Č 2010 European Virtual Atomic and Molecular Data Center – VAMDC (JPCS preprint SPIG 25th)
[59] Dubernet ML, Boudon V et al. 2010 JQSRT 111 2151