Spectral line broadening in astrophysical plasmas

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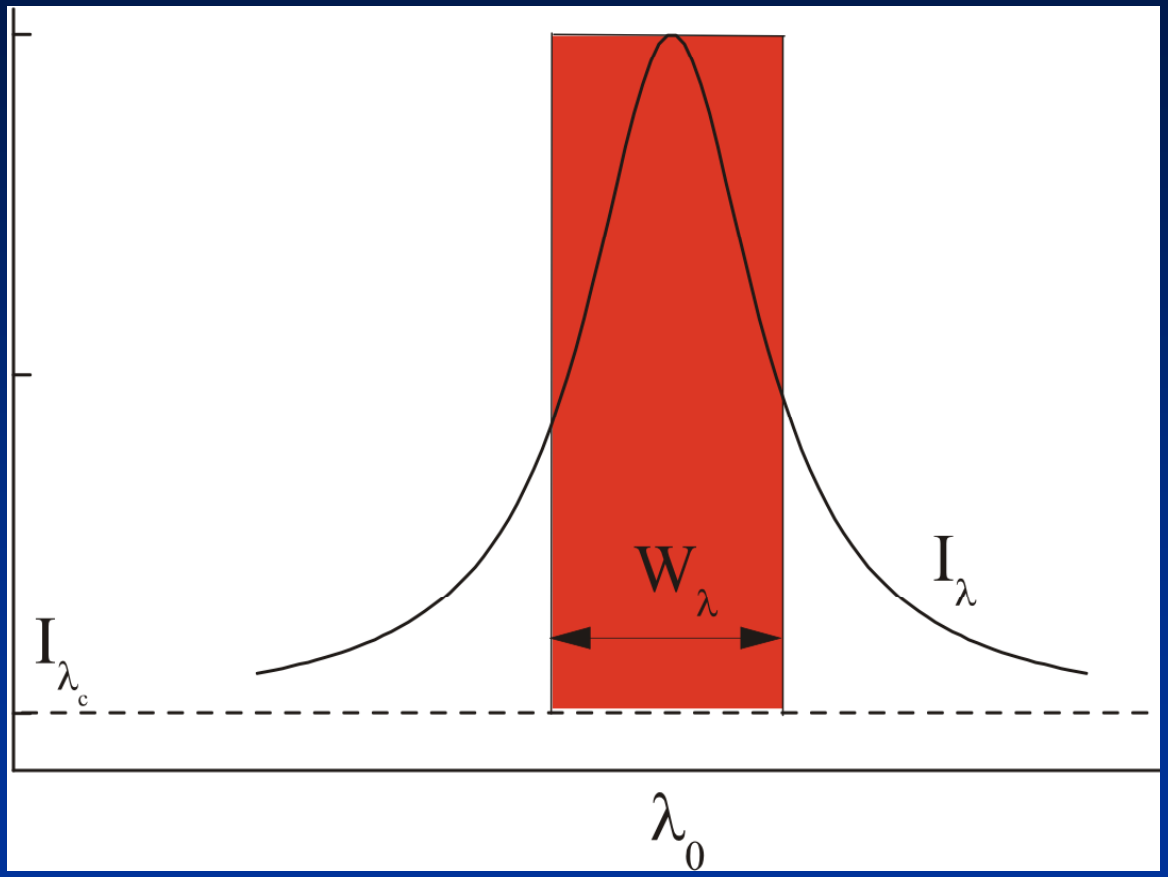
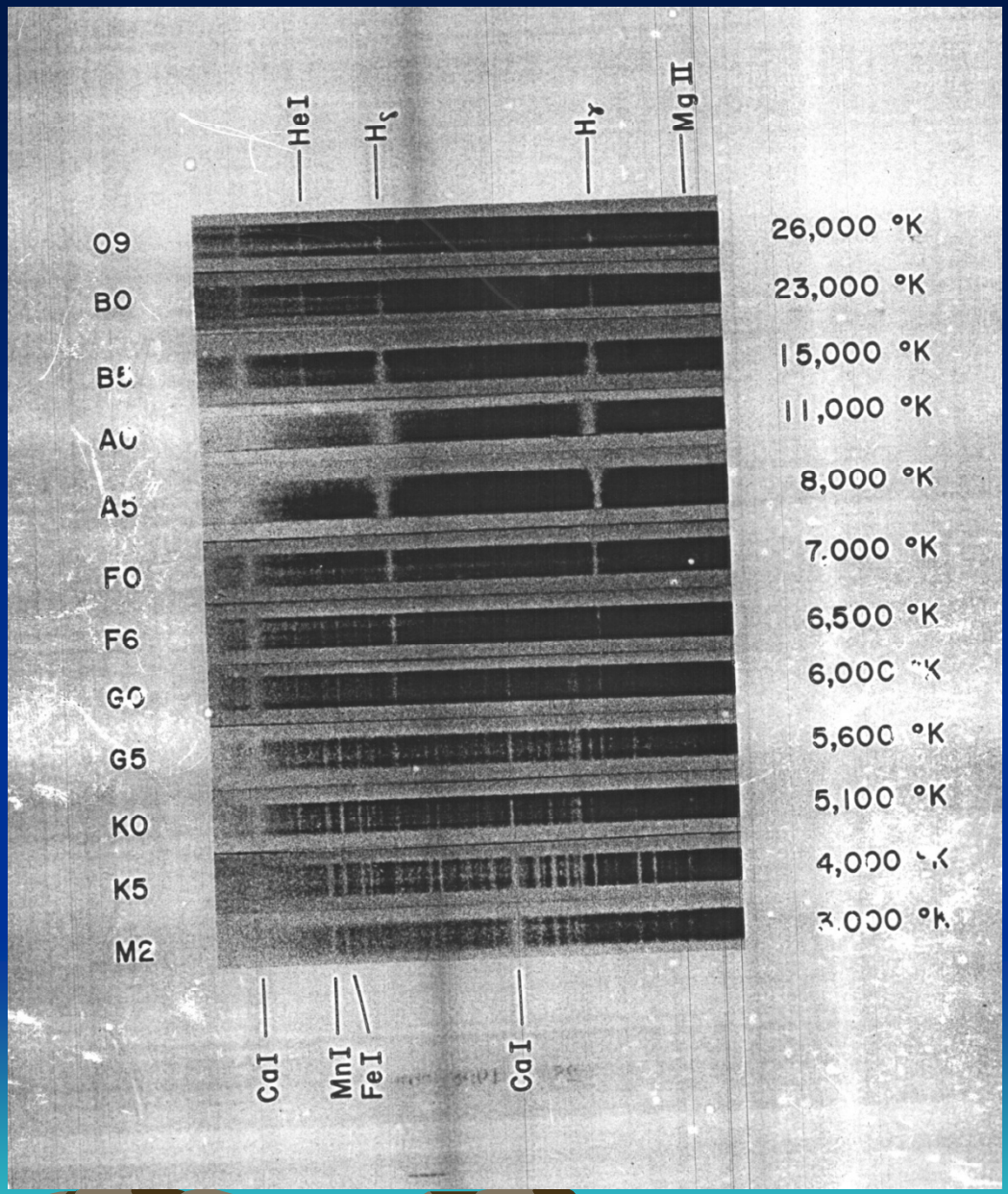
- A spectral line is never monochromatic. It always has some width due to various reasons.
- BROADENING MECHANISMS:
- NATURAL BROADENING
- DOPPLER BROADENING – depends on Temperature
- PRESSURE BROADENING – depends on temperature and perturber density (pressure)



EMISSION SPECTRAL LINE

With I is denoted intensity, with c continuum and with W equivalent width

Spectral type and effective temperature of a star can be determined by comparing its spectrum with a standard spectrum for a spectral type and effective temperature. In Fig. left are spectral types and right effective temperatures.



PRESSURE BROADENING

- VAN DER WAALS BROADENING – broadening by collisions with neutral atoms
- RESONANCE BROADENING – broadening due to non radiative charge exchange for atoms of the same kind when one of the energy levels of the transition responsible for the line has an allowed transition on the ground level
- STARK BROADENING – broadening by interaction with charged particles producing Stark effect – splitting and shift of atomic energy levels depending on the strength of electric field.

STARK BROADENING

- Stark effect may have a linear dependence on the strength of electric field – LINEAR STARK EFFECT, which is the case for Hydrogen and Hydrogen-like ions, or a quadratic dependence – QUADRATIC STARK EFFECT, which is the case for non-hydrogenic atoms and ions.

NATURAL BROADENING

- Natural broadening is the consequence of the fundamental relations in nature described by the Heizenberg uncertainty relation for position and momentum. It may be transformed in relation between energy value for an atomic energy level and electron lifetime on this level i.e.
- $\Delta E \, \Delta t \geq = h/2\pi$

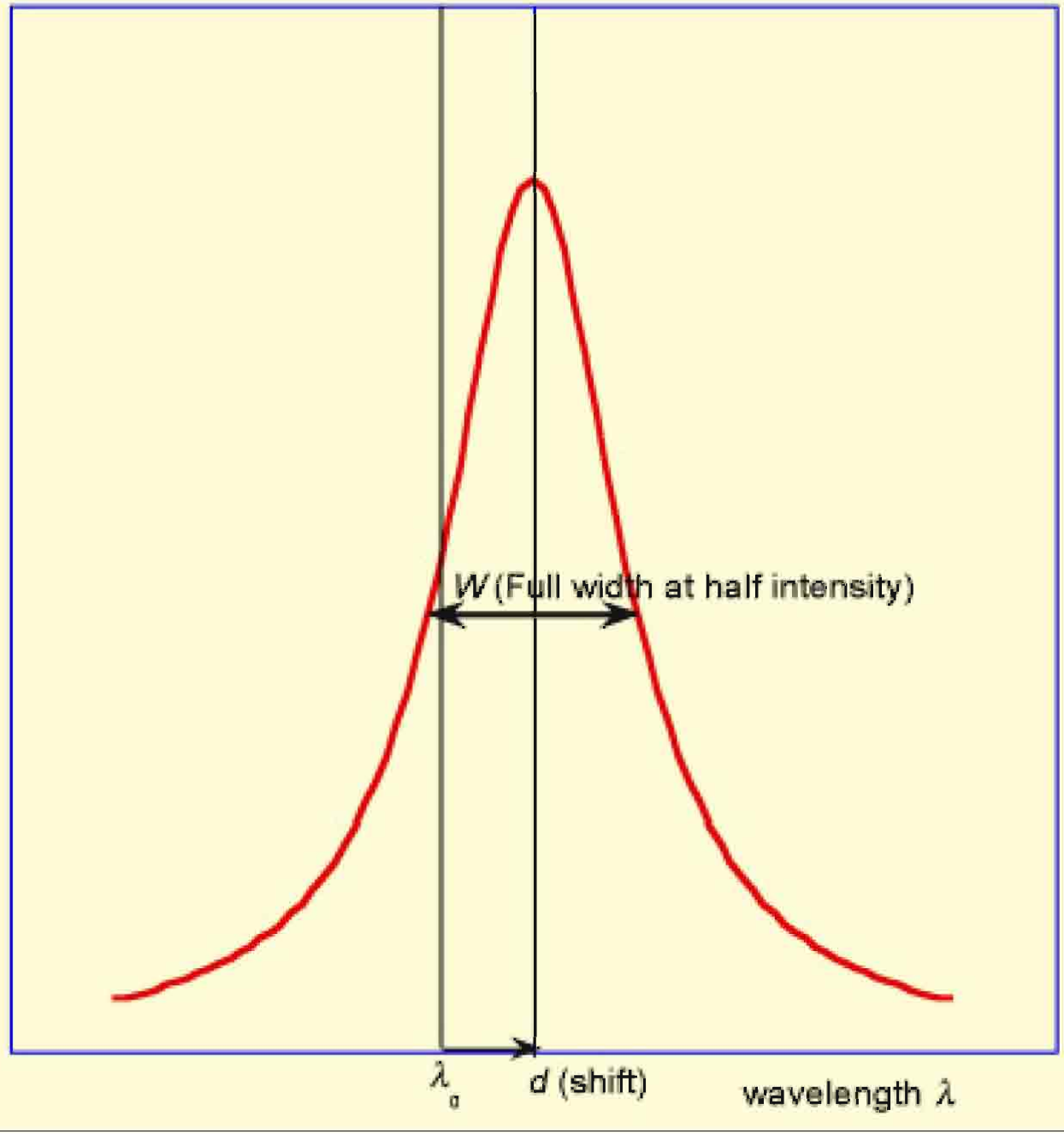
- Classical value for the natural line width (Full Width at Half Intensity Maximum – FWHM) does not depend on atomic characteristics and plasma conditions and
- is equal to 0.000118 Å. The line profile is the Lorentz one.

LORENTZ PROFILE

I – Intensity; γ =W – Full width at half intensity maximum, ω - frequency

$$I(\omega)d\omega = I_0 \frac{\gamma d\omega}{2\pi\left[(\omega-\omega_0)^2 + \left(\frac{\omega}{2}\right)^2\right]} .$$

Lorentz Profile



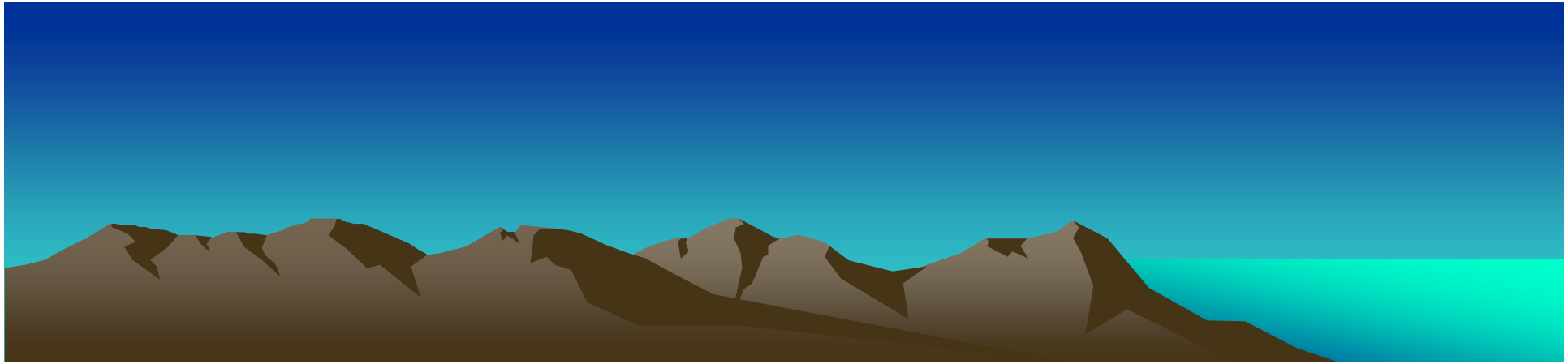
DOPPLER BROADENING

- Emitters (or absorbers) in plasma move chaotically and have a random distribution of velocity components in direction of observer. Due to the Doppler effect, the radiation is shifted and these randomly distributed shifts produce a line shape having Gaussian distribution of line intensity (I) with wavelengths λ.

$$I(\Delta\lambda) = (\Delta\lambda_D\sqrt{\pi})^{-1}\exp\left[-(\Delta\lambda/\Delta\lambda_D)^2\right]$$

$$\Delta\lambda_D = \left(\frac{\lambda_0}{c}\right)\ (2kT/M)^{1/2}$$

$$2\mathrm{w}(\text{Å}) = 1.665\Delta\lambda_D = 7.16\times10^{-7}\lambda(\text{Å})\sqrt{T(\text{K})/M(\text{a.j.m.})}\ .$$



VAN DER WAALS BROADENING

- Due to van der Waals force between neutral atoms the atomic energy level value depends on the distance between atoms and consequently also the energy of the emitted photon. When we make a statistical average over the ansemble of emitters or absorbers in plasma, we obtain a broadened line shape. Within the simple theory of Lindholm and Foley the FWHM is equal to:

Here v barr is the average relative velocity of colliding atoms and N zero perturber density.

-

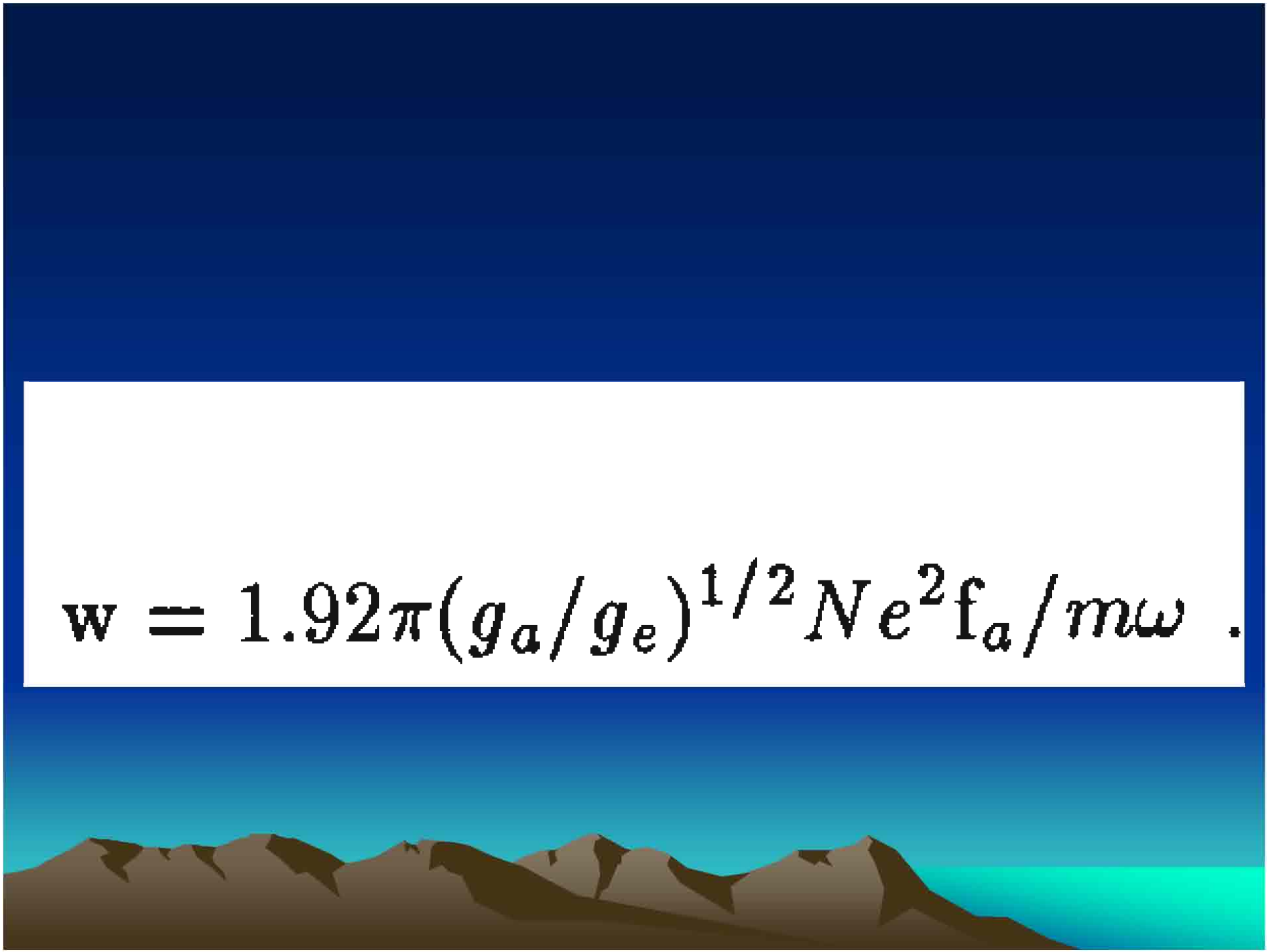
$$\gamma = 8.16 \left(\frac{C_6}{\hbar} \right)^{2/5} \bar{v}^{3/5} N_0$$

RESONANCE BROADENING

- If from the upper or lower level of transition forming spectral line there is a dipolly allowed transition to the ground state, and the emitter/absorber is surrounded by the atoms of the same kind in the ground state, resonance broadening may be present. Namely if we have an excited atom, it is possible that the emitted photon will be absorbed by one of surrounding atoms. Since we have again

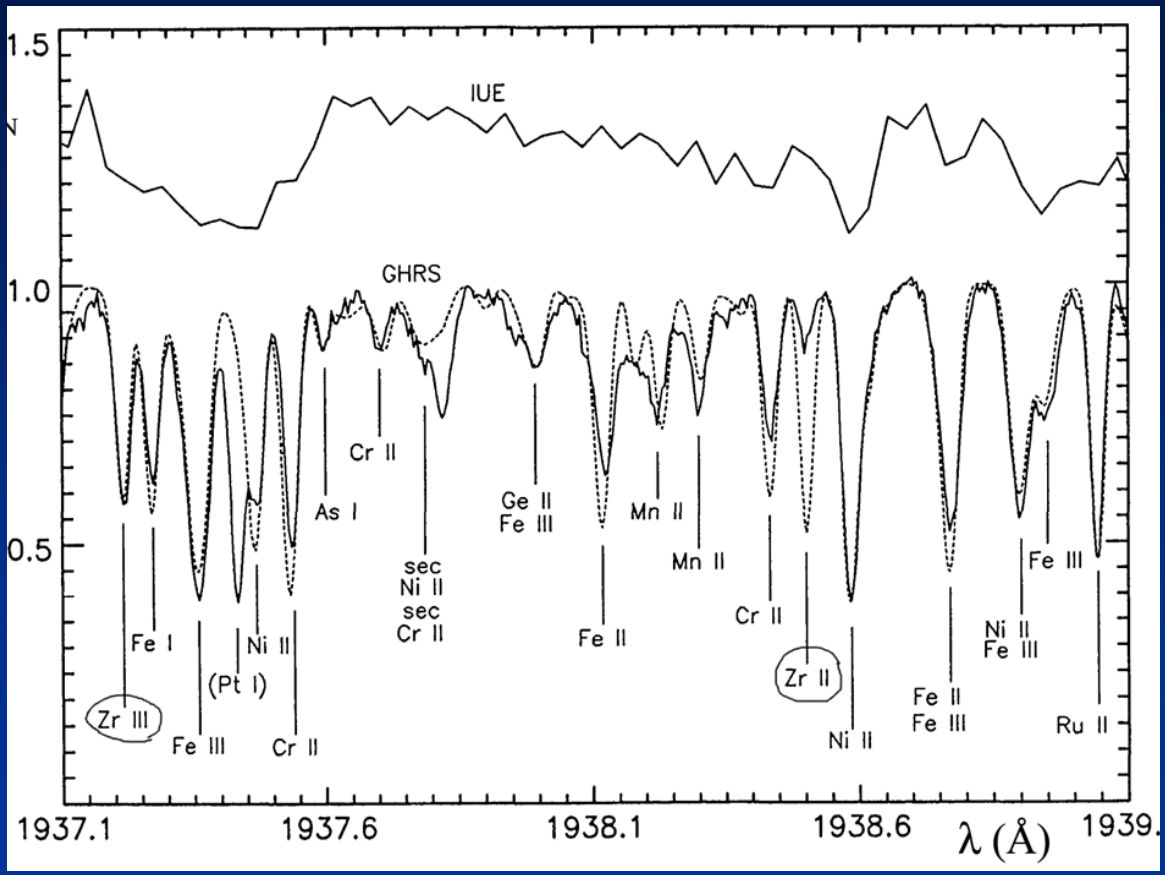
- an excited atom and an atom in the ground state, we can not detect this. However this is an additional possibility for the shortening of lifetime of the optical electron on the considered atomic energy level so that the corresponding spectral line, in accordance with the Heizenberg uncertainty principle, is addiitionally broadened.

- Ali and Griem (Phys. Rev. A 1966, 140, 1044, Phys. Rev. A 144, 366) obtained for the width of resonantly broadened line in function of statistical weights g of emitting (e) and absorbing (a) states, density of atoms of the same kind in the ground state N and oscillator strength f for the transition to the ground state, the expression:


$$w = 1.92\pi(g_a/g_e)^{1/2} N e^2 f_a / m\omega \ .$$

NEEDS FOR LARGE STARK BROADENING DATA SET

- - DEVELOPMENT OF COMPUTERS
- FOR EXAMPLE:
- PHOENIX CODE FOR MODELLING OF STELLAR ATMOSPHERES INCLUDES A PERMANENTLY GROWING DATABASA WITH ATOMIC DATA FOR MORE THAN 500 MILLIONS TRANSITIONS
- - SATELLITE BORNE SPECTROSCOPY



Example of advance of satellite born spectroscopy

Part of Chi Lupi spectrum obtained with International Ultraviolet explorer (IUE) and with Godhard High Resolution Spectrograph on Hubble telescope (GHRS). One can see how lines of trace elements become more and more important.

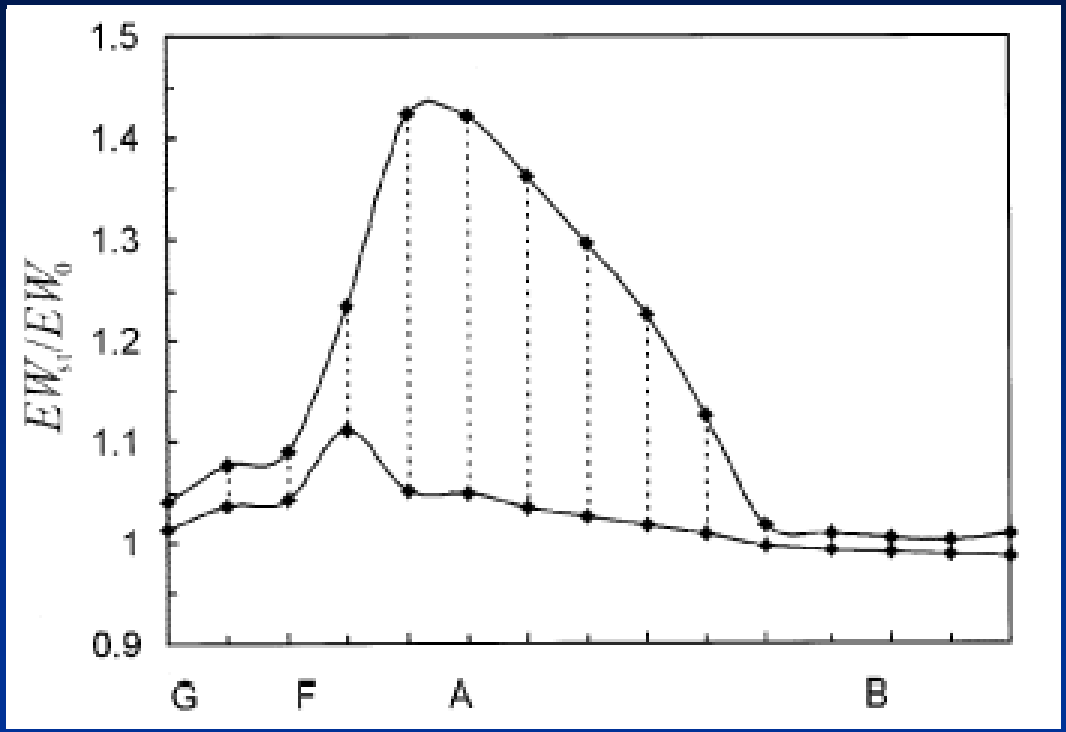
- STARK BROADENING IS IMPORTANT FOR:
- - ASTROPHYSICAL PLASMAS
- - LABORATORY PLASMAS
- - TECHNOLOGICAL PLASMAS

ASTROPHYSICAL PLASMAS

- Stark broadening may be important for plasma conditions from
- NEUTRON STARS $T=10^6$-10^7K
- Ne= (1-100)x10^{22}cm^{-3}, white dwarfs, hot stars, up to other extreme conditions :
- FOR RADIO RECOMBINATION LINES FROM H I (T=50K) AND H II (T=10000K) REGIONS Ne = 1-1000 cm^{-3}

INTERSTELLAR MOLECULAR CLOUDS

- In interstellar molecular clouds, typical electron temperatures are around 30 K or smaller, and typical electron densities are 2-15 cm^{-3}. In such conditions, free electrons may be captured (recombination) by an ion in very distant orbit with principal quantum number (n) values of several hundreds and deexcite in cascade to energy levels n-1, n-2,... radiating in radio domain. Such distant electrons are weakly bounded with the core and may be influenced by very weak electric microfield. Consequently, Stark broadening may be significant.

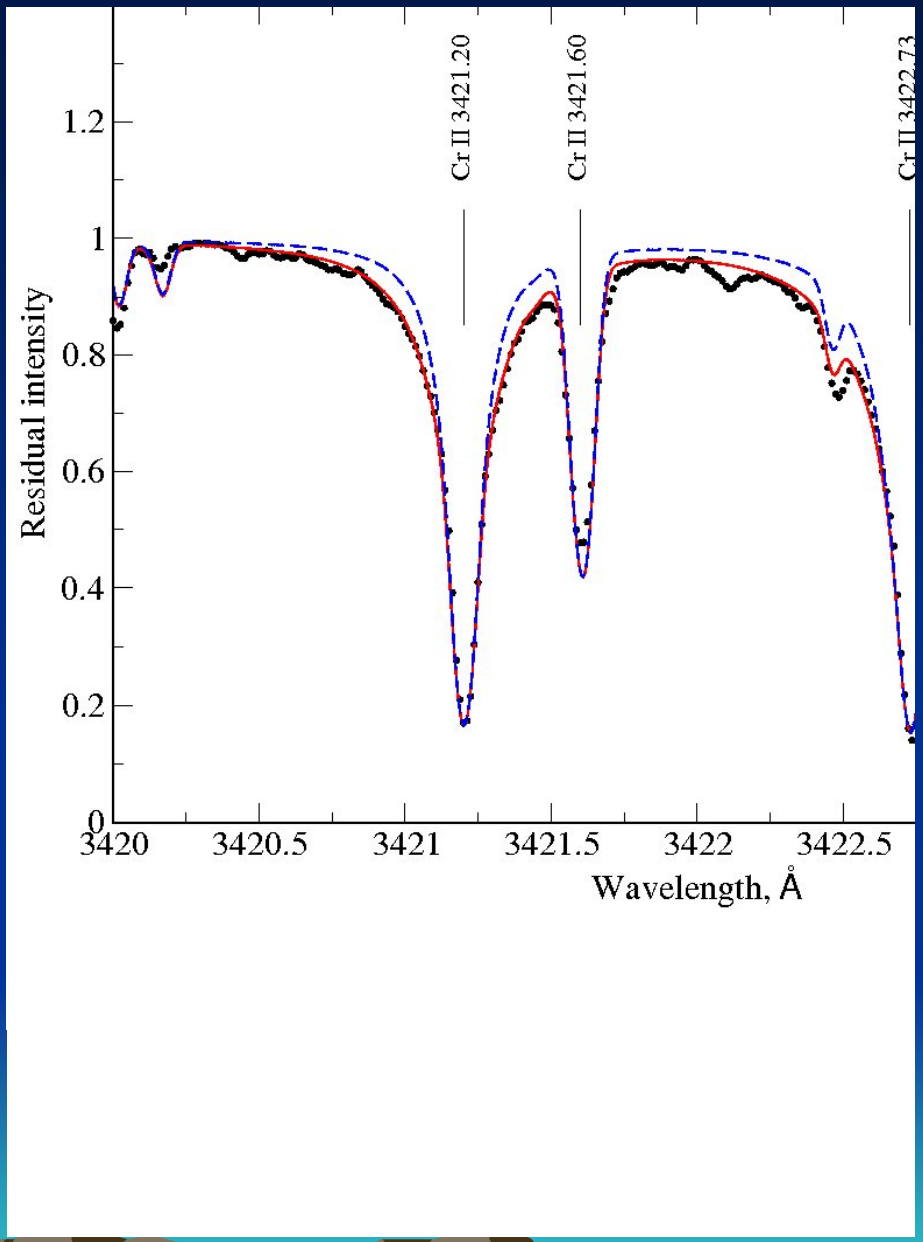


Maximum (top line) and minimum (bottom line) of the ratio of the equivalent widths EW_{St}/EW_0 (with – St and without – 0 Stark broadening included) for different types of stars. The maximum and minimum value for 38 Nd II lines considered are summarized (L.Č. Popović, S. Simić, N. Milovanović, M.S. Dimitrijević Astrophys. J. Suppl. Ser. 135, 109, 2001). One can see that the maximum is for A type stars.

Dimitrijević, M. S., Ryabchikova, T., Simić, Z., Popović, L. Č., Dačić, M. 2007, A&A, 469, 681

Comparison between observed Cr II line profiles in spectrum of Ap star HD133792 with synthetic. Full red line with semiclassical Stark broadening calculation. Blue dashed line with Kurucz estimates of Stark broadening.

The article is in the folder
BIBLIOGRAPHY_DIMITRIJEVIC



- For example, the influence of Stark broadening within a spectral series
- increases with the increase of the principal quantum number of the upper level and consequently, Stark broadening
- contribution may become significant even in the Solar spectrum.

STARK BROADENING DATA ARE NEEDED IN ASTROPHYSICS FOR EXAMPLE FOR:

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- STELLAR PLASMA DIAGNOSTIC
- - ABUNDANCE DETERMINATIONS
- - STELLAR SPECTRA MODELLING, ANALYSIS AND SYNTHESIS
  - CHEMICAL STRATIFICATION
  - SPECTRAL CLASSIFICATION
  - NUCLEAR PROCESSES IN STELLAR INTERIORS
  - RADIATIVE TRANSFER
  - STELLAR OPACITIES

- Line shapes enter in the models of radiative envelopes by the estimation of the Rosseland optical depth Let we take the direction of gravity as z-direction, dealing with a stellar atmosphere. If the atmosphere is in macroscopic mechanical
- equilibrium and with ρ is denoted gas density, the optical depth is

$$\tau_\nu = \int_z^\infty \kappa_\nu \rho \, \mathrm{dz},$$

$$\kappa_\nu = \mathrm{N(A,\, i)} \phi_\nu \frac{\pi \mathrm{e}^2}{\mathrm{mc}} \, \mathrm{f_{ij}},$$

- where κ_v is the absorption coefficient at a frequency v, N(A,i) is the volume density of radiation in the state I, f_{ij} is the absorption oscillator strength, m is the electron mass and ϕ_v is spectral line profile. The total opacity cross section per atom is:

$$\sigma_\nu(\mathrm{op}) = \mathrm{M}\kappa_\nu,$$

where M is the mean atom mass, and the opacity per unit length is

$$\rho\kappa_\nu = \mathrm{N}\sigma_\nu(\mathrm{op}).$$

Let us introduce an independent variable, a mean optical depth

$$\tau_{\mathrm{Ross}} = \int_z^\infty \kappa_{\mathrm{Ross}}\rho \, \mathrm{dz}.$$

For the Rosseland mean optical depth τ_{Ross}, κ_{Ross} is defined as

$$\frac{1}{\kappa_{\mathrm{Ross}}}\int_0^\infty \frac{\mathrm{dB}_\nu}{\mathrm{dT}}\,\mathrm{d}\nu = \int_0^\infty \frac{1}{\kappa_\nu}\frac{\mathrm{dB}_\nu}{\mathrm{dT}}\,\mathrm{d}\nu,$$

where

$$\mathrm{B}_\nu(\mathrm{T}) = \frac{2\mathrm{h}\nu^3}{\mathrm{c}^2}(\mathrm{e}^{\mathrm{h}\nu/\mathrm{kT}} - 1)^{-1}.$$

Now the Rosseland mean opacity cross-section is

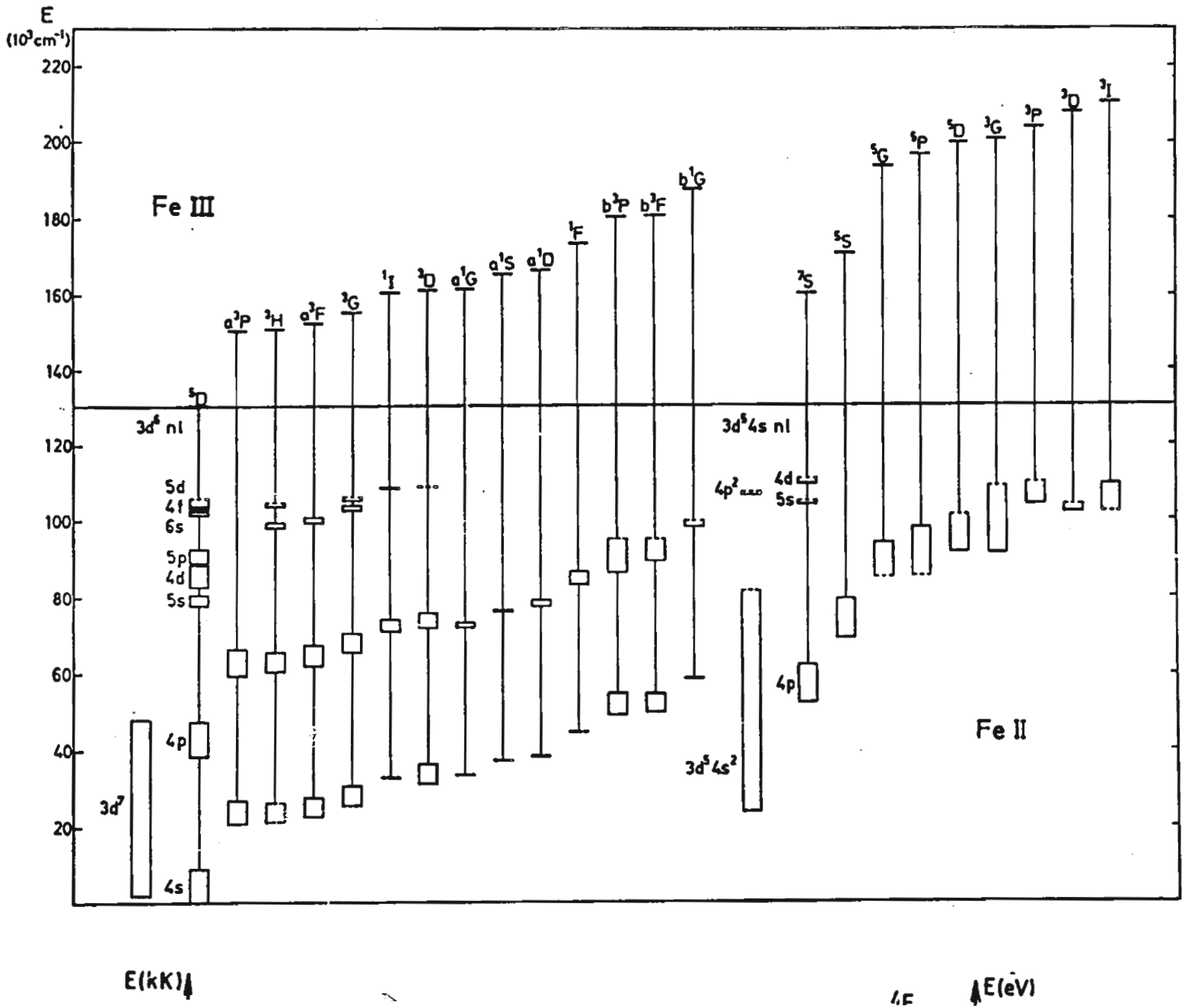
$$\sigma_{\mathrm{Ross}} = \mathrm{M}\kappa_{\mathrm{Ross}}.$$

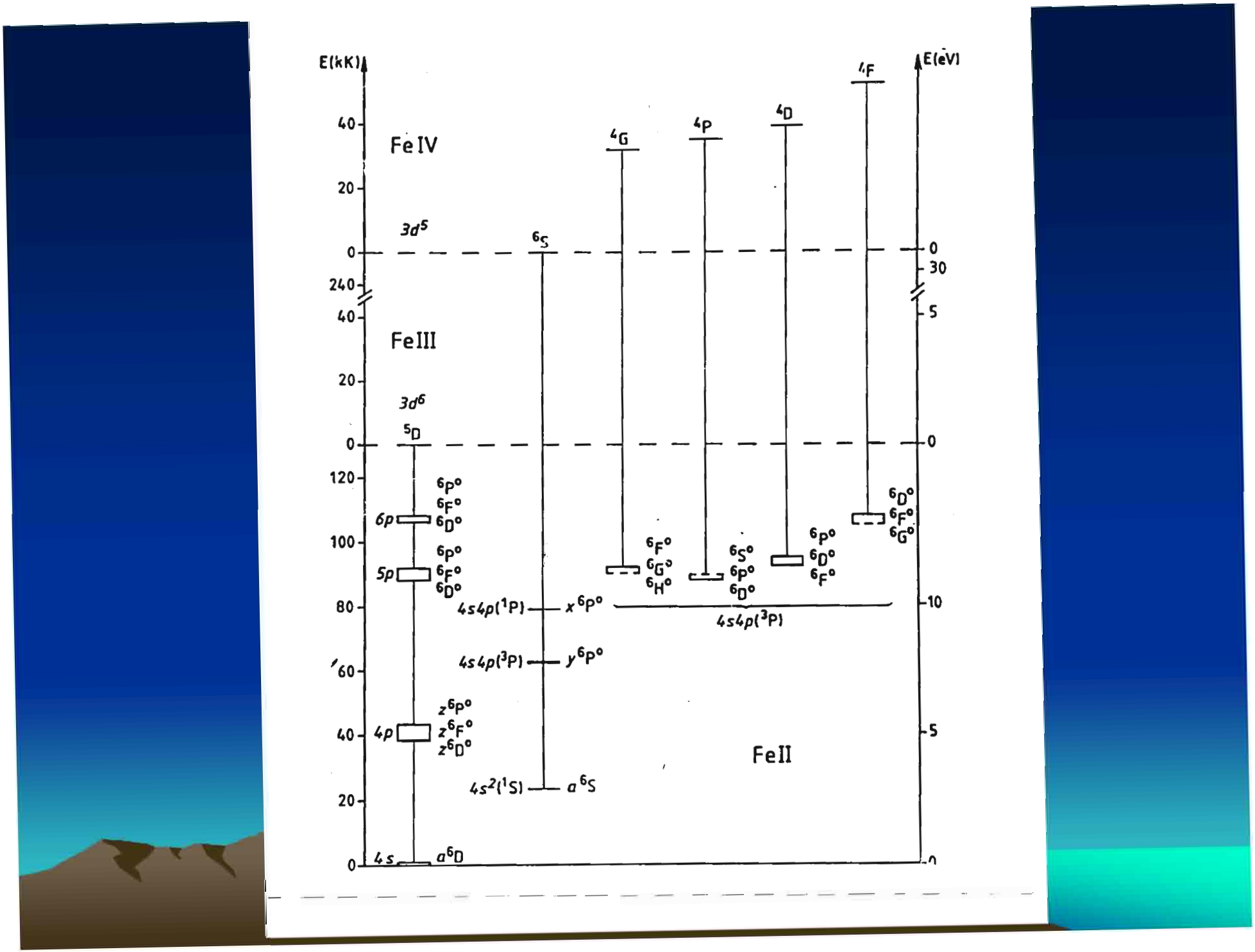
- THERE IS MORE INFORMATION IN THE ARTICLE :
- Dimitrijecić, M. S., 2003, Astron. Astrophys. Transactions, 22, 389,
- WHICH IS IN THE FOLDER “BIBLIOGRAPHY_DIMITRIJEVIC”

ASTROPHYSICAL SPECTRA

- In 1926, Henry Russel published in Astrophysical Journal his article with the analysis of Fe II spectrum resulting in 61 energy levels determined from 214 Fe II spectral lines, stating that "all the lines of astrophysical
- importance have been classified". This statement however, was too optimistic. In ninetiees 675 Fe II energy levels was known but that 50\% individual spectral features in high resolution astrophysical spectra is stil unclassified.

- This is, among other reasons, the consequence of the fact that energy levels of complex atoms, in particular of rare-earth atoms and ions are not always well known. As one example are shown energy levels of Fe II and Fe III. Also are shown examples how energy levels are presented in the literature.

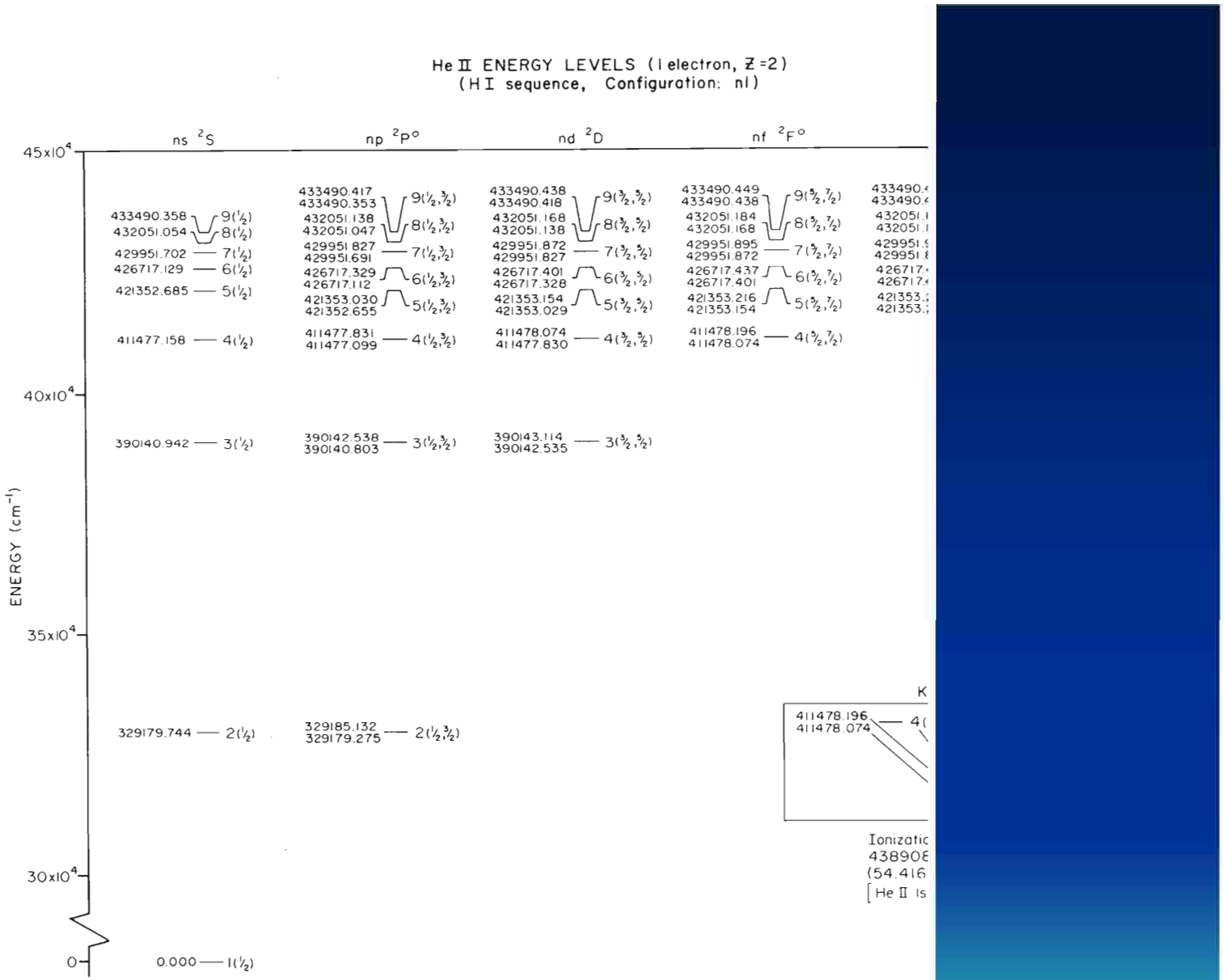

E
(10³cm⁻¹)
220
200
180
160
140
120
100
80
60
40
20
Fe III
Fe II
3d⁶ nl
3d⁵4s nl
3d⁵4s²
3d⁷
5d
4f
6s
5p
4d
5s
4p
4s
4d
5s
4p
a³P
³H
a³F
³G
¹I
³D
a¹G
a¹S
a¹D
¹F
b³P
b³F
b¹G
³S
⁵S
⁵G
⁵P
⁵D
³G
³P
³D
³I
⁵D
E(kK)
E(eV)


E(kK)
E(eV)
Fe IV
Fe III
Fe II
3d5
3d6
5D
6S
4G
4P
4D
4F
6P°
6F°
6D°
6p
5p
4p
4s
a 6D
4s2(1S)
a 6S
4s4p(1P)
x 6P°
4s4p(3P)
y 6P°
z 6P°
z 6F°
z 6D°
6F°
6G°
6H°
6S°
6P°
6D°
6F°
6P°
6D°
6F°
6D°
6F°
6G°
4s4p(3P)

ENERGY LEVELS OF IRON

Fe I—Continued

Configuration	Term	J	Level (cm^{-1})	g	Leading percentages		
$3d^7(^4F)4s$	$a\ ^5F$	5	6 928.266	1.40021	100		
		4	7 376.760	1.35004	100		
		3	7 728.056	1.24988	100		
		2	7 985.780	0.99953	100		
		1	8 154.710	-0.014	100		
$3d^7(^4F)4s$	$a\ ^3F$	4	11 976.234	1.254	98	1	$3d^64s^2\ ^3F2$
		3	12 560.930	1.086	98	1	
		2	12 968.549	0.670	98	1	
$3d^7(^4P)4s$	$a\ ^5P$	3	17 550.175	1.666	99		
		2	17 726.981	1.820	99		
		1	17 927.376	2.499	99		
$3d^6\ 4s^2$	$a\ ^3P2$	2	18 378.181	1.506	55	32	$^3P1$
		1	19 552.473	1.500	55	32	
		0	20 037.813		55	32	
$3d^6(^5D)4s4p(^3P^\circ)$	$z\ ^7D^\circ$	5	*19 350.892*	1.597	99		
		4	*19 562.440*	1.642	98		
		3	*19 757.033*	1.746	99		
		2	*19 912.494*	2.008	99		
		1	*20 019.635*	2.999	100		
$3d^6\ 4s^2$	$a\ ^3H$	6	19 390.164	1.163	100		
		5	19 621.005	1.038	100		
		4	19 788.245	0.811	100		
$3d^6\ 4s^2$	$b\ ^3F2$	4	20 641.109	1.235	71	21	$^3F1$
		3	20 874.484	1.073	71	21	
		2	21 038.985	0.663	71	21	
$3d^7(^2G)4s$	$a\ ^3G$	5	21 715.730	1.197	88	10	$3d^64s^2\ ^3G$
		4	21 999.127	1.051	88	10	
		3	22 249.428	0.756	88	10	
$3d^6(^5D)4s4p(^3P^\circ)$	$z\ ^7F^\circ$	6	*22 650.421*	1.498	100		
		5	*22 845.868*	1.498	99		
		4	*22 996.676*	1.493	99		
		3	*23 110.937*	1.513	99		
		2	*23 192.497*	1.504	99		
		1	*23 244.834*	1.549	100		
		0	*23 270.374*		100		
$3d^7(^4P)4s$	$b\ ^3P$	2	22 838.318	1.498	92	4	$3d^64s^2\ ^3P1$
		1	22 946.808	1.489	79	10	$3d^7(^2P)4s\ ^3P$
		0	23 051.742		79	12	$3d^7(^2P)4s\ ^3P$
$3d^6(^5D)4s4p(^3P^\circ)$	$z\ ^7P^\circ$	4	*23 711.457*	1.747	98		
		3	*24 180.864*	1.908	99		
		2	*24 506.919*	2.333	98		
$3d^6\ 4s^2$	$b\ ^3G$	5	23 783.614	1.200	88	10	$3d^7(^2G)4s\ ^3G$
		4	24 118.814	1.048	88	10	
		3	24 338.762	0.761	88	10	


He II ENERGY LEVELS (1 electron, Z=2)
(H I sequence, Configuration: nl)
ns ²S
np ²P°
nd ²D
nf ²F°
45x10⁴
40x10⁴
35x10⁴
30x10⁴
0
ENERGY (cm⁻¹)
433490.358 9(½)
432051.054 8(½)
429951.702 7(½)
426717.129 6(½)
421352.685 5(½)
411477.158 4(½)
390140.942 3(½)
329179.744 2(½)
0.000 1(½)
433490.417 433490.353 9(½,3/2)
432051.138 432051.047 8(½,3/2)
429951.827 429951.691 7(½,3/2)
426717.329 426717.112 6(½,3/2)
421353.030 421352.655 5(½,3/2)
411477.831 411477.099 4(½,3/2)
390142.538 390140.803 3(½,3/2)
329185.132 329179.275 2(½,3/2)
433490.438 433490.418 9(3/2,5/2)
432051.168 432051.138 8(3/2,5/2)
429951.872 429951.827 7(3/2,5/2)
426717.401 426717.328 6(3/2,5/2)
421353.154 421353.029 5(3/2,5/2)
411478.074 411477.830 4(3/2,5/2)
390143.114 390142.535 3(3/2,5/2)
433490.449 433490.438 9(5/2,7/2)
432051.184 432051.168 8(5/2,7/2)
429951.895 429951.872 7(5/2,7/2)
426717.437 426717.401 6(5/2,7/2)
421353.216 421353.154 5(5/2,7/2)
411478.196 411478.074 4(5/2,7/2)
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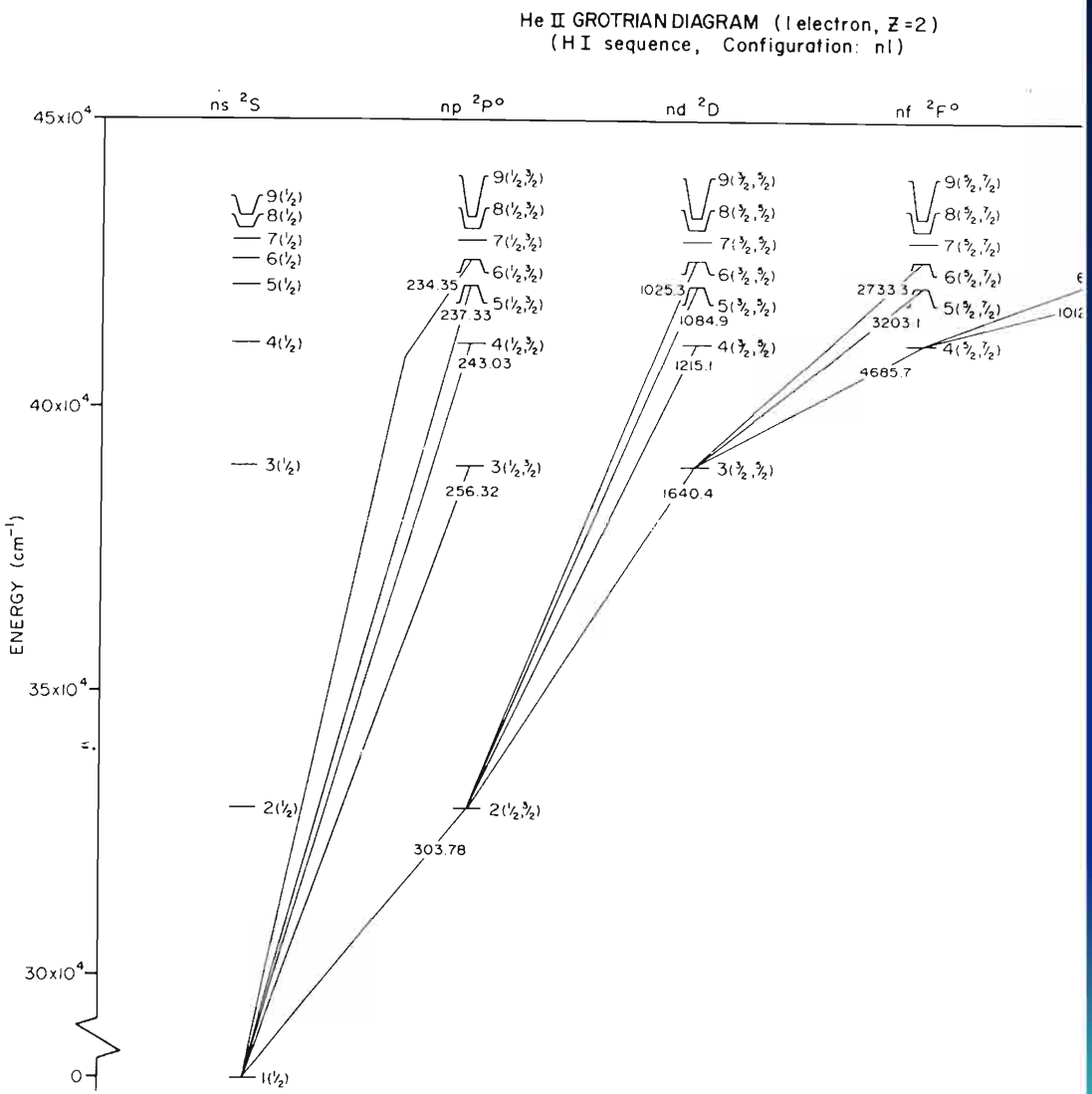

He II GROTRIAN DIAGRAM (1 electron, Z=2)
(H I sequence, Configuration: nl)
ns ²S
np ²P°
nd ²D
nf ²F°
45x10⁴
40x10⁴
35x10⁴
30x10⁴
0
ENERGY (cm⁻¹)
9(½)
8(½)
7(½)
6(½)
5(½)
4(½)
3(½)
2(½)
1(½)
9(½,3/2)
8(½,3/2)
7(½,3/2)
6(½,3/2)
5(½,3/2)
4(½,3/2)
3(½,3/2)
2(½,3/2)
9(3/2,5/2)
8(3/2,5/2)
7(3/2,5/2)
6(3/2,5/2)
5(3/2,5/2)
4(3/2,5/2)
3(3/2,3/2)
9(3/2,7/2)
8(3/2,7/2)
7(3/2,7/2)
6(3/2,7/2)
5(3/2,7/2)
4(3/2,7/2)
234.35
237.33
243.03
256.32
303.78
1025.3
1084.9
1215.1
1640.4
2733.3
3203.1
4685.7

Pb IV

Authors	Config.	Desig.	J	Level	Interval	Obs. g	Authors	
	$5d^{10}(^1S)6s$	$6s\ ^2S$	0½	0			17°	$5d^9_{1½}$
	$5d^{10}(^1S)6p$	$6p\ ^2P°$	0½	*76158*	21061		18°	$5d^9_{1½}$
			1½	*97219*			19°	$5d^9_{1½}$
1	$5d^9\ 6s^2$	$6s^2\ ^2D$	2½	101252	−21316			
2			1½	122568			20°	
1°	$5d^9_{2½}\ 6s_{0½}\ 6p_{0½}$		2½	*166369*			21°	$5d^9_{1½}$
2°	"		3½	*172667*			22°	
3°	"		2½	*173248*			23°	
4°	"		1½	*175388*			24°	
	$5d^{10}(^1S)6d$	$6d\ ^2D$	1½	184558. 8	2258. 0	0. 78	25°	
			2½	186816. 8		1. 17	26°	
	$5d^{10}(^1S)7s$	$7s\ ^2S$	0½	185103. 0		1. 92	27°	
5°	$5d^9_{2½}\ 6s_{0½}\ 6p_{1½}$		1½	*188759*				$5d^{10}(^1$
7°	"		2½	*193776*				$5d^{10}(^1$
8°	"		3½	*193855*				
9°	"		1½	*193954*				$5d^{10}(^1$
10°	"		0½	*194147*				$5d^{10}(^1$
11°	"		2½	*197024*				$5d^{10}(^1$
12°	$5d^9_{1½}\ 6s_{0½}\ 6p_{0½}$		1½	*200021*				$5d^{10}(^1$
13°	"		0½	*201460*				
14°	$5d^9_{2½}\ 6s_{0½}\ 6p_{1½}$		3½	*208524. 0*				Pb
15°	$5d^9_{1½}\ 6s_{0½}\ 6p_{0½}$		1½	*209051. 1*				
16°	$5d^9_{1½}\ 6s_{0½}\ 6p_{1½}$?		0½	*209788. 4*		0. 68		

September 1954.

DIFFERENT COUPLING SCHEMES

Coupling Scheme	Quantum numbers for vectors that couple to give J	Term Symbol
LS	L, S	${}^{2S+1}L$
J_1J_2	J_1, J_2	(J_1, J_2)
$J_1L_2(\rightarrow K)$	K, S_2	${}^{2S_2+1}[K]$
$LS_1(\rightarrow K)$	K, S_2	${}^{2S_2+1}[K]$

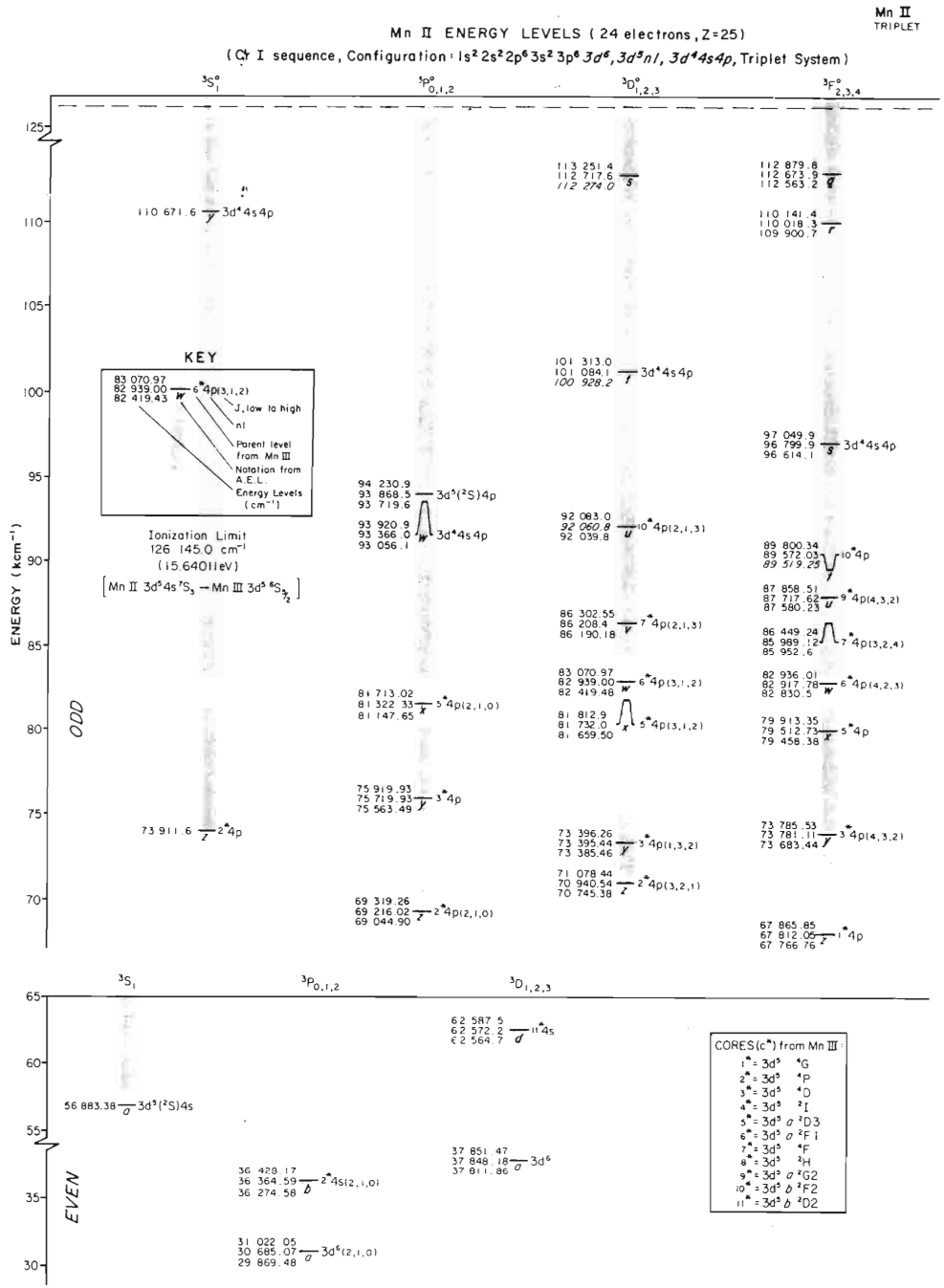
E. Rasmussen, Zeit. Phys. **80**, 720 (1933). (1 P) (1) (C L)
B. Edlén, Ark. Mat. Astr. Fys. (Stockholm) **29A**, No. 21, 4 (1

Rn I

Author	Config.	Desig.	J	Level	Auth
p_0	$6p^6$	$6p^6\ {}^1S$	0	0. 0	$3d_3$
$1s_5$	$6p^5(^2P^\circ_{1½})7s$	$7s\ [1½]^\circ$	2	*54620. 35*	
$1s_4$			1	*55989. 03*	$3p_1$
$1s_3$	$6p^5(^2P^\circ_{0½})7s$	$7s'\ [0½]^\circ$	0	[*85976*]	$3p_2$
$1s_2$			1	[*87053*]	$3p_3$
					$3p_7$
$2p_{10}$	$6p^5(^2P^\circ_{1½})7p$	$7p\ [0½]$	1	66244. 97	$3p_6$
$2p_9$	"	$7p\ [2½]$	2	66707. 53	$3p_5$
$2p_8$			3	68039. 48	
$2p_7$	"	$7p\ [1½]$	1	68332. 10	$4d_6$
$2p_6$			2	68789. 93	$4d_5$
$2p_5$	"	$7p\ [0½]$	0	69743. 98	$4d'_4$
					$4d_4$
$3d_6$	$6p^5(^2P^\circ_{1½})6d$	$6d\ [0½]^\circ$	0	*67906. 52*	$4d_3$
$3d_5$			1	*68891. 34*	$4d_2$
$3d'_4$	"	$6d\ [3½]^\circ$	4	*69798. 00*	$4d''_1$
$3d_4$			3	*70440. 42*	$4d'_1$

Mn II ENERGY LEVELS (24 electrons , Z=25)

(Cr I sequence, Configuration : $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,3d^6, 3d^5nl, 3d^44s4p$, Triplet System)



STARK BROADENING

- SEMICLASSICAL METHOD

•In spite of the fact that the most sophysticated theoretical method for the calculation of a Stark broadened line profile is the quantum mechanical strong coupling approach, due to its complexity and numerical difficulties,it can be applied only to limited number of lines from simpler spectra.

SEMICLASSICAL METHOD

- In a lot of cases such as e.g. complex spectra, heavy elements or transitions between more excited energy levels,
- the more sophysticated quantum mechanical approach is very difficult or even practically impossible to use and, in such cases, the semiclassical approach remains the most efficient method for Stark broadening calculations.

- The literature and some nummerical results could be found in database STARK-B described later.

- http://stark-b.obspm.fr/

- Whenever line broadening data for a large number of lines are required, and the high precision of every particular result is not so important, simple approximative formulae with good average accuracy may be very useful.
- Moreover, in the case of more complex atoms or multiply charged ions the lack of the accurate atomic data needed for more sophysticated calculations, makes that the reliability of the semiclassical results decreases. In such cases approximate methods might be very interesting.

- Due to the considerably smaller set of needed atomic data in comparison with the complete semiclassical method, the Modified Semiempirical Method (MSE – Dimitrijević and Konjević 1980, Dimitrijević and Kršljanin 1986) is particularly useful for stellar spectroscopy depending on very extensive list of elements and line transitions with their atomic and line
- broadening parameters where it is not possible to use sophysticated theoretical approaches in all cases of interest.

Modified Semiempirical Method

•The MSE method is also very useful whenever line broadening data for a large number of lines are required, and the high precision of every particular result is not so important like e.g. for opacity calculations or plasma modeling. Moreover, in the case of more complex atoms or multiply charged ions the lack of the accurate atomic data needed for more sophysticated calculations, makes that the reliability of the semiclassical results decreases. In such cases the MSE method might be very interesting as well.

- THE BASIC ARTICLES ON MODIFIED SEMIEMPIRICAL APPROACH ARE IN THE FOLDER BIBLIOGRAPHY_DIMITRIJEVIC:
- 1. Dimitrijević, M. S., Konjević, N., 1981, Spectral Line Shapes 1, Walter de Gruyter, p. 211.
- 2. Dimitrijević, M. S., Kršljanin, V., 1986, A&A, 165, 269.
- 3. Dimitrijević, M.S., Popović, L. Č., 2001, Journal of Applied Spectroscopy, 68, 893

SYMPLIFIED MODIFIED SEMIEMPIRICAL FORMULA

- For the astrophysical purposes, of particular interest
- might be the symplified semiempirical formula for
- Stark widths of isolated, singly, and multiply charged ion lines applicable in the cases when the nearest atomic energy level (j'=i‘ or f') where a dipolly allowed transition can occur from or to initial (i) or final (f) energy level of the considered line, is so far, that the condition $x_{jj'} = E/(E_{j'} - E_{j})$ smaller than or equal to 2 is satisfied.

In such a cases full width at half maximum is given by the expression:

$$W(\text{Å}) = 2.2151 \times 10^{-8} \frac{\lambda^2(\text{cm}) N(\text{cm}^{-3})}{T^{1/2}(\text{K})}$$

$$\left(0.9 - \frac{1.1}{Z}\right) \sum_{j=i,f} \left(\frac{3n_j^*}{2Z}\right)^2 (n_j^{*2} - \ell_j^2 - \ell - 1).$$

•Here, N and T are the electron density and temperature respectively, E = 3kT/2 is the energy of perturbing electron, Z-1 is the ionic charge and n the effective principal quantum number. This expression is of interest for abundance calculations, as well as for stellar atmospherae research, since the validity conditions are often satysfied for stellar plasma conditions.

- Similarly, in the case of the shift:

$$d(\text{Å}) = 1.1076 \times 10^{-8} \frac{\lambda^2(\text{cm})N(\text{cm}^{-3})}{T^{1/2}(\text{K})} \left(0.9 - \frac{1.1}{Z}\right) \frac{9}{4Z^2}$$

$$\times \sum_{j=i,f} \frac{n_j^{*2}\varepsilon_j}{2\ell_j + 1} \left\{(\ell_j + 1)[n_j^{*2} - (\ell_j + 1)^2] - \ell_n(n_j^{*2} - \ell_j^2)\right\}$$

- If all levels $l_{i,f} \pm 1$ exist, an additional summation may be performed in the above equation (here, $\varepsilon = +1$ if $j = i$ and -1 if $j = f$).

$$d \approx 1.1076\ 10^{-8}\ \frac{\lambda^2(\mathrm{cm})\, N(\mathrm{cm}^{-3})}{T^{1/2}(\mathrm{K})} \left(0.9 - \frac{1.1}{Z}\right) \frac{9}{4Z^2}$$

$$\cdot \sum_{j=i,\,f} \frac{n_j^2\, \varepsilon}{2l_j + 1} \left(n_j^2 - 3l_j^2 - 3l_j - 1\right).$$

- THE BASIC ARTICLE ON THE SYMPLIFIED MODIFIED SEMIEMPIRICAL APPROACH IS IN THE FOLDER “BIBLIOGRAPHY_DIMITRIJEVIC”:
- Dimitrijević, M. S., Konjević, N., 1987, A&A, 172, 349.
- IN THE SAME FOLDER IS THE ARTICLE WITH A SIMPLIFIED FORMULA FOR NEUTRAL ATOM LINES:
- Dimitrijević, M. S., Konjević, N., 1986, A&A, 163, 297.

SOME USEFUL DATABASES

- ATOMIC ENERGY LEVELS AND SPECTRA BIBLIOGRAPHIC DATABASE A.E. Kramida, W.C. Martin, A. Musgrove, K. Olsen, J. Reader, and E.B. Saloman
- http://physics.nist.gov/cgi-bin/ASBib1/ELevBib.cgi

- NIST ATOMIC SPECTRA DATABASE
- http://physics.nist.gov/PhysRefData/ASD/index.html

- ATOMIC SPECTRAL LINE BROADENING BIBLIOGRAPHIC DATABASE
- J.R. Fuhr, A.E. Kramida, H.R. Felrice, and K. Olsen
- http://physics.nist.gov/cgi-bin/ASBib1/LineBroadBib.cgi

STARK-B

- http://stark-b.obspm.fr/
- This 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 modellisation and spectroscopic diagnostics of stellar atmospheres and envelopes. In addition, it is also devoted to laboratory plasmas, laser equipments and technological plasmas. So, the domain of temperatures and densities covered by the tables is wide and depends on the ionization degree of the considered ion. The temperature can vary from several thousands for neutral atoms to several hundred thousands of Kelvin for highly charged ions. The electron or ion density can vary from 10^{12} (case of stellar atmospheres) to several 10^{19} cm^{-3} (some white dwarfs and some laboratory plasmas).

- The impact approximation and the isolated line approximation are applied, so that the line profile is Lorentzian. The basis for calculations is the computer code which evaluates electron and ion impact broadening of isolated spectral lines of neutral atoms and ions, using the semiclassical-perturbation approach developed by Sahal-Bréchot (1969ab, 1974), and supplemented in Fleurier etal. (1977), see below. This computer code has been updated by Dimitrijevic and Sahal-Bréchot in their series of papers, Dimitrijevic and Sahal-Bréchot (1984) and following papers. The data are derived from this series of papers and are cited in the tables.
Dimitrijevic, M.S., and Sahal-Bréchot, S.: 1984, JQSRT 31, 301-313
- Fleurier C., Sahal-Bréchot, S., and Chapelle, J.: 1977, JQSRT, 17, 595-604
- Sahal-Bréchot, S.: 1969a, A&A 1, 91-123
- Sahal-Bréchot, S.: 1969b, A&A 2, 322-354

SPECTRAL LINE SHAPES IN YUGOSLAVIA AND SERBIA

- - FIRST ARTICLE – 1962 (ZAGREB) – 1964 (BELGRADE)
- - I-III YUGOSLAV CONFERENCE OF SPECTRAL LINE SHAPES – 1995,1997, 1999
- - IV SERBIAN CONFERENCE OF SPECTRAL LINE SHAPES – 2003
- - V -VI SERBIAN CONFERENCE ON SPECTRAL LINE SHAPES IN ASTROPHYSICS 2005, 2007.
- VII SCSLSA ZRENJANIN 15-19 JUNE 2009.


THANK YOU
FOR
ATTENTION