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RECENT WORKS ON ATOMIC AND PMI DATA FOR CONTROLLED FUSION RESEARCH IN RUSSIA

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Outline

- **Generation of atomic data for fundamental science and controlled nuclear fusion**
- **Use of atomic data in controlled nuclear fusion research**
- **Recent works on plasma-material interaction data**
- **Conclusions**

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- **Generation of atomic data for fundamental science and controlled nuclear fusion**
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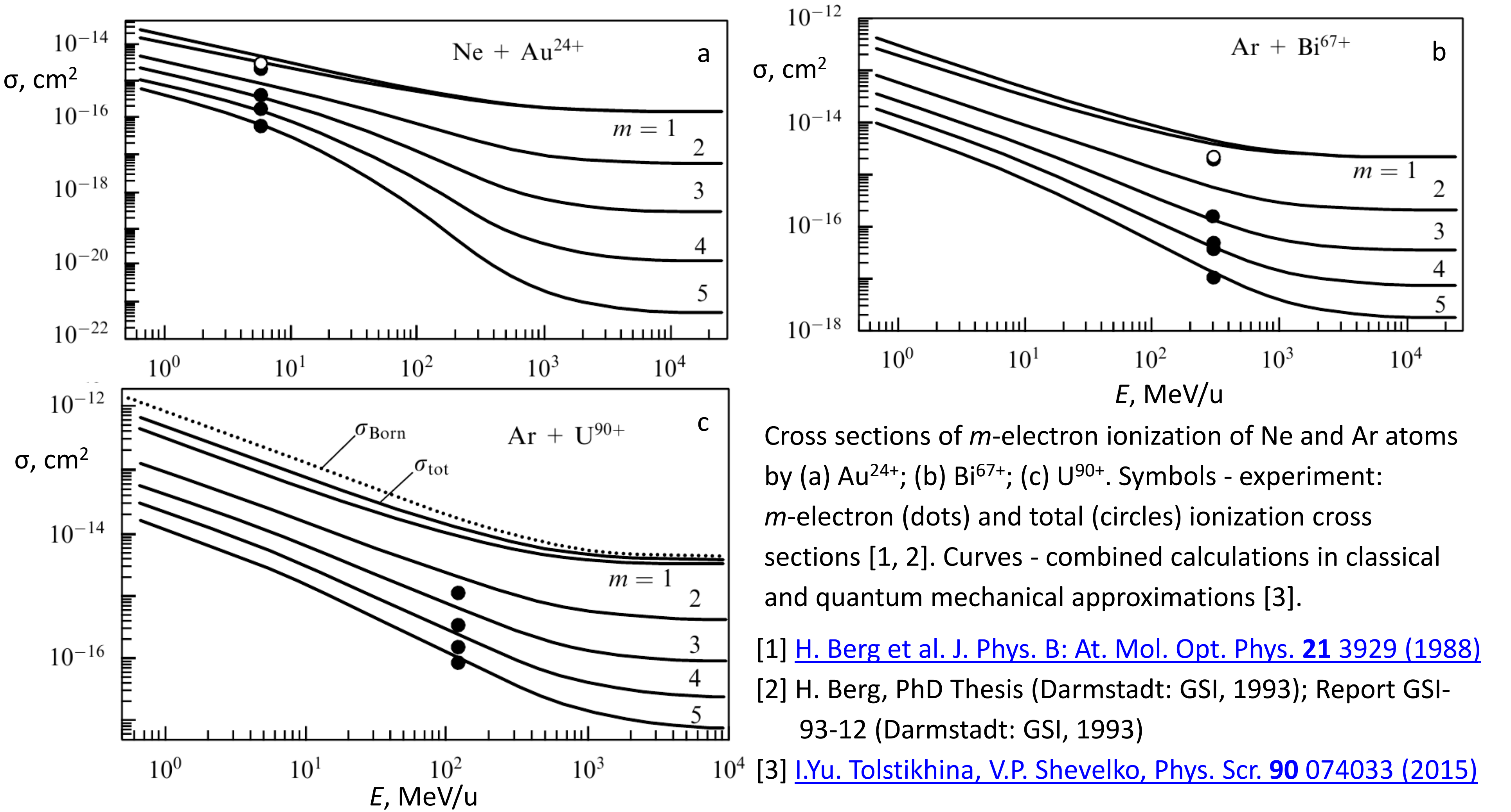
Process	Method	Data Source / Code	Publications	Verification / Application	Problem
Overview of experimental data and theor. methods for charge-changing processes with ion beams passing through gaseous, solid and plasma targets: e^- capture and e^- loss processes with heavy many-electron ions, (e.g. Ar^{q+}, …, U^{q+}) from 50 keV/u to 50 GeV/u, including multielectron processes. Stopping power is considered, and briefly isotopic effect at low energies.	Combined calculations using classical and quantum mechanics approaches.	*Codes:* ETACHA, GLOBAL, CHARGE, and BREIT	I.Yu. Tolstikhina, V.P. Shevelko *Influence of atomic processes on charge states and fractions of fast heavy ions passing through gaseous, solid, and plasma targets* **Physics-Uspekhi 61** 247 (2018), 33 pages	Cross-validation and comparisons with experimental data.	Detection of superheavy elements, atomic processes in stellar astrophysics, use of heavy ion beams as drivers for inertial confinement fusion.

Electron capture and electron loss processes with heavy many-electron ions; stopping power; isotopic effect at low energies (to be taken into account in modeling near-wall and divertor plasmas in facilities using hydrogen isotopes); short description of the computer programs ETACHA, GLOBAL, CHARGE and BREIT and their applications, including the use of heavy ion beams as drivers for inertial conf. fusion

I.Yu. Tolstikhina, V.P. Shevelko, *Physics-Uspekhi* **61** 247 (2018) https://doi.org/10.3367/UFNe.2017.02.038071



Cross sections of *m*-electron ionization of Ne and Ar atoms by (a) Au^{24+}; (b) Bi^{67+}; (c) U^{90+}. Symbols - experiment: *m*-electron (dots) and total (circles) ionization cross sections [1, 2]. Curves - combined calculations in classical and quantum mechanical approximations [3].

[1] H. Berg et al. J. Phys. B: At. Mol. Opt. Phys. **21** 3929 (1988)

[2] H. Berg, PhD Thesis (Darmstadt: GSI, 1993); Report GSI-93-12 (Darmstadt: GSI, 1993)

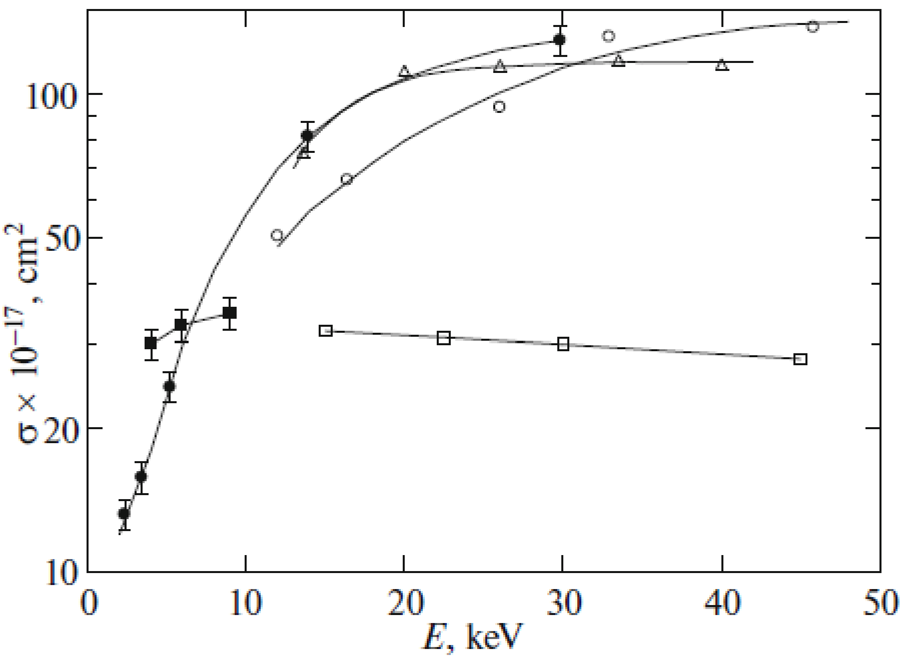
[3] I.Yu. Tolstikhina, V.P. Shevelko, Phys. Scr. **90** 074033 (2015)

Process	Method	Data Source / Code	Publications	Verification / Application	Problem
One- and two- electron capture by He^{2+} ions from Ar atoms and electron capture with ionization	Target Ar atoms were supplied with an effusion gas jet. A collimated beam of $^3He^{2+}$ ions was used with energy in keV range. Calculations of cross sections using different model atomic particle interaction potentials.	Experimental setup described in V.V. Afrosimov, A.A. Basalaev, G.N. Ogurtsov, M.N. Panov **Tech. Phys. 59** 642 (2014)	A.A. Basalaev, G.N. Ogurtsov, M.N. Panov **Tech. Phys. 63** 947 (2018) A.A. Basalaev, M.N. Panov **Tech. Phys. 64** 306 (2019)	Verification of model interaction potentials used in the analysis of collisions of α-particles with multielectron atoms.	Plasma diagnostics, numerical simulations of processes in controlled fusion devices.

[*] A.A. Basalaev et al., *Tech. Phys.* ***64*** *306 (2019)* https://doi.org/10.1134/S1063784219030058

No.	Process	Name of the process
1	$He^{2+} + Ar \rightarrow He^{+} + Ar^{+}$	One-electron capture
2	$He^{2+} + Ar \rightarrow He^{+} + Ar^{2+} + e^{-}$	One-electron capture with ionization
3	$He^{2+} + Ar \rightarrow He^{0} + Ar^{2+}$	Two-electron capture
4	$He^{2+} + Ar \rightarrow He^{0} + Ar^{3+} + e^{-}$	Two-electron capture with ionization
5a	$He^{2+} + Ar \rightarrow He^{+} + Ar^{n+} + (n-1)e^{-}\ n \geq 3$	One-electron capture with n-degree ionization
5b	$He^{2+} + Ar \rightarrow He^{0} + Ar^{n+} + (n-2)e^{-}\ n \geq 4$	Two-electron capture with n-degree ionization
5c	$He^{2+} + Ar \rightarrow He^{2+} + Ar^{n+} + ne^{-}\ n \geq 1$	n-Degree ionization

Total cross sections of capture of one or two electrons in collisions of He^{2+} ions with Ar atoms



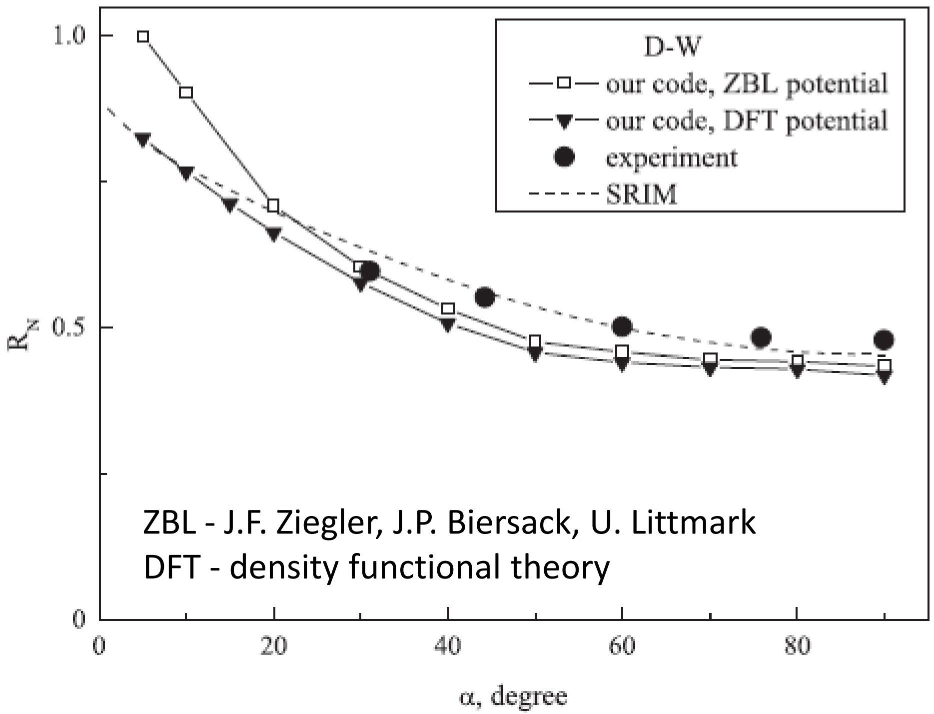
Sum of cross sections of processes 1+2: dots – [*], triangles – [1], circles – [2].
Sum of cross sections of processes 3+4: solid squares – [*], open squares – [3].

[1] M.B. Shah et al., J. Phys. B: At. Mol. Phys. **7** 256 (1974)
[2] J.E. Bayfield et al., Phys. Rev. A **11** 920 (1975)
[3] M.E. Rudd et al., Phys. Rev. A **32** 2128 (1985)

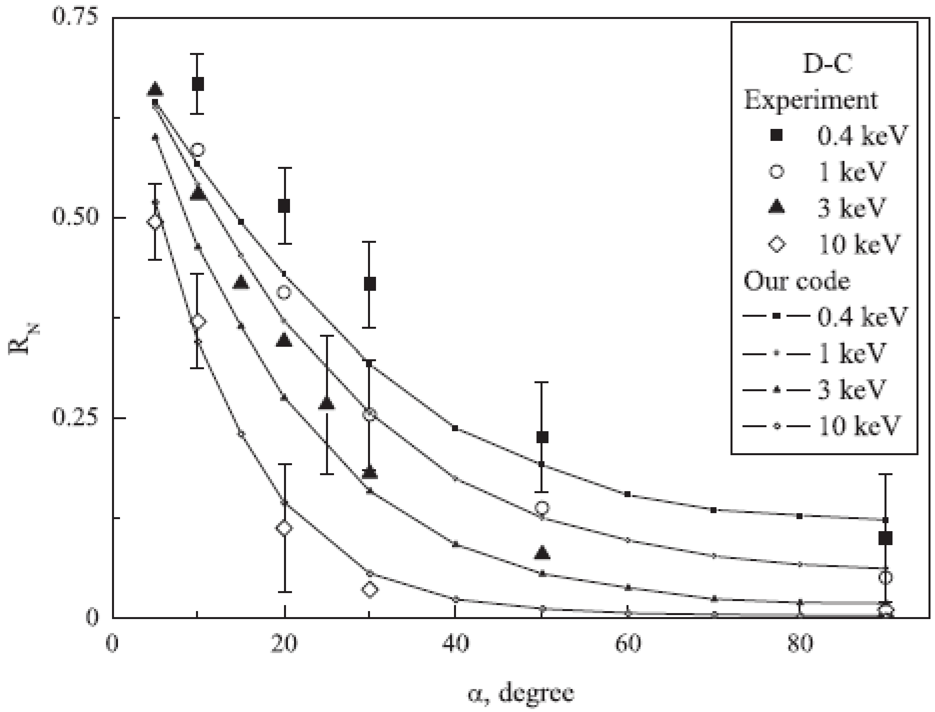
The contribution of process 5 to the total cross section can be disregarded.

Process	Method	Data Source / Code	Publications	Verification / Application	Problem
Particle reflection coefficients for scattering of Hydrogen and Deuterium atoms from amorphous Beryllium, Carbon and Tungsten (For the D - W case also for polycr. and crystalline target)	Calculations using binary collision approximation and a method based on particle trajectory calculations.	Details of calculations are described in P.Yu. Babenko et al. **Nucl. Inst. Methods Phys. Res. B 406** 538 (2017) and P.Yu. Babenko et al. **Nucl. Inst. Methods Phys. Res. B 406** 460 (2017)	D.S. Meluzova et al. *Reflection of hydrogen and deuterium atoms from the beryllium, carbon, tungsten surfaces* **Nucl. Inst. Methods Phys. Res. B** (2019)	Checking the influence of the attractive well in the interatomic potential on the calculation of reflection coefficients. Obtaining reflection coefficients needed for thermonuclear reactor physics.	The reflection of Hydrogen and Deuterium atoms from tokamak wall and divertor materials determines the material balance between the plasma and the wall.

D.S. Meluzova et al., *Nucl. Inst. Methods Phys. Res. B (2019)* https://doi.org/10.1016/j.nimb.2019.03.037



Reflection coefficients for D atoms scattered from amorphous W. Dots – experiment [1]



Reflection coefficients for D atoms scattered from amorphous C. Experimental data are from [2].

[1] V.V. Bandurko et al. J. Nucl. Mater. **176–177** 630 (1990)

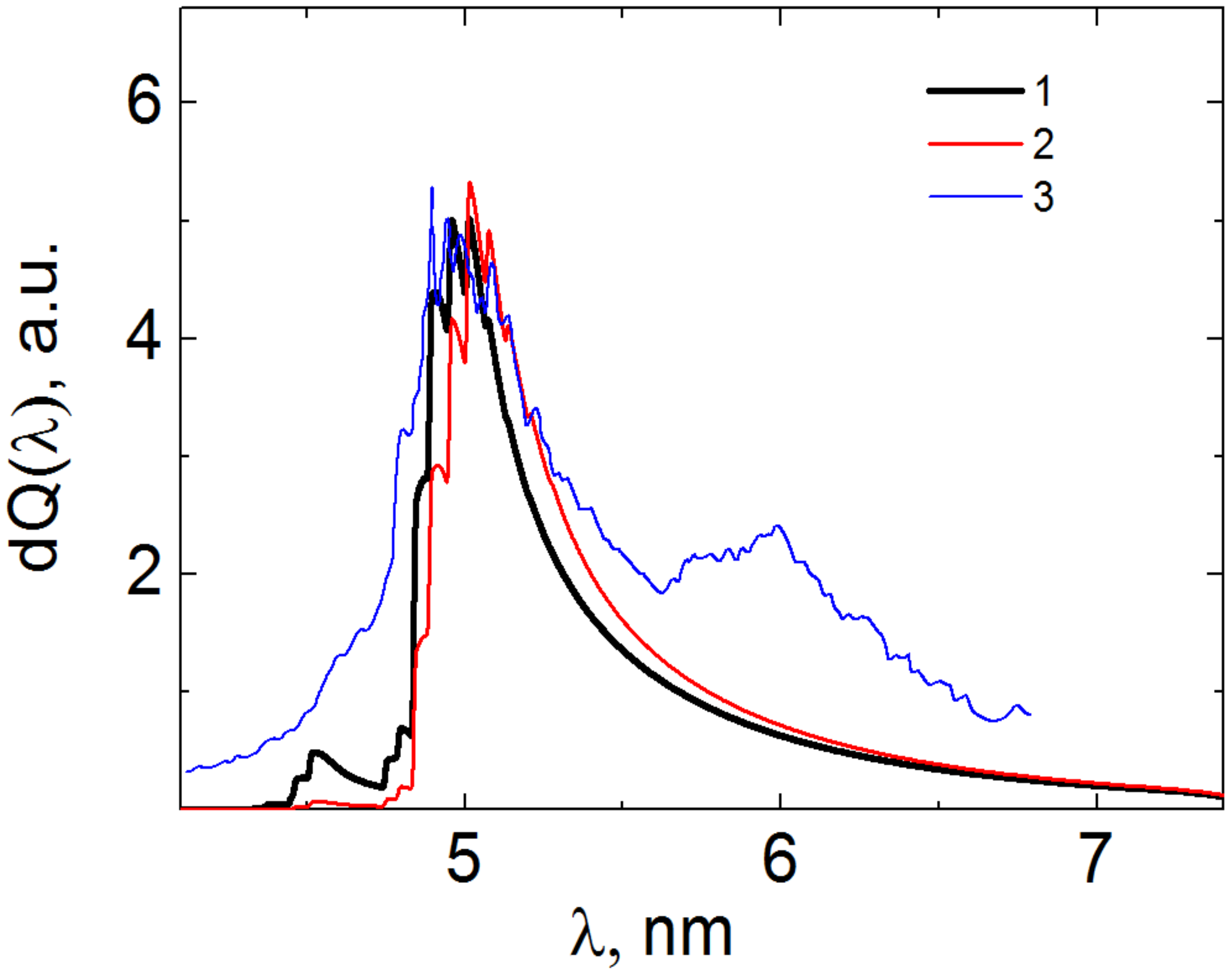
[2] C.K. Chen et al. Appl. Phys. A **33** 265 (1984)

Additional bibliography:

A.N. Zinoviev *Potentials of the Interaction of Atomic Particles at Large, Medium, and Small Collision Energies* J. of Surface Investigation: X-ray, Synchrotron and Neutron Techniques **12** 554 (2018)

The interatomic potential determines the nuclear stopping power in materials. A review of the most recent papers concerning the study of interatomic potentials is given.

Process	Method	Data Source / Code	Publications	Verification / Application	Problem
Statistical modeling of heavy ions quasicontinuum in thermonuclear plasmas	Slater approximation for electron subshells	The statistical model of quasicontinuum of heavy ions	A.V. Demura, D.S. Leontyev, V. S. Lisitsa, V.A. Shurygin ECA 2019 V. **43C** P1.1066	Comparison with experim. data and data from level-by-level computations	Integrated modeling of fusion experiments
Radiative losses of alpha particles on tungsten impurities in thermonuclear plasmas	Local plasma frequency model of collective oscillations of atomic electron density	The statistical model of the radiation losses of electrons and alpha particles	A.V. Demura, D.S. Leontyev, V.S. Lisitsa, V.A. Shurygin JETP Letters **106** 429 (2017)	Refinement of the critical concentration of heavy-ion impurities in fusion plasma	Diagnostics of thermonuclear plasma
First experimental results on tungsten transport in T-10 tokamak plasma			M.R. Nurgaliev, V.A. Krupin et al. Physics of Atomic Nuclei **81** 1037 (2018)		Investigations of transport of heavy impurity ions in a thermonuclear plasma



1 - statistical model [1] with $<Z_i>=23$ calculated by the statistical approach in coronal equilibrium;
2 - statistical model [1] with <Zi>=24 calculated with data [2] for elementary processes;
3 – experimental data from LHD [3]

Quasicontinuum from tungsten ions at T=1.5 keV

Statistical model predicts a sharp cut of quasicontinuum at short wavelengths, that satisfactorily coincides with experimentally observed spectra

[1] A.V. Demura et al. ECA vol. **43C** P1.1066 (2019)
[2] K. Asmussen et al. Nucl. Fusion **38** 967 (1998)
[3] C.S. Harte et al. J. Phys. B: At. Mol. Opt. Phys. **43** 205004 (2010)

Courtesy **D.S. Leontyev**

A.V. Demura, et al. (NRC Kurchatov Institute)

Process	Method	Data Source / Code	Publications	Verification / Application	Problem
Spectral line shapes in plasmas	Superdiffusive (nonlocal) transport method	Automodel solutions of Biberman-Holstein radiative transfer	A.V. Demura *Beyond the linear Stark effect: A Retrospective* Atoms **6** 33 (2018) (Special Issue "Spectral Line Shapes in Plasmas II“) A.B. Kukushkin et al. Atoms **6** 43 (2018) (Special Issue “Stark Broadening of Spectral Lines in Plasmas”)	Contributions to: Spectral Line Shapes in Plasmas (SLSP) workshops (1st-4th). Available online (2019): http://plasma-gate.weizmann.ac.il/slsp/ Massive distributed computing vs. analytical method	Development and verification of theoretical models of spectral line shapes (SLS) in plasmas, including the SLS models for high energy density plasmas of inertially confined fusion plasmas

V.A. Astapenko, V.S. Lisitsa et al. (MIPT, NRC Kurchatov Institute, Aix Marseille U., Sorbonne U.)

Process	Method	Data Source / Code	Publications	Verification / Application	Problem
Radiative transitions in atoms in plasma under ultra-short electromagnetic pulse (USP)	Time-dependent probability of atomic transitions. Hard ion sphere model for dense strongly coupled plasmas, local plasma frequency model.	Cross-sections of scattering/ absorption of USP by an atom in a broad spectral range	V.A. Astapenko, V.S. Lisitsa Atoms **6** 38 (2018) V.A. Astapenko, A. Calisti, V.S. Lisitsa High Energy Density Physics **31** 59 (2019) F.B. Rosmej, V.A. Astapenko, V.S. Lisitsa, X. Li, E.S. Khramov Contributions to Plasma Physics **59** 189 (2019)	Atomic spectra for different broadening mechanisms, with optical depth effects. Generalized line shapes of absorption.	Interaction of ultra-short electromagnetic pulses with hot dense plasmas. Diagnostics of matter, including the inertially confined fusion plasmas, using free-electron lasers.

Outline

- Generation of atomic data for fundamental science and controlled nuclear fusion

➢ **Use of atomic data in controlled nuclear fusion research**

- Recent works on plasma-material interaction data

- Conclusions

Peter the Great St. Petersburg Polytechnic University
(in collaboration with NIFS, Japan)

Problem	Task	Publication	Processes	Data Source	Data Needs
Measurements of the ion distribution function with an active PCX diagnostic	Calculation of the neutral fraction of the incident flux of fast particles.	*I.A. Sharov et al. Tech. Phys. Lett.* ***44*** *387 (2018)*	**Charge changing collisions of H with C ions**	I. Tolstikhina, P. Goncharov, NIFS-DATA-102 (2008) and earlier published sources	Updated cross sections

Electron Capture and Loss Processes in Hydrocarbon and Li Pellet Clouds

I. Electron capture by H^+ ions

$H^+ + C^{q+} \rightarrow H^0 + C^{(q+1)+}$, q = 0, …, 5

$H^+ + H^0 \rightarrow H^0 + H^+$

$H^+ + Li^{q+} \rightarrow H^0 + Li^{(q+1)+}$, q = 0, 1, 2

II. Electron loss by H^0 atoms

$H^0 + C^{q+} \rightarrow H^+ + C^{(q-1)+}$, q = 1, …, 6

$H^0 + C^{q+} \rightarrow H^+ + C^{q+} + e^-$, q = 0, …, 6

$H^0 + H^+ \rightarrow H^+ + H^0$

$H^0 + H^+ \rightarrow H^+ + H^+ + e^-$

$H^0 + H^0 \rightarrow H^+ + H^0 + e^-$

$H^0 + e^- \rightarrow H^+ + e^- + e^-$

$H^0 + Li^{q+} \rightarrow H^+ + Li^{(q-1)+}$, q = 1, 2, 3

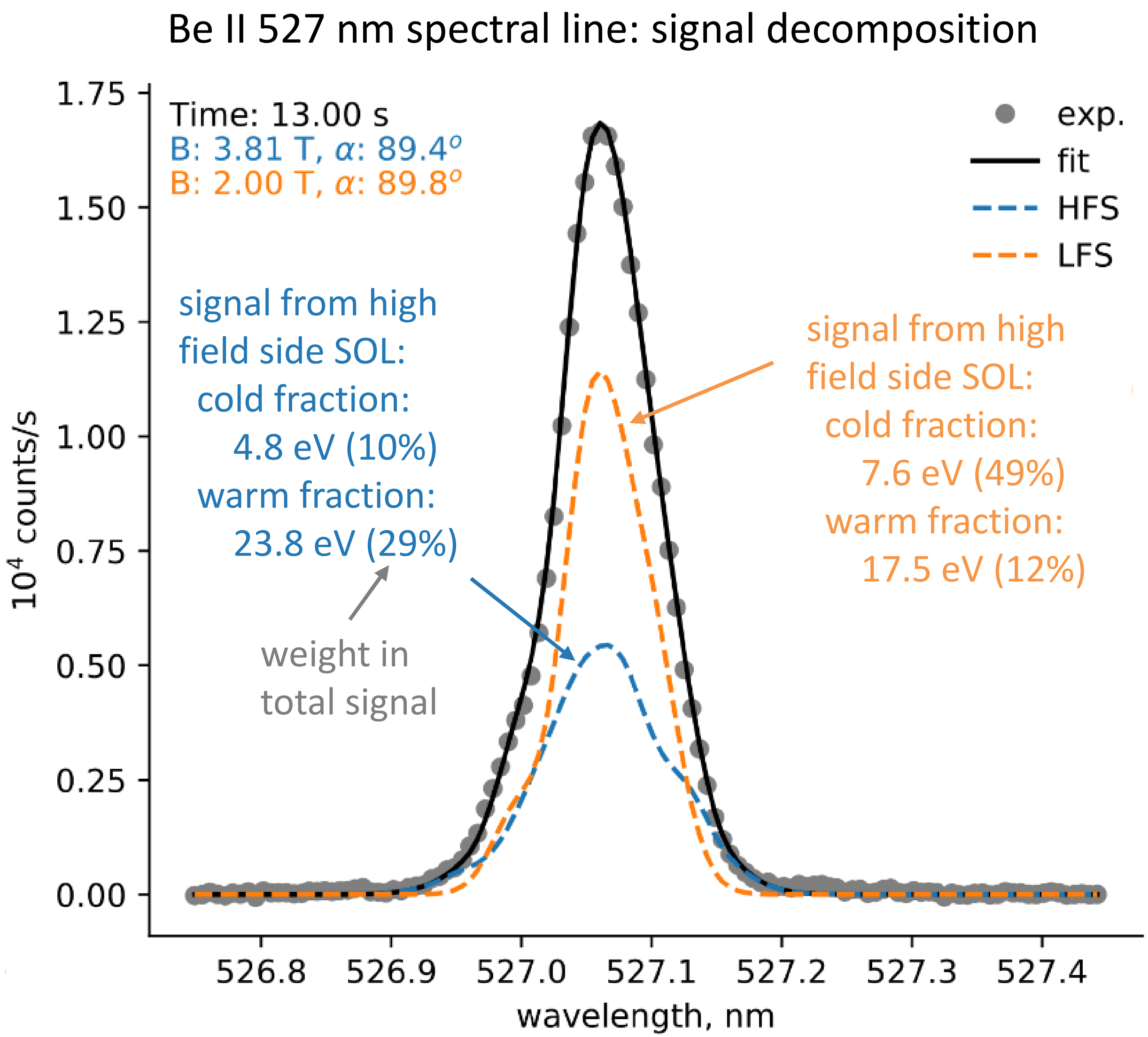
$H^0 + Li^{q+} \rightarrow H^+ + Li^{q+} + e^-$, q = 0, 1, 2, 3

$H^0 + e^- \rightarrow H^+ + e^- + e^-$

I.Yu. Tolstikhina, P.R. Goncharov, T. Ozaki ,S. Sudo, N. Tamura, V.Yu. Sergeev
***NIFS-DATA-102 Research Report**, ISSN 0915-6364*

V.S. Neverov, et al., NRC “Kurchatov Institute”, Moscow, Russia + ITER + JET (EUROfusion)

Problem	Task	Publication	Processes	Data Source	Data Needs
Verification of experimental data interpretation methods proposed for ITER Main Chamber H-alpha and Visible Spectroscopy on the data from JET	Interpretation of high-resolution spectra of hydrogen isotopes (Balmer-alpha) and beryllium in JET-ILW (passive spectroscopy) Recommendations for H-alpha diagnostics in the future D-T campaign on JET	*The results for beryllium are not published yet.* *Balmer-alpha data: V.S. Neverov, A.B. Kukushkin, U. Kruezi, M.F. Stamp, H. Weisen and JET Contributors, Determination of isotope ratio in the divertor of JET-ILW by high-resolution Hα spectroscopy: H-D experiment and implications for D-T experiment. Nucl. Fusion 59 (2019) 046011 (18pp)*	Combined action of Zeeman splitting and fine structure	ADAS603 (xPaschen code)	



The program fits the signal on the line of sight (LoS) in the main chamber and separates the contributions from high field side and low field side scrape-off layer (SOL)

ADAS603 code is used to simulate the line shape under combined action of Zeeman splitting and fine structure

B - magnetic field, α - angle between the directions of magnetic field and the line of sight (LoS),

Courtesy ***V.S. Neverov***

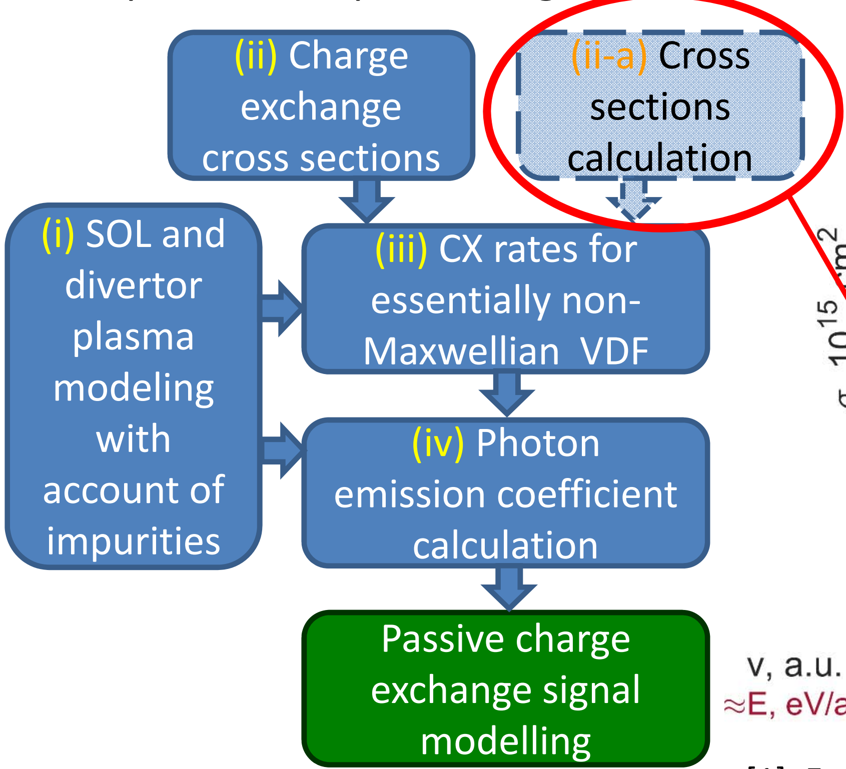
P.A. Sdvizhenskii et al. (NRC “Kurchatov Institute”, Moscow, Russia)

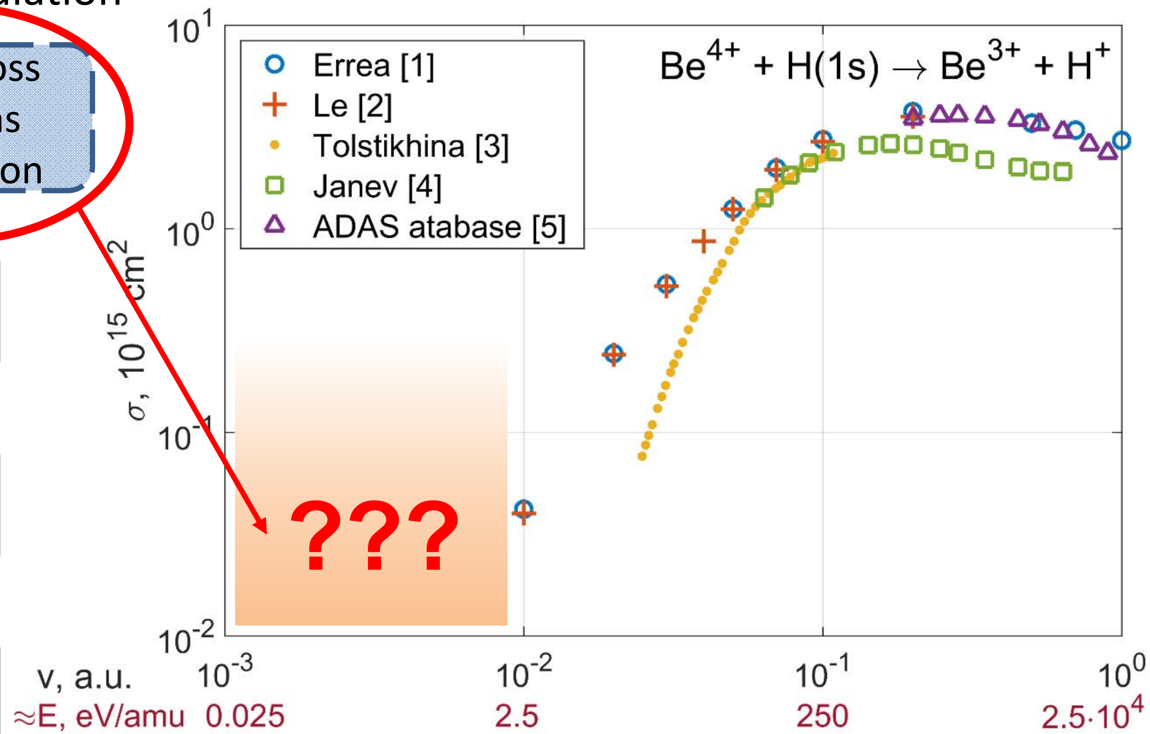
Problem	Task	Publication	Processes	Data Source	Data Needs
ITER charge-exchange recombination spectroscopy (CXRS) diagnostics of the core and edge plasmas	The problem of passive signal simulation for CXRS Edge diagnostics	P.A. Sdvizhenskii, A.B. Kukushkin, et al. Proc. 46th EPS Conference on Plasma Phys., Milan, Italy, 2019, ECA vol. 43C, P4.1006 http://ocs.ciemat.es/EPS2019PAP/pdf/P4.1006.pdf S.V. Serov, S.N. Tugarinov, M. von Hellermann. Problems of Atomic Science and Technology, Series Thermonuclear Fusion, 2018, 41(2), pp. 89-94, http://vant.iterru.ru/vant_2018_2/10.pdf	Charge exchange reactions with Be, C and other impurity ions involving H, D, T	Errea L.F. et al. 1996 Phys. Scr. T62, 27-32 Errea L.F. et al. 1998 J. Phys. B: At. Mol. Opt. Phys. 31, 3527 Janev R.K. et al. 1996 Phys. Scr. T62, 43 ADAS database https://open.adas.ac.uk/	Charge exchange *nl*-resolved cross sections for reactions with Be, C and other impurity ions involving H, D, T in low energy region

ITER charge-exchange recombination spectroscopy (CXRS) diagnostics of the core and edge plasmas (NRC «Kurchatov Institute», TRINITI, Troitsk, Moscow Region, in cooperation with ITER Organization, France)

Courtesy ***P.A. Sdvizhenskii***

The problem of passive signal simulation





P.A. Sdvizhenskii, A.B. Kukushkin, et al. Proc. 46th EPS Conf. Plasma Phys., Milan, Italy, 2019, ECA vol. 43C, P4.1006 *http://ocs.ciemat.es/EPS2019PAP/pdf/P4.1006.pdf*

[1]. Errea L.F. *et al*. 1998 J. Phys. B: At. Mol. Opt. Phys. **31**, 3527.

[2]. Le Anh-Thu *et al.* 2003 J. Phys. B: At. Mol. Opt. Phys. **36**, 3281.

[3]. Tolstikhina I.Yu. *et al.* 2014 J. Phys. B: At. Mol. Opt. Phys. **47**, 035206.

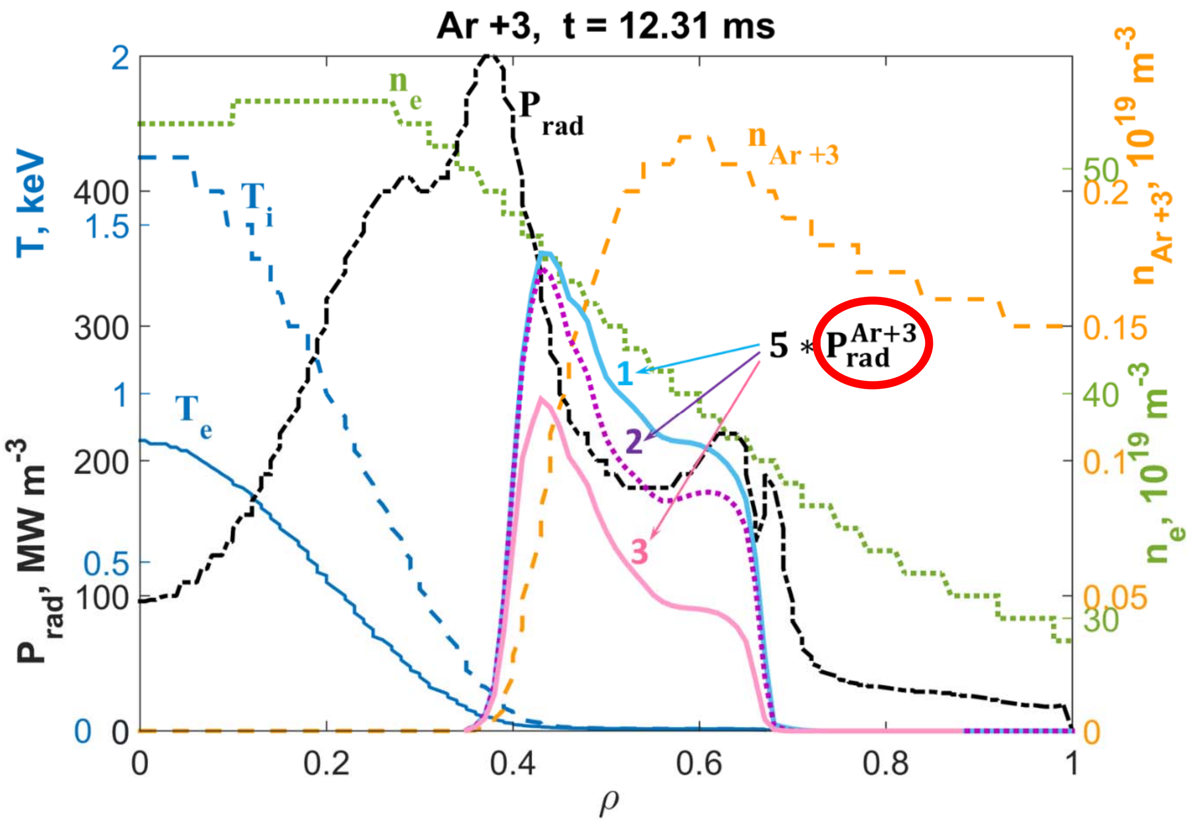
[4]. Janev R.K. *et al.* 1996 Phys. Scr. **T62**, 43.

[5]. ADAS database, https://open.adas.ac.uk/

P.A. Sdvizhenskii et al. (NRC "Kurchatov Institute", Moscow, Russia)

Problem	Task	Publication	Processes	Data Source	Data Needs
Massive gas injection for discharge quenching in fusion facilities, including ITER	The problem of using the data for fine structure of atomic level in radiative-collisional kinetics and radiation losses simulation for edge plasmas in fusion facilities, including the radiation losses during massive gas injection for discharge quenching in ITER	P.A. Sdvizhenskii, A.B. Kukushkin, *et al.* Proc. 45th EPS Conference on Plasma Physics, 2-6 July 2018, Prague, Czech Republic, ECA, Vol. 42A, P4.1083 P.A. Sdvizhenskii, A.B. Kukushkin, *et al.* Problems of Atomic Science and Technology, Series Thermonuclear Fusion, 2018, 41(4), pp. 5-13, http://vant.iterru.ru/vant_2018_4/1.pdf	The transitions, corresponding to high intensity spectral lines of ions of gases used in massive gas injection disruption mitigation	ADAS database https://open.adas.ac.uk/ NIST Atomic Spectra Database https://www.nist.gov/pml/atomic-spectra-database	Radiated Power Data PLT - Line Emission from excitation under ADF11 derived data class (updated 2019 data for Argon plt42_ar.dat) was used. Updated data for Neon would be beneficial.

The problem of using the data for fine structure of atomic level in radiative-collisional kinetics and radiation losses simulation for edge plasmas in fusion facilities, including the radiation losses during massive gas injection for discharge quenching in ITER (NRC «Kurchatov Institute»)



P.A. Sdvizhenskii, A.B. Kukushkin, M.G. Levashova, V.E. Zhogolev, V.M. Leonov, V.S. Lisitsa, S.V. Konovalov. Problems of Atomic Science and Technology, Series Thermonuclear Fusion, 2018, 41(4), pp. 5-13, DOI: 10.21517/0202-3822-2018-41-4-5-13 http://vant.iterru.ru/vant_2018_4/1.pdf

Figure. Spatial profiles of plasma parameters at time t = 12.31 ms from the MGI start for ion Ar^{+3}. Lines:

(3p → 3s), λ= 702.867 Å (*)
(3d → 3p), λ= 532.718 Å (**)

The optical thickness Θ over the path along major radius for lines (*) and (**) is: $\Theta_{532} \approx 16.30$, $\Theta_{702} \approx 6.88$.

$$\mathbf{PEC}(n_e(\mathbf{r}), T_e(\mathbf{r})) \Rightarrow P_{rad}^{(coronal)}(\mathbf{r}) \Rightarrow (\text{+opacity and fine structure effects}) \Rightarrow P_{rad}^{Ar+3}(\mathbf{r}).$$

Curve 1 – local emissivity in the lines (*) and (**), calculated with account of the exact structure of atomic energy levels and the respective coronal limit of radiative-collisional model without opacity effect;

curve 2 – the same but for the simplified radiative collisional model with the opacity effect;

curve 3 – total emissivity of Ar^{+3} ion in the coronal limit for the approximate structure of atomic energy levels, used in the ZIMPUR code.

Courtesy ***P.A. Sdvizhenskii***

Opacity effect gives ~ 25-30% corrections

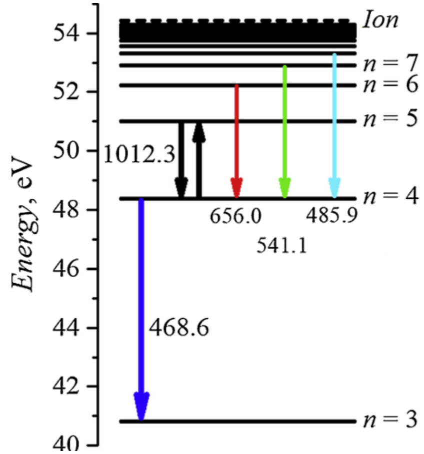
A.V. Gorbunov et al. (NRC “Kurchatov Institute”, Moscow, Russia)

Problem	Task	Publication	Processes	Data Source	Data Needs
Laser-induced fluorescence diagnostics for ITER divertor plasmas	Collision-radiative models of HeI and HeII Evaluation of fluorescence signals	A.V. Gorbunov, E.E. Mukhin, E.B. Berik et al., Fusion Eng. Des., 2019, 146(B), 2703-2707 J. M. Muñoz Burgos, M. Griener, J. Loreau, A. Gorbunov, et al., Physics of Plasmas, 2019, 26, 063301	All processes for He atoms and ions	ADAS: EIE for all transitions NIFS: EII NIST: radiative transitions R.K. Janev et al., Elementary Processes in Hydrogen-Helium Plasmas: recombination	EIE rates for spin-forbidden transitions between *n* = 1-4 states should be checked
Laser-Induced Quenching diagnostics of H (D,T) atoms	Collision-radiative model of HI	E.E. Mukhin, G.S. Kurskiev, A.V. Gorbunov et al., Nuclear Fusion, 2019, 59(8), 086052	All processes for H/D atoms	ADAS: EIE, EII NIST: radiative transitions R.K. Janev et al., Collision Processes in Low-Temperature Hydrogen Plasmas: other processes	EIE, EII rates for fine structure transitions (*nl*-splitting)

EII - Electron Impact Ionisation, EIE - Electron Impact Excitation

LIQ diagnostics of HeII for ITER*

HeII LIQ spectroscopic scheme



Laser pumping:

$n = 4 \rightarrow 5$

$\lambda_l = 1012.3$ nm

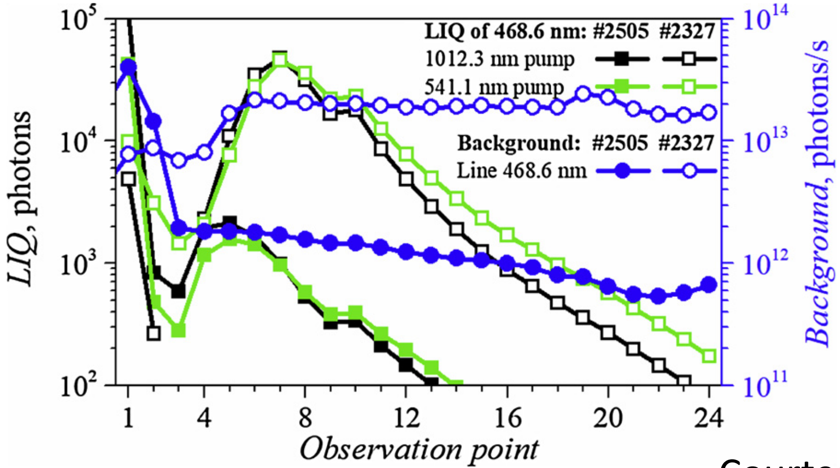
Quenching obs.:

$n = 4 \rightarrow 3$

$\lambda_l = 468.6$ nm

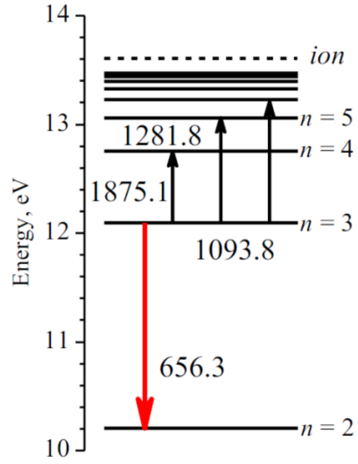
Expected LIQ and background signals

(HeII CRM calculations for ITER)



LIQ diagnostic test at Globus-M tokamak**

HI LIQ



H_α quenching

OPO laser:

(gray area)

$\lambda = 1005$ nm,

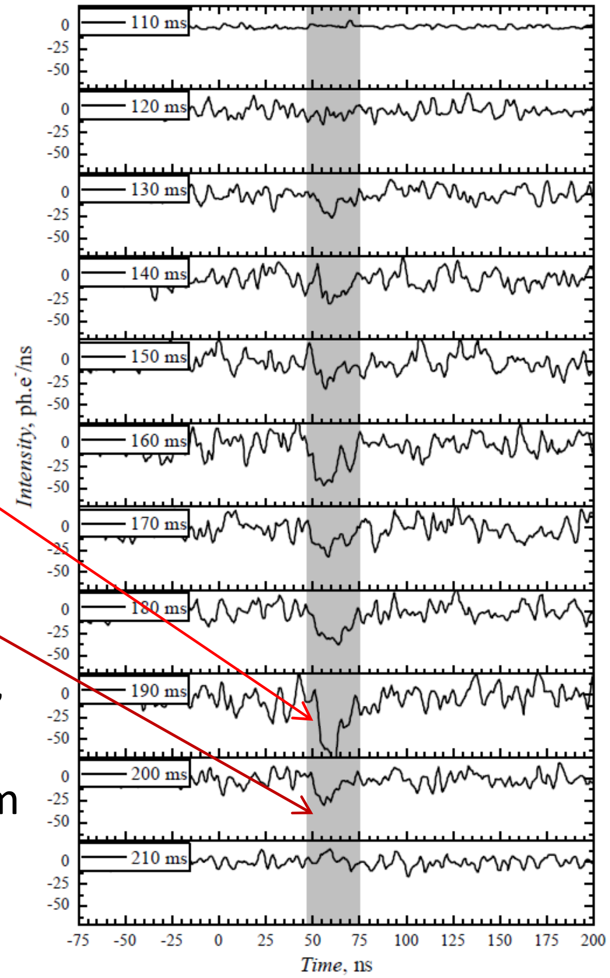
$n = 3 \rightarrow 7$

$\Delta\lambda = 2000$ pm

$\tau = 10$ ns

$E = 2.2$ mJ

H_α LIQ signals detected at Globus-M tokamak



Courtesy A.V. Gorbunov

*A.V. Gorbunov, E.E. Mukhin, E.B. Berik et al., Fusion Eng. Des., 2019, 146(B), 2703-2707

*E.E. Mukhin, G.S. Kurskiev, A.V. Gorbunov et al., Nuclear Fusion, 2019, 59(8), 086052

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- Generation of atomic data for fundamental science and controlled nuclear fusion
- Use of atomic data in controlled nuclear fusion research
- ➢ **Recent works on plasma-material interaction data**
- Conclusions

- Annual conference organized by Moscow Eng. Physics Institute

- **Russian Conferences on Plasma Surface Interaction** are mostly attended by domestic participants reporting on activities in Russia
- **21st Conference 24-25 January 2018**, proceeding are available at http://plasma.mephi.ru/ru/uploads/files/conferences/PSI_/PSI_2018.pdf
- **22nd Conference 23-24 January 2019**, proceeding are available at http://plasma.mephi.ru/ru/uploads/files/conferences/PSI_/PSI_2019.pdf

- A biennial conference organized and sponsored by
  - Russian Academy of Sciences
  - Ministry of Education and Science
  - Moscow Eng. Physics Institute
  - Moscow State University
  - St. Petersburg Polytechnic University

  and other institutions

- Newest PMI activities in Russia and in the world were reported at the **24th International Conference on Ion-Surface Interactions** https://isi2019.mephi.ru/eng/frst_en.html
- Book of Abstracts is currently available on demand

Process	Method	Data Source / Code	Publications	Verification / Application	Problem
Joint experiments of TRINITI (N. Klimov, D. Kovalenko) and MEPhI (O. Ogorodnikova, Yu. Gasparyan, A. Poskakalov)					
Deuterium retention in W under pulsed plasma heat loads relevant to ITER Transient Events	Plasma irradiation and thermal desorption spectroscopy	*Plasma exposure at QSPA- T (TRINITI), H retention analysis in UHV TDS facility (MEPhI) Modeling using TMAP7 code (MEPhI)*	*O.V. Ogorodnikova et al. JNM, 515 (2019) 150. A. Poskakalov et al. Influence of Plasma Heat Loads Relevant to ITER Transient Events on Deuterium Retention in Tungsten, submitted to Physica scrypta.*	Comparison of experimental results and modeling. Modeling is planned to extend to ITER-relevant conditions	Prediction and control of tritium retention in the bulk of PFC in ITER and future fusion devices

Process	Method	Data Source / Code	Publications	Verification / Application	Problem
MEPhI (S. Krat, Yu. Gasparyan, A. Pisarev et al.)					
Temperature dependence of deuterium co-deposition with metals (W, Al, Mo)	Magnetron sputter deposition and thermal desorption spectroscopy	*Experiments at the MD-2 facility (MEPhI). Analytical solution of diffusion equations.*	*S. Krat et al., Vacuum, 149 (2018) 23. Yu. Gasparayan et al. Fusion Engineering and Design, 146 (2019) 1043.*	Comparison of experimental results and analytical equations.	Prediction and control of tritium retention in co-deposits in ITER and future fusion devices

Process	Method	Data Source / Code	Publications	Verification / Application	Problem
MEPhI (S. Krat, Yu. Gasparyan, A. Pisarev et al.) and IPP-Garching (M. Mayer)					
Elastic backscattering as a method for the measurement of the integral lithium content in thin films on fusion-relevant substrates	Elastic backscattering	*Joint experiments at the Tandem accelerator (IPP, Garching). Simulations using SIMNRA code.*	*S. Krat, et al. Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms, 455 (2019) 124*	Comparison of experimental results and calculations	Analysis of Lithium content in co-deposits formed in fusion devices

Process	Method	Data Source / Code	Publications	Verification / Application	Problem
MEPhI (S. Ryabtsev, Yu. Gasparyan, A.Pisarev et al.)					
Helium retention in W irradiated with He+ ions at elevated temperatures (300-1200 K)	Ion beam implantation and thermal desorption spectroscopy (up to 2500 K). Secondary electron microsopy	*Medion facility (MEPhI)*	*S. Ryabtsev et al.* Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms, https://doi.org/10.1016/j.nimb.2019.01.051	Low fluence experiments in well conrtolled conditions can used as a reference for modeling	Influence of He plasma irradiation of PFM on H isotope retention and surface moorphology

Add-on:
Database Activities in Snezhinsk and Novosibirsk

- **SPECTR-W3 database on spectroscopic properties of atoms and ions (http://spectr-w3.snz.ru/index.phtml) developed at E.I. Zababakhin All-Russian Scientific Research Institute of Technical Physics in Snezhinsk was earlier reported in the context of VAMDC activity**

OPEN ACCESS
IOP Publishing — Journal of Physics B: Atomic, Molecular and Optical Physics

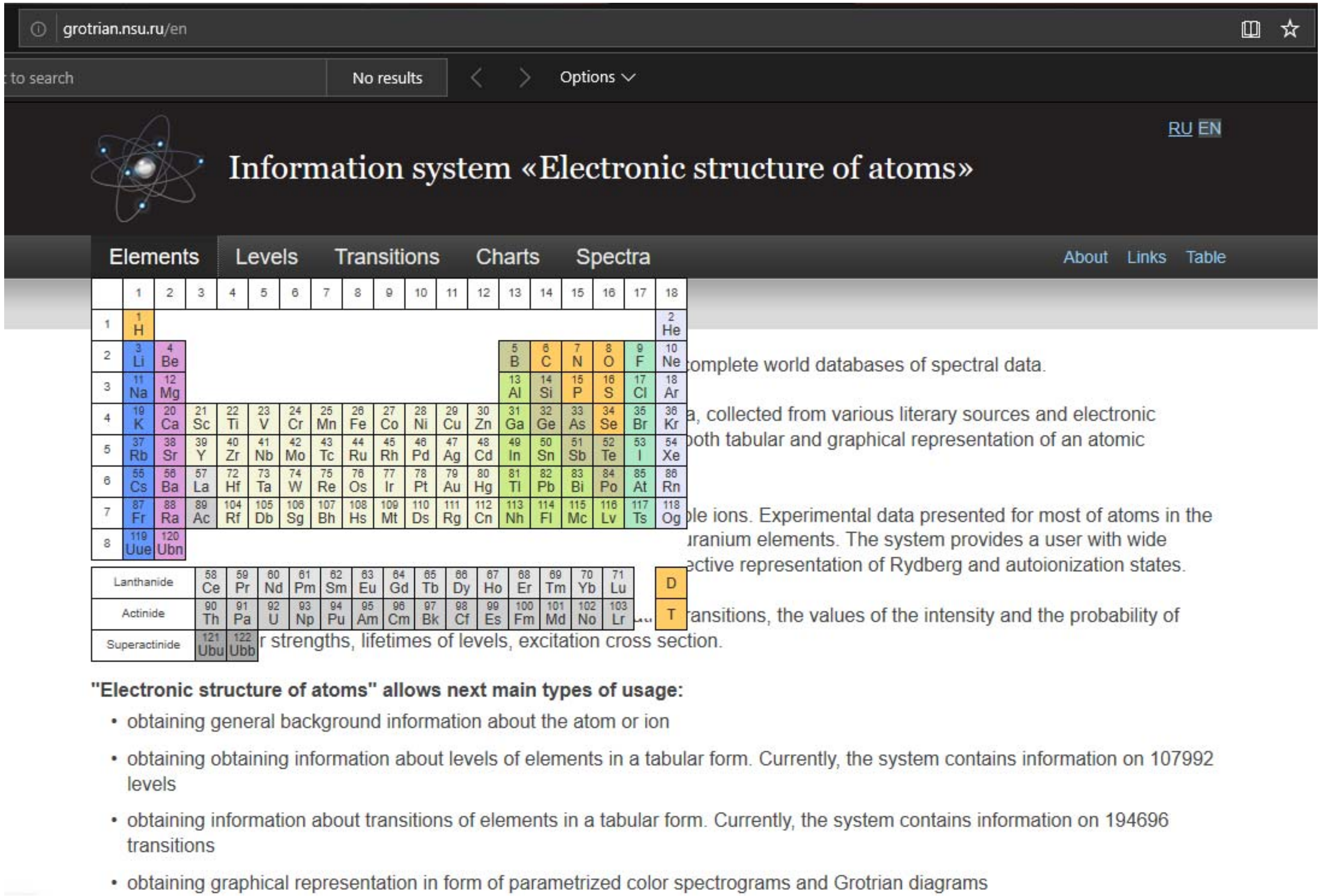
J. Phys. B: At. Mol. Opt. Phys. **49** (2016) 074003 (18pp) — doi:10.1088/0953-4075/49/7/074003

The virtual atomic and molecular data centre (VAMDC) consortium*

- **Current status was reported at**
  I.Yu. Skobelev, P.A. Loboda
  Database SPECTR-W3 on spectroscopic properties of atoms and ions
  17th International Workshop “Complex Systems of Charged Particles and their Interactions with Electromagnetic Radiation 2019”
  Moscow, Russia, 25-27 March 2019
  https://cscpier.org/

G.I. Budker Institute of Nuclear Physics

Russian atomic spectroscopy, information system electronic structure of atoms (IS ESA) (http://grotrian.nsu.ru) was described in
[V.V. Kazakov et al. Phys. Scr. **92** 105002 (2017)]()
An update was published in
[V.V. Kazakov et al. AIP Conference Proceedings **2052**, 020010 (2018)]()



Outline

- Generation of atomic data for fundamental science and controlled nuclear fusion
- Use of atomic data in controlled nuclear fusion research
- Recent works on plasma-material interaction data

➢ **Conclusions**

Conclusions

- Works on atomic data in the past two years were motivated by both fundamental science and controlled nuclear fusion research

- Further development of ITER diagnostics in Russia reveals new data needs

- Priorities of Russian research programme on controlled fusion determine the activity on PMI data

- Activities on SPECTR-W3 and IS ESA databases are continuing