Soft X-ray analysis at TEXTOR

(from atomic data to impurity transport)

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ADAS-Workshop

Contents

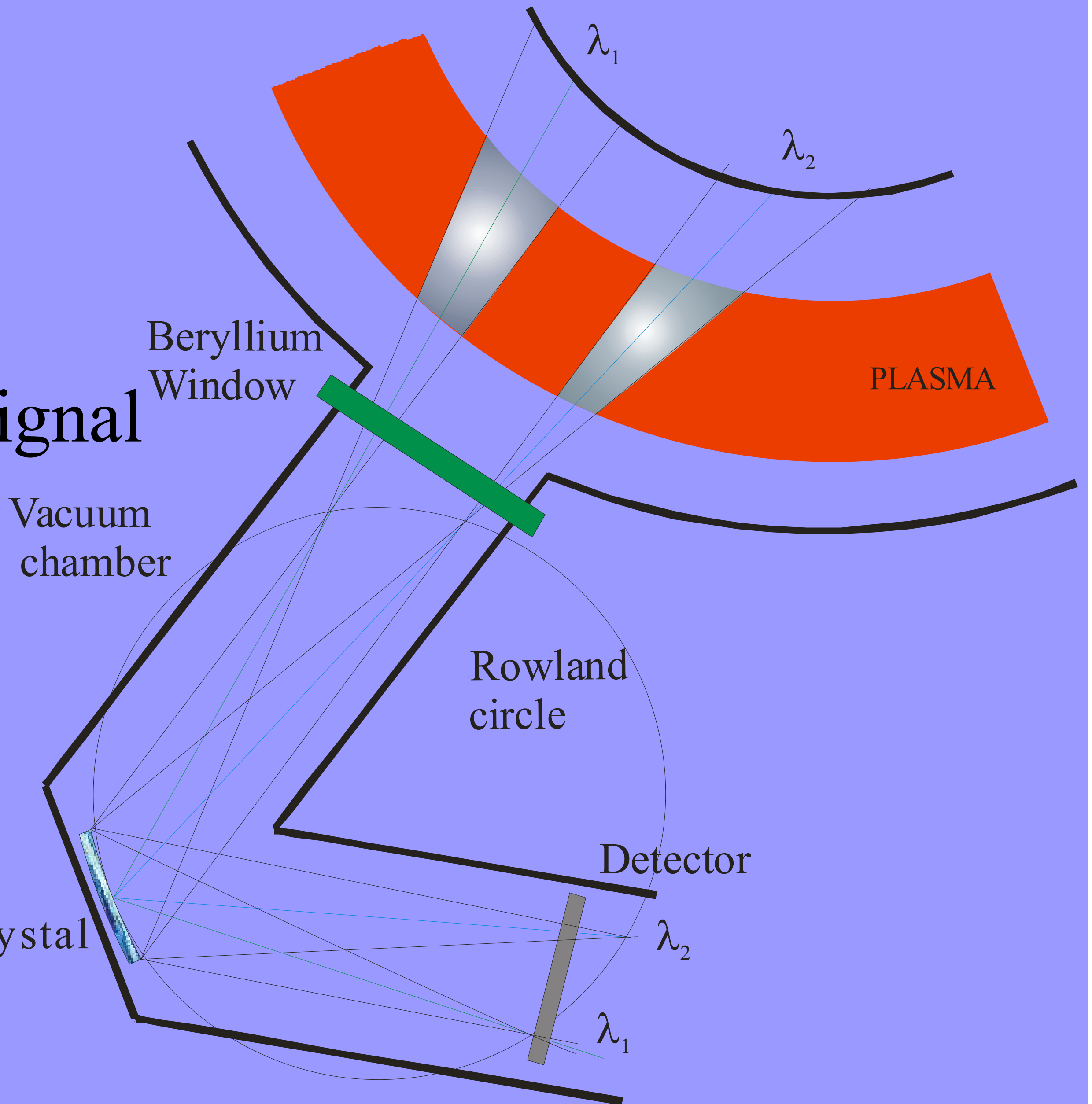
- Measurements of He-like Argon at TEXTOR
- Theoretical modeling of the spectra
- Measurements of the H/He/Li - like ions
- Influence of recombination (CXR) & Transport
- First results on 2-D X-ray spectra
- Results and conclusions

Experiment at TEXTOR

- Bragg condition

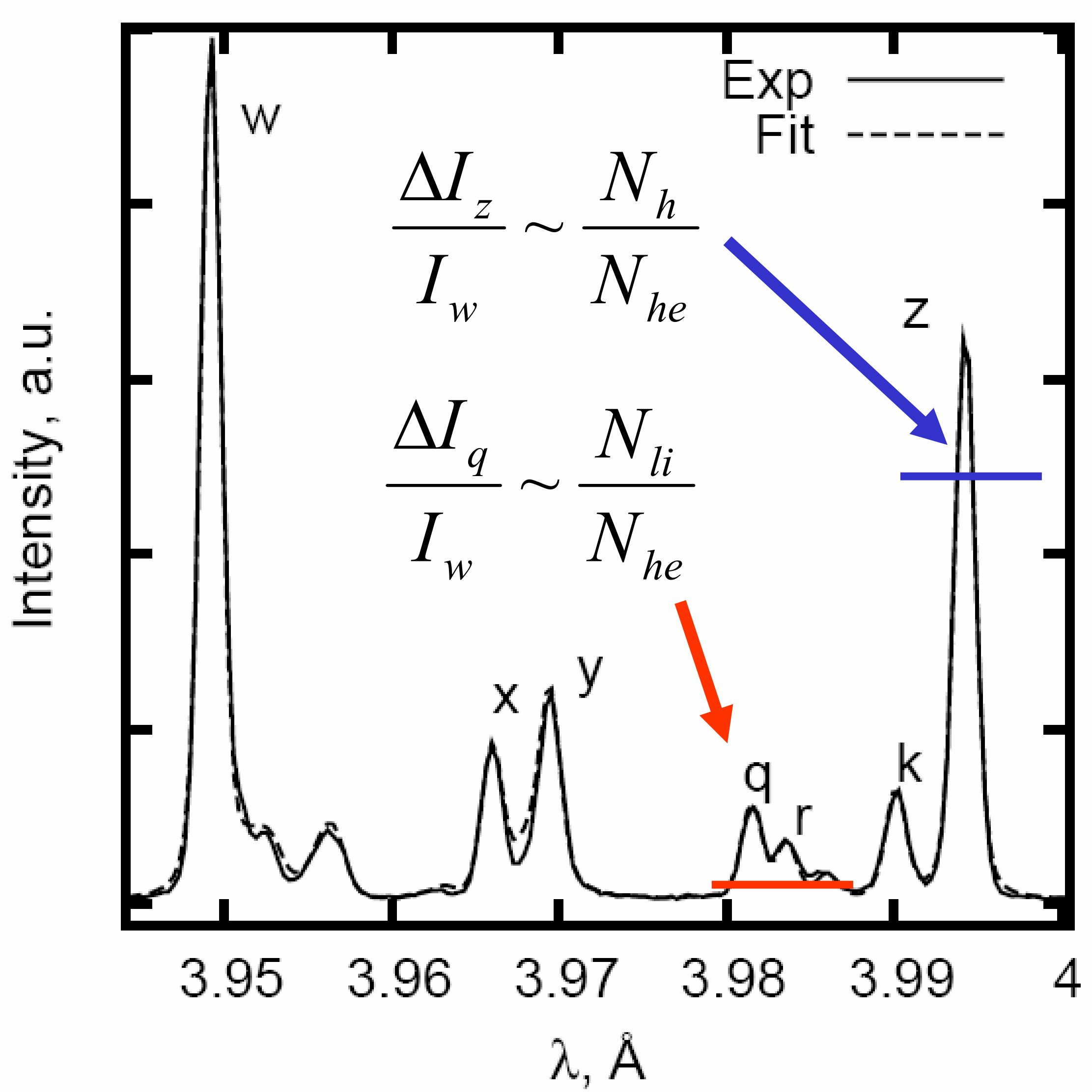
  $$n\lambda=2d\cdot sin\theta$$

- Line integrated signal



The modelling of the Ar spectra in the coronal approximation

(including the integration along the line of sight)



Intensity of the lines is proportional to :

<u>Density of He-like ions</u>

•Excitation

<u>Density of H-like ions</u>

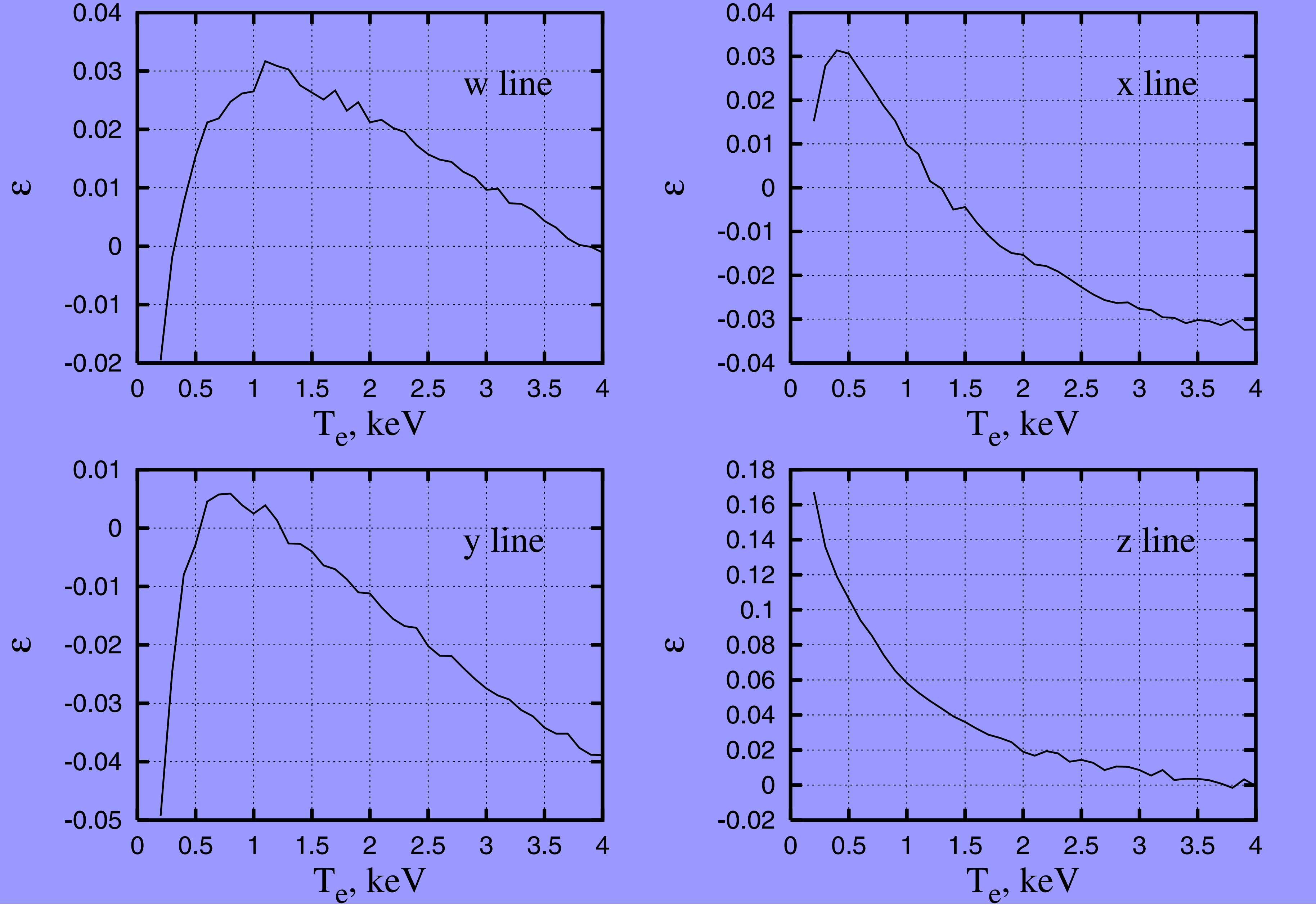
•Electron recombination
- radiative
- dielectronic

<u>Density of Li-like ions</u>

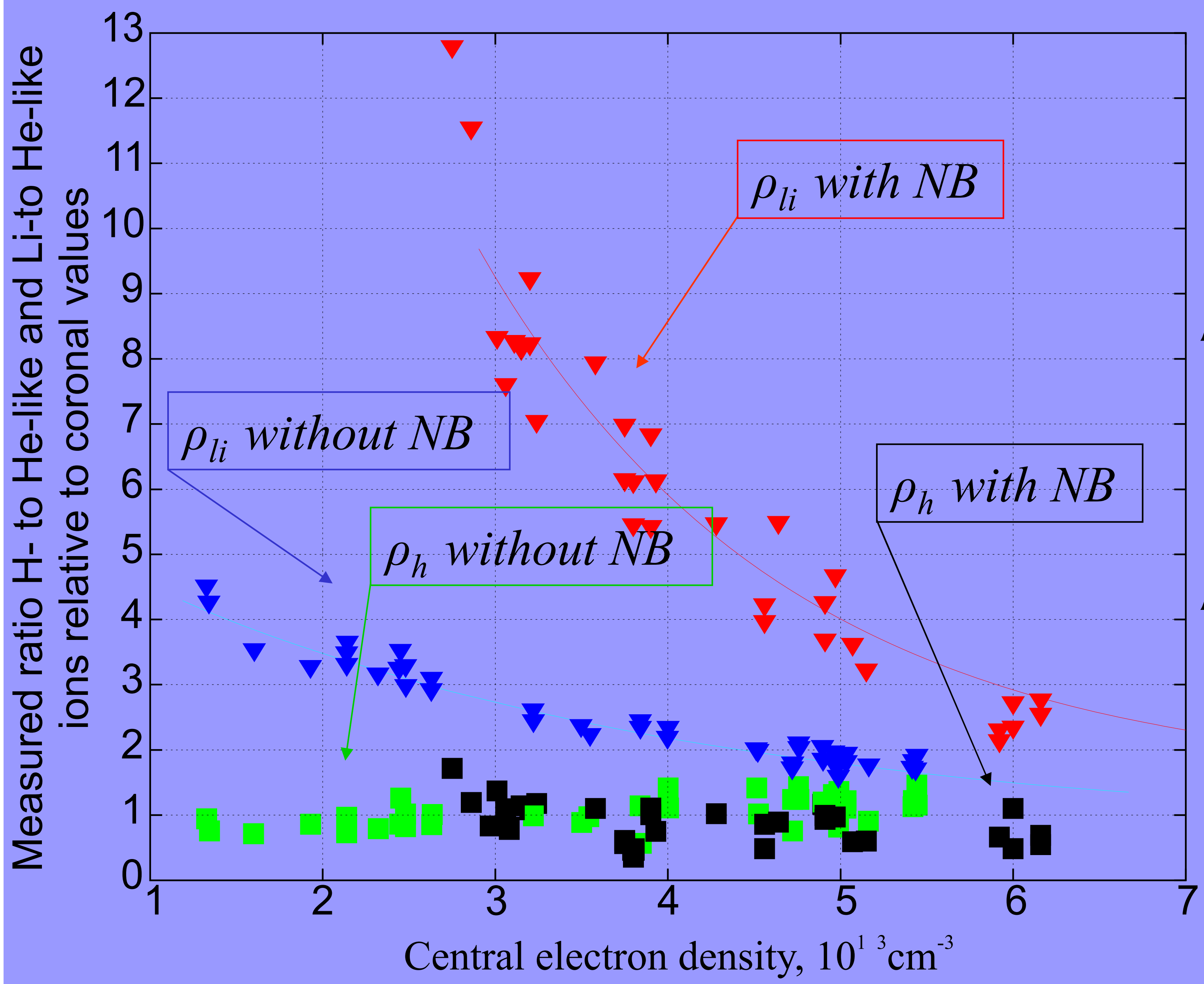
•Excitation

•Ionisation

Comparison R-matrix/Coulomb-Born. Effective excitation rates



Measurements of H/He and Li/He (no transport & no CXR).



$$\rho_h = \frac{\left(N_h / N_{he}\right)}{\left(N_h / N_{he}\right)_{cor}}$$

$$\rho_{li} = \frac{\left(N_{li} / N_{he}\right)}{\left(N_{li} / N_{he}\right)_{cor}}$$

Question to the measurements

- Why the density of Li- like ions shows strong deviation from the coronal balance and density of H-like ions is „frozen“ to the coronal values?

Question to the model

- Can the missed processes :

  •Charge-exchange recombination (CXR)

  •Transport of Impurities (T)

explain the measurements ?

→ Measured density of Li-like ions proposes to start with the influence of CXR.

Expectations

- Coronal Balance $$\frac{n_z}{n_{z+1}} = \frac{S_z}{\alpha_z}$$

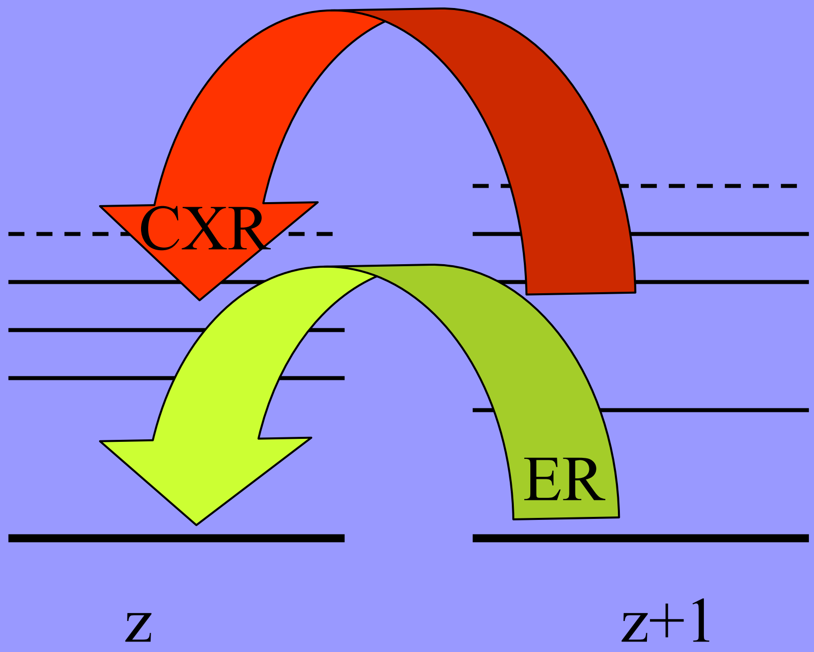
S_z - electron recombination (z+1, z)

α_z - electron ionization (z, z+1)

z = {H-like, He-like, Li-like, ...} = {Ar^{17+}, Ar^{16+}, Ar^{15+}, ...}

- Coronal Balance with CXR, $n_a \neq 0$

$$\frac{n_z}{n_{z+1}} = \frac{S_z}{\alpha_z}\left(1 + \frac{n_a}{n_e}\frac{S_z^{cx}}{S_z}\right)$$

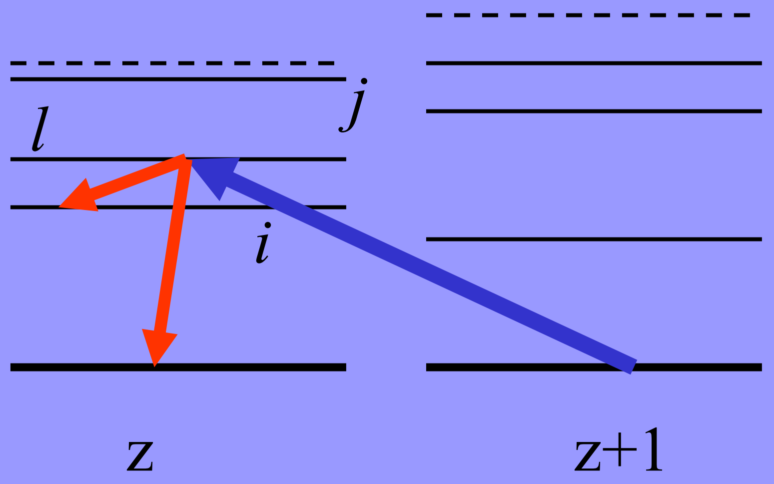


ER CXR

Density of the Li-like ions ↗

Density of the H-like ions ↘

Impact of the CXR to the excited states of the He-like lines

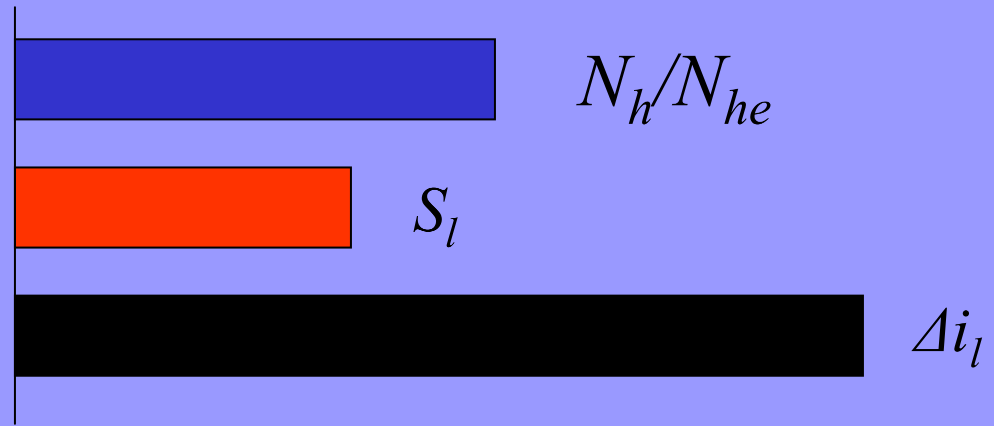


•CXR depopulates the density of the ground state of the ion $A^{(z+1)+}$

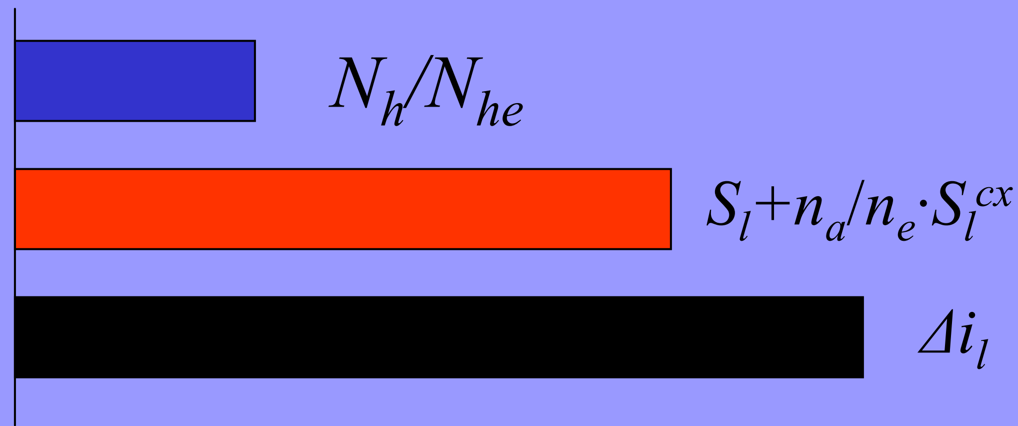
•CXR populates the excited states (n~10...20) of the ion A^{z+} and so inreases the recombination rate from $A^{(z+1)+}$ to A^{z+}

Intensity = Ion Density(H-like) x Rate

a) without CXR

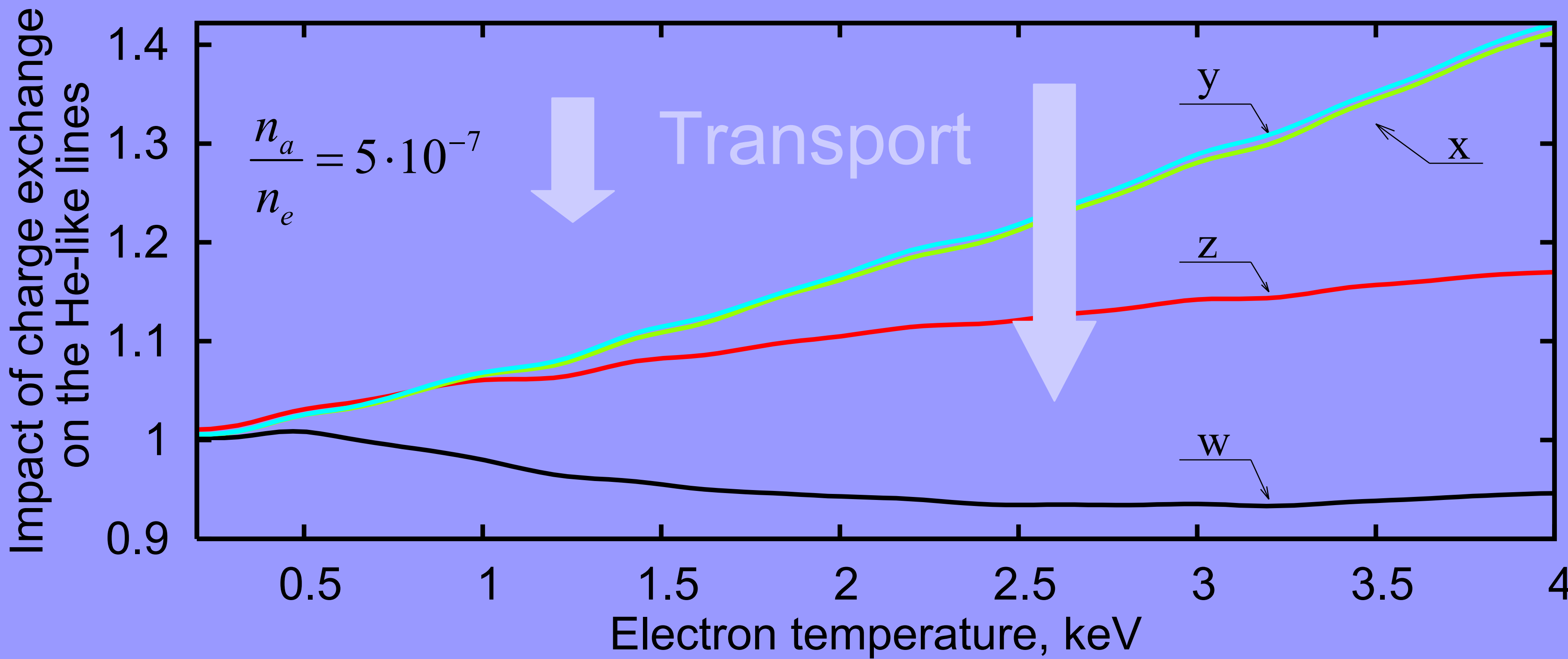


b) with CXR (collisional radiative model)



Results of calculations

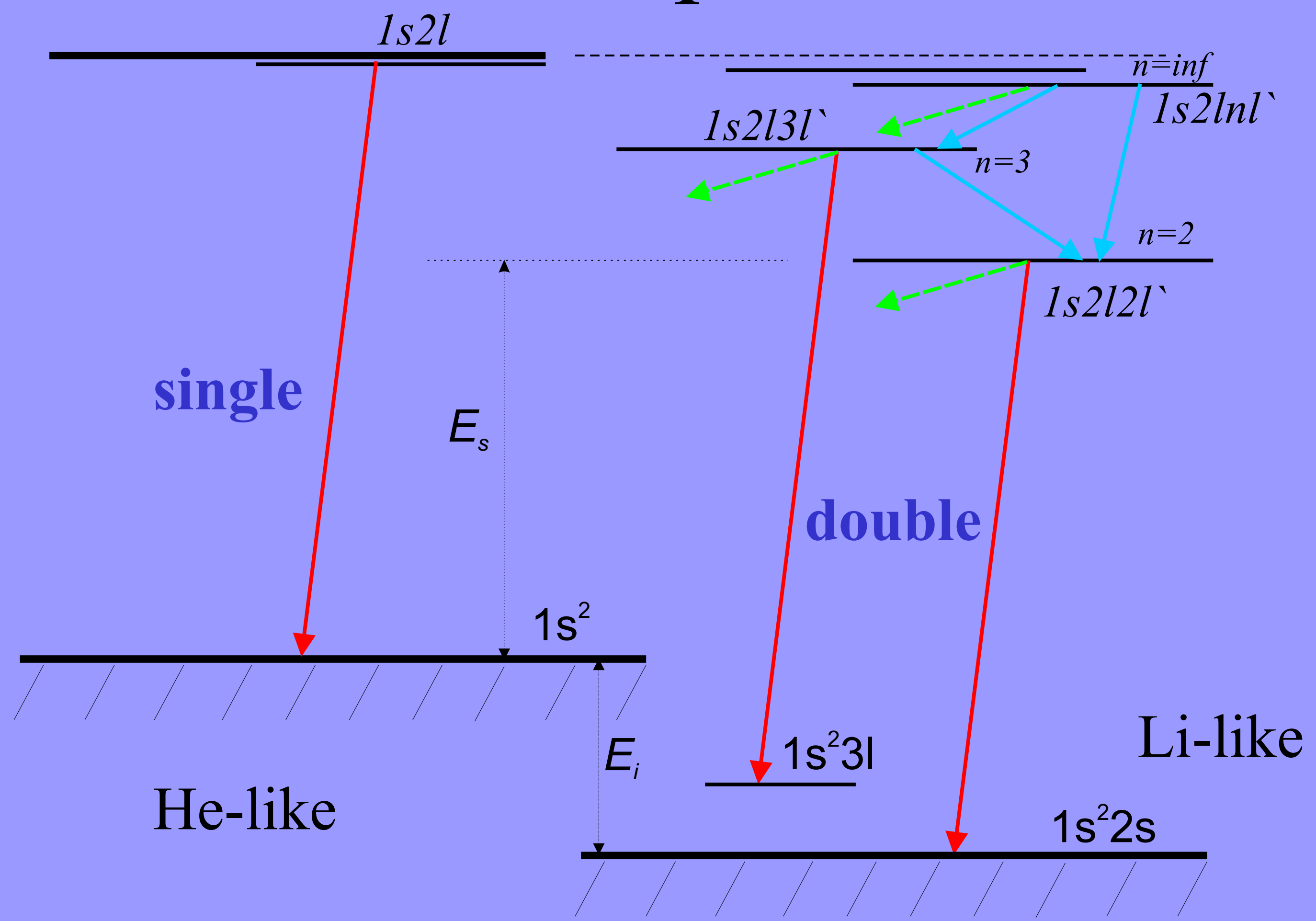
$$\rho_l = \left(1 + \frac{n_a}{n_e}\frac{S_l^{cx}}{S_l}\right)\left(1 + \frac{n_a}{n_e}\frac{S_{he}^{cx}}{S_{he}}\right)^{-1}$$



•The results of calculations confirm the measurements and importance of the CXR to the excited states

•Trend can be partly suppressed in the experiment by Transport

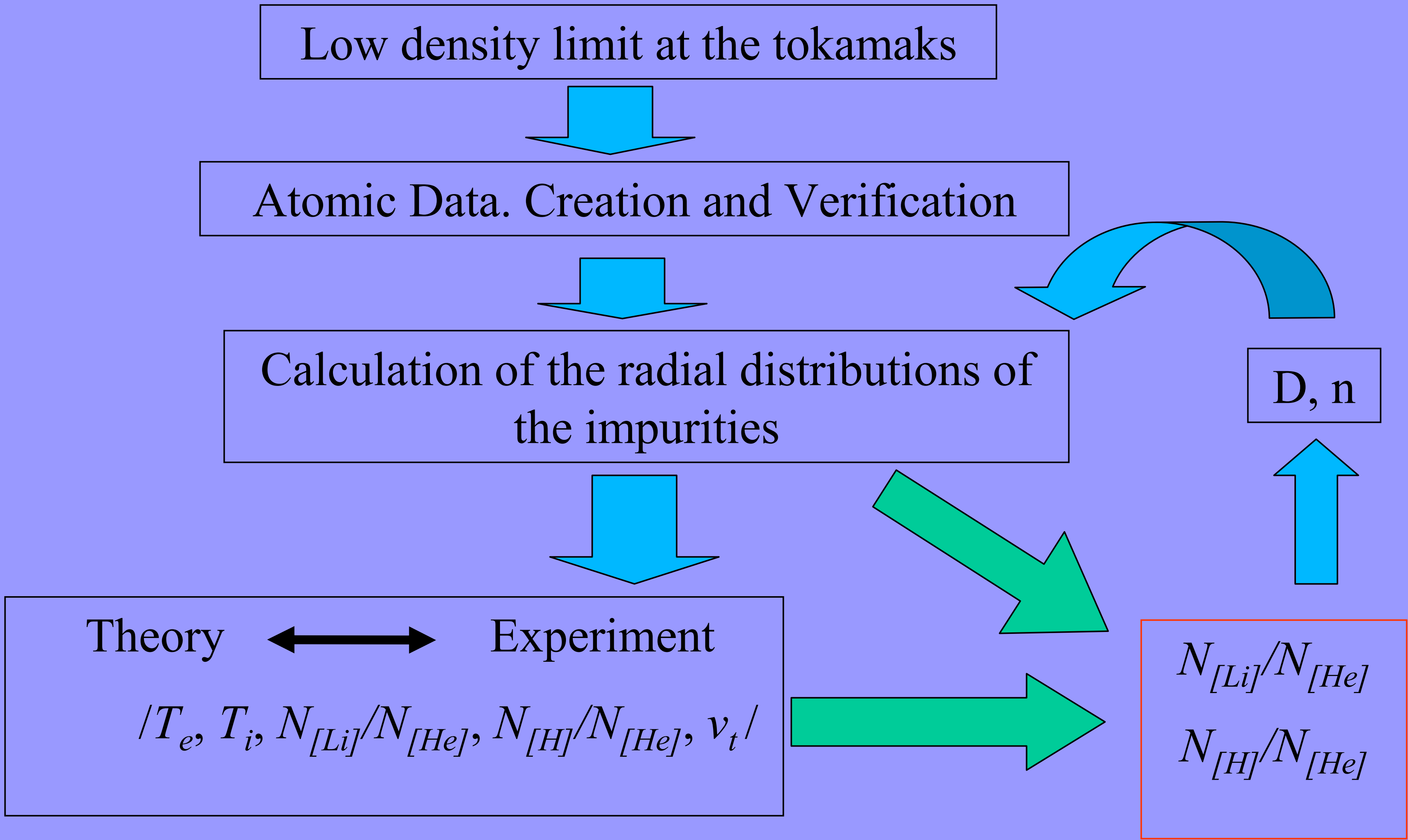
Why it is possible to distinguish between transport and CXR.



In low-density limit CXR populates excited states of He

($1s^2$-$1snl$) but not Li- doubly excited ($1s^22s$-$1s2lnl$‘)

Modelling Step by Step



Errors (Experimental + Corona Calculation ~ 20%)

Impurity Transport Model + Model of He-like spectra.

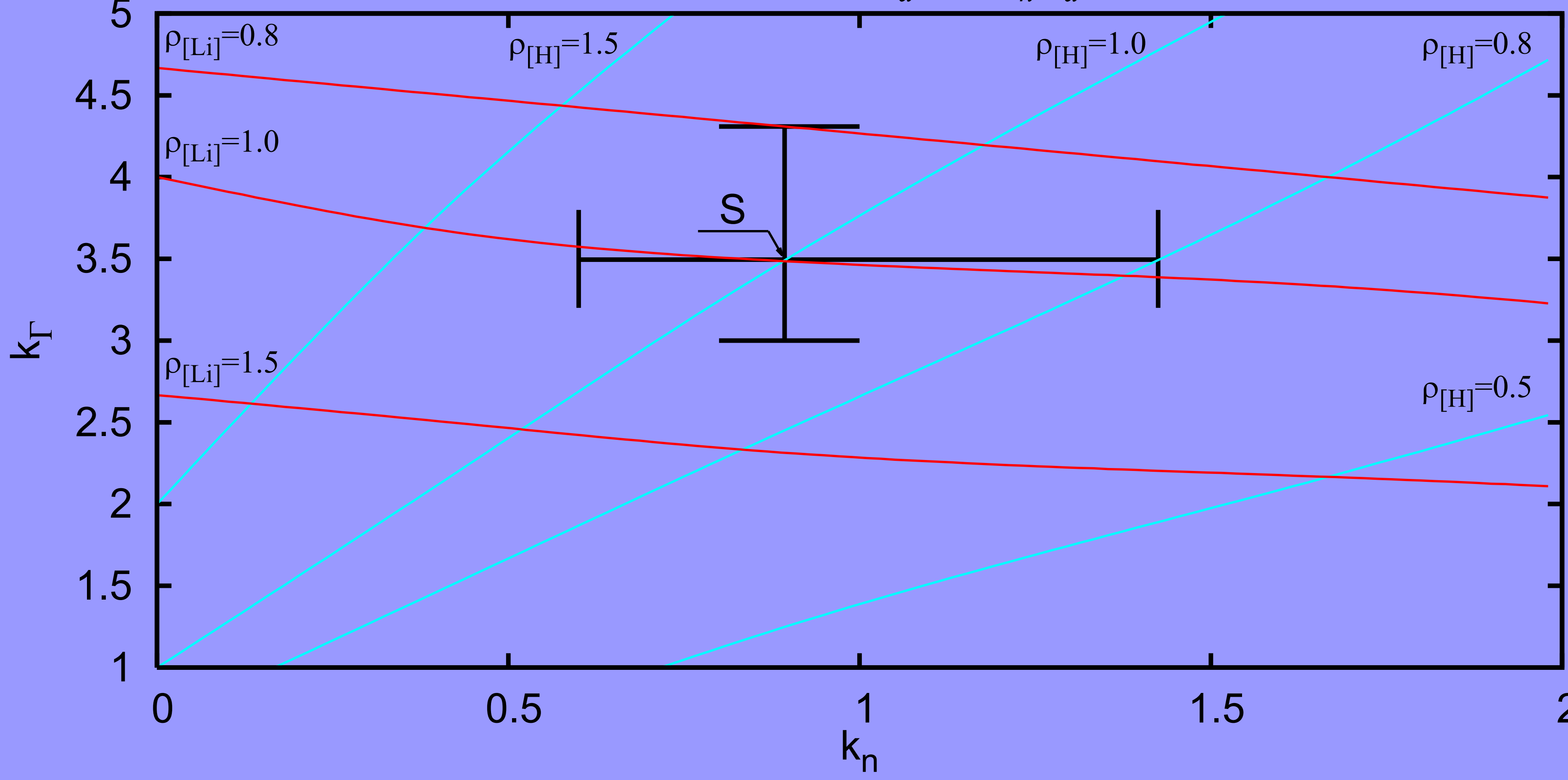
$\rho_{[H]}(k_n,k_\Gamma)=1$

$\rho_{[Li]}(k_n,k_\Gamma)=1$

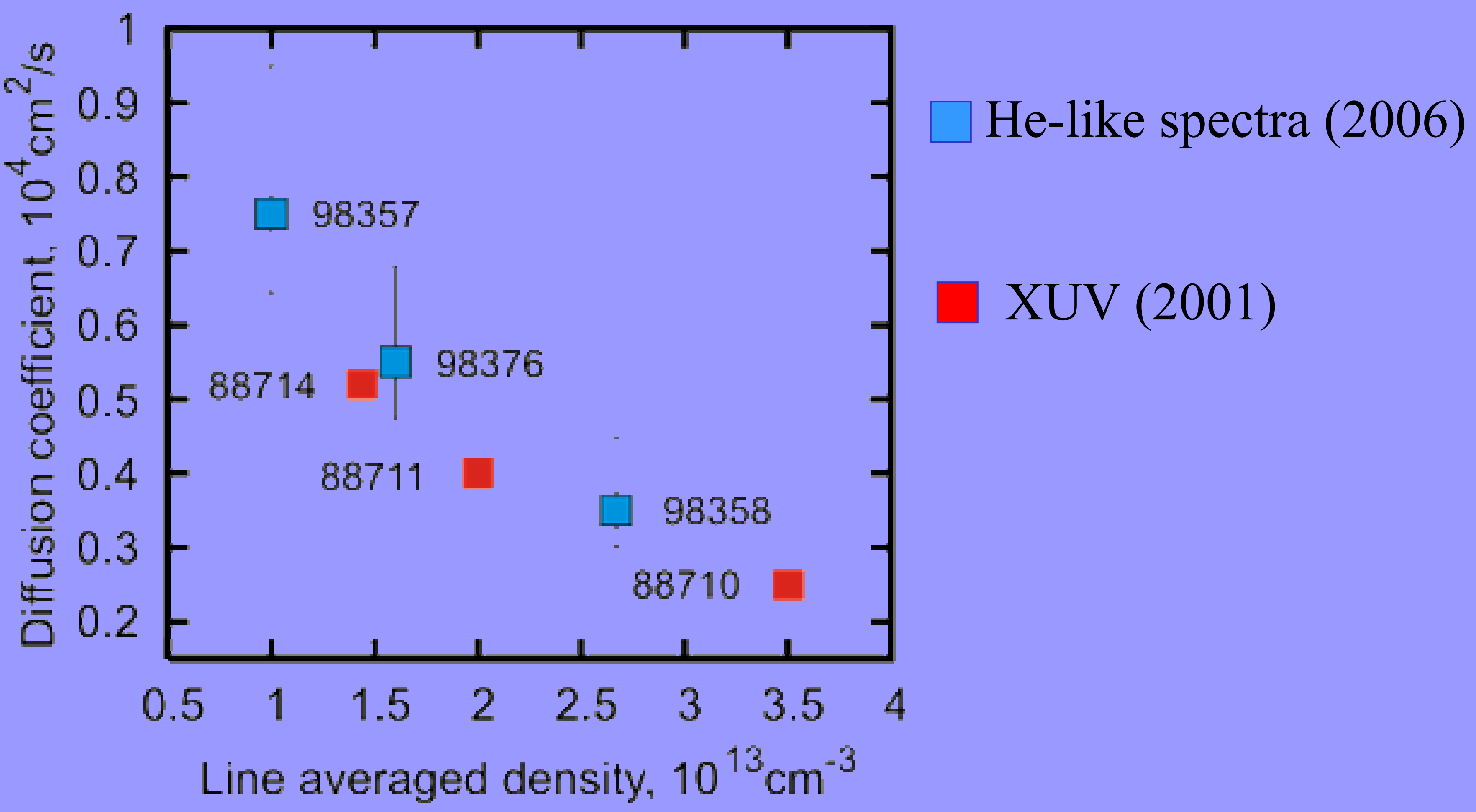
$D \rightarrow k_\Gamma D$

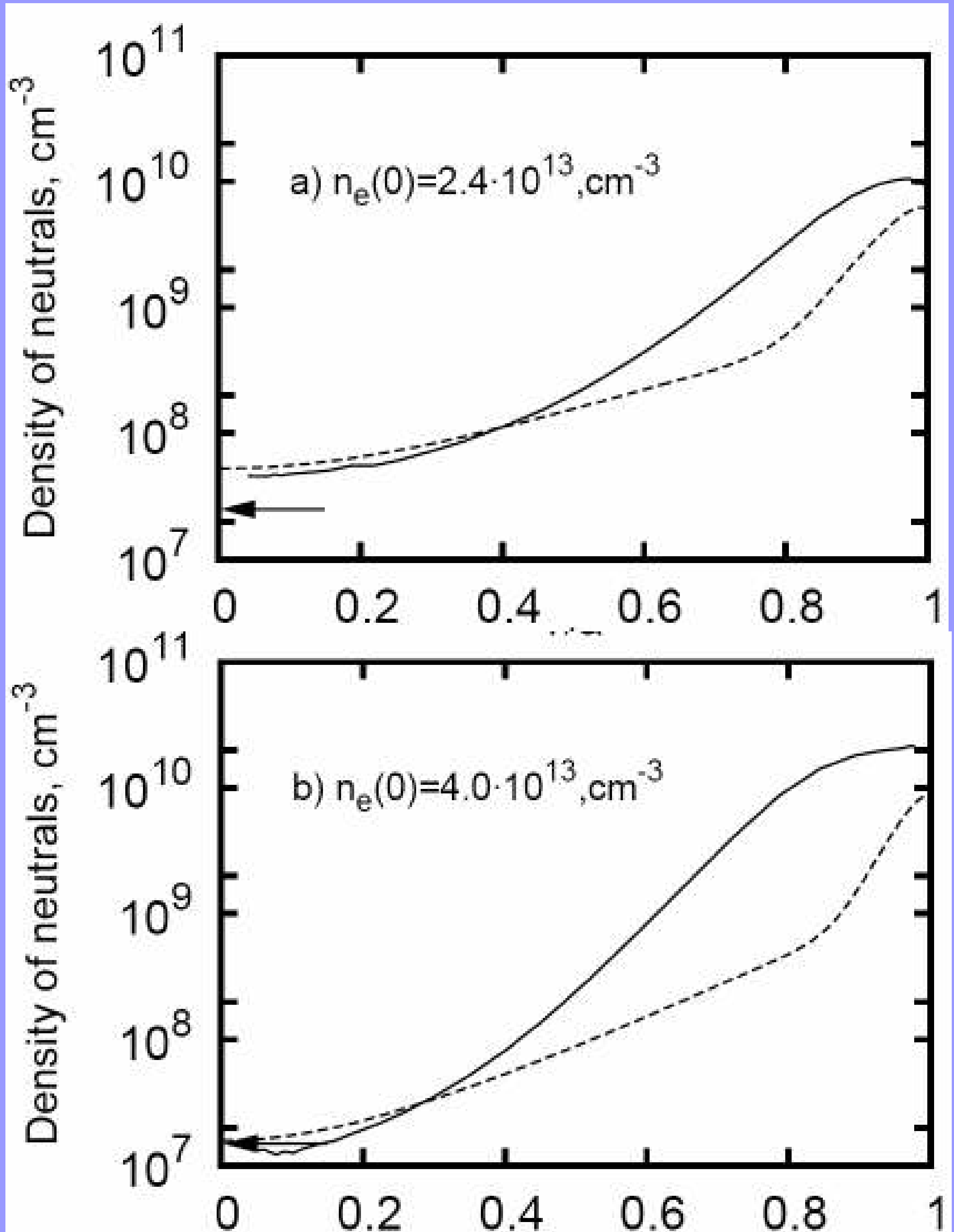
$V \rightarrow k_\Gamma V$

$n_a \rightarrow k_n n_a$



Diffusion coefficents for the plasma core in ohmic plasma.





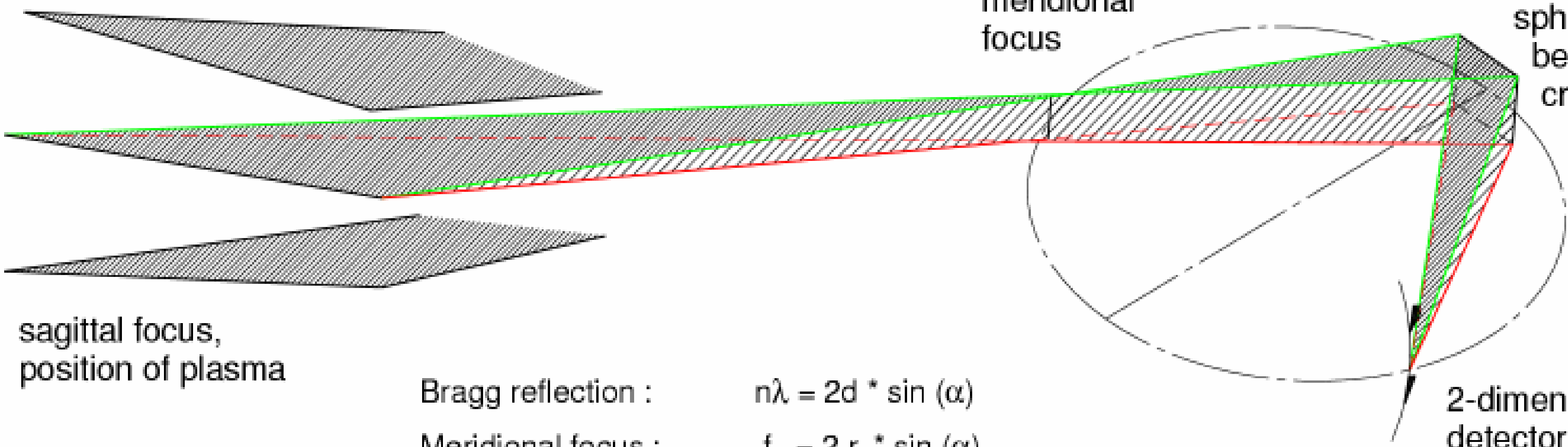
Neutral Density

Eirene vs. Diffusion Model.

Deviations are observed in the region of the gradients of the plasma parameters.

Arrow shows the result from the He-like spectra

Principle of Imaging Bragg spectrometer



Bragg reflection : $n\lambda = 2d * \sin(\alpha)$

Meridional focus : $f_m = 2\, r_r * \sin(\alpha)$

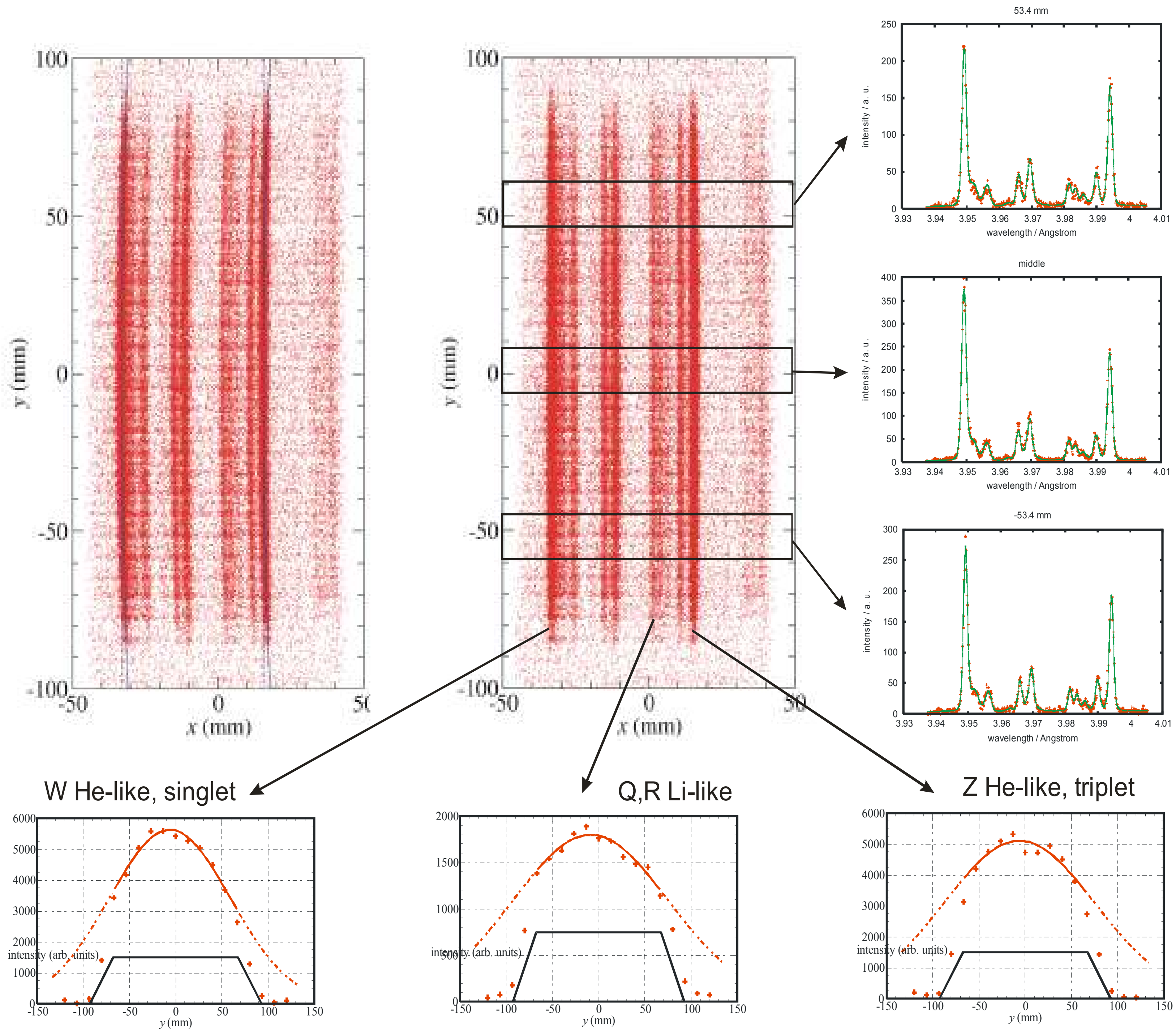
Saggital focus : $f_s = - f_m / \cos(2\alpha)$

α : Bragg angle

d : crystal plane spacing

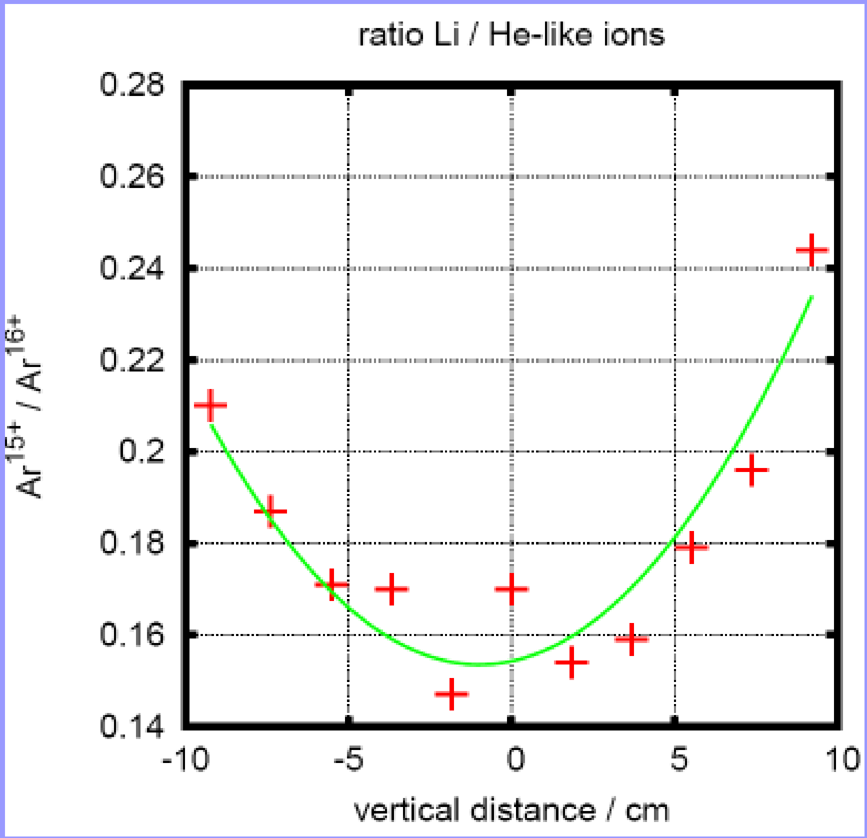
r_r : radius of Rowland circle

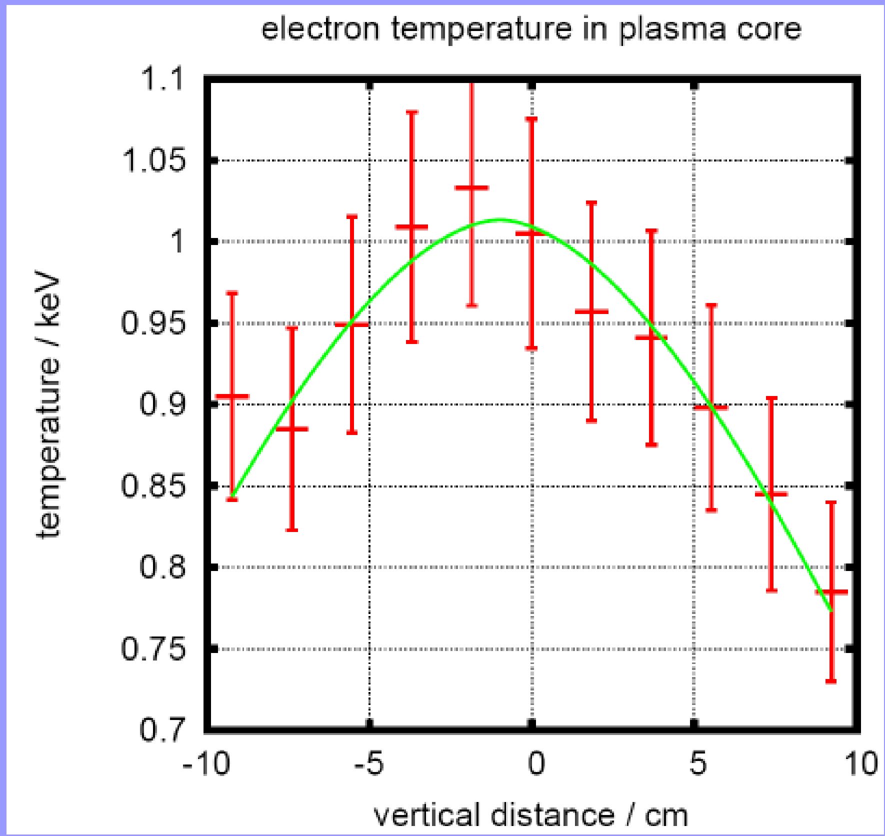
f_m, f_s : distance of meridional / saggital focus from the crystal



53.4 mm
middle
-53.4 mm
intensity / a. u.
wavelength / Angstrom
y (mm)
x (mm)
W He-like, singlet
Q,R Li-like
Z He-like, triplet
intensity (arb. units)
y (mm)

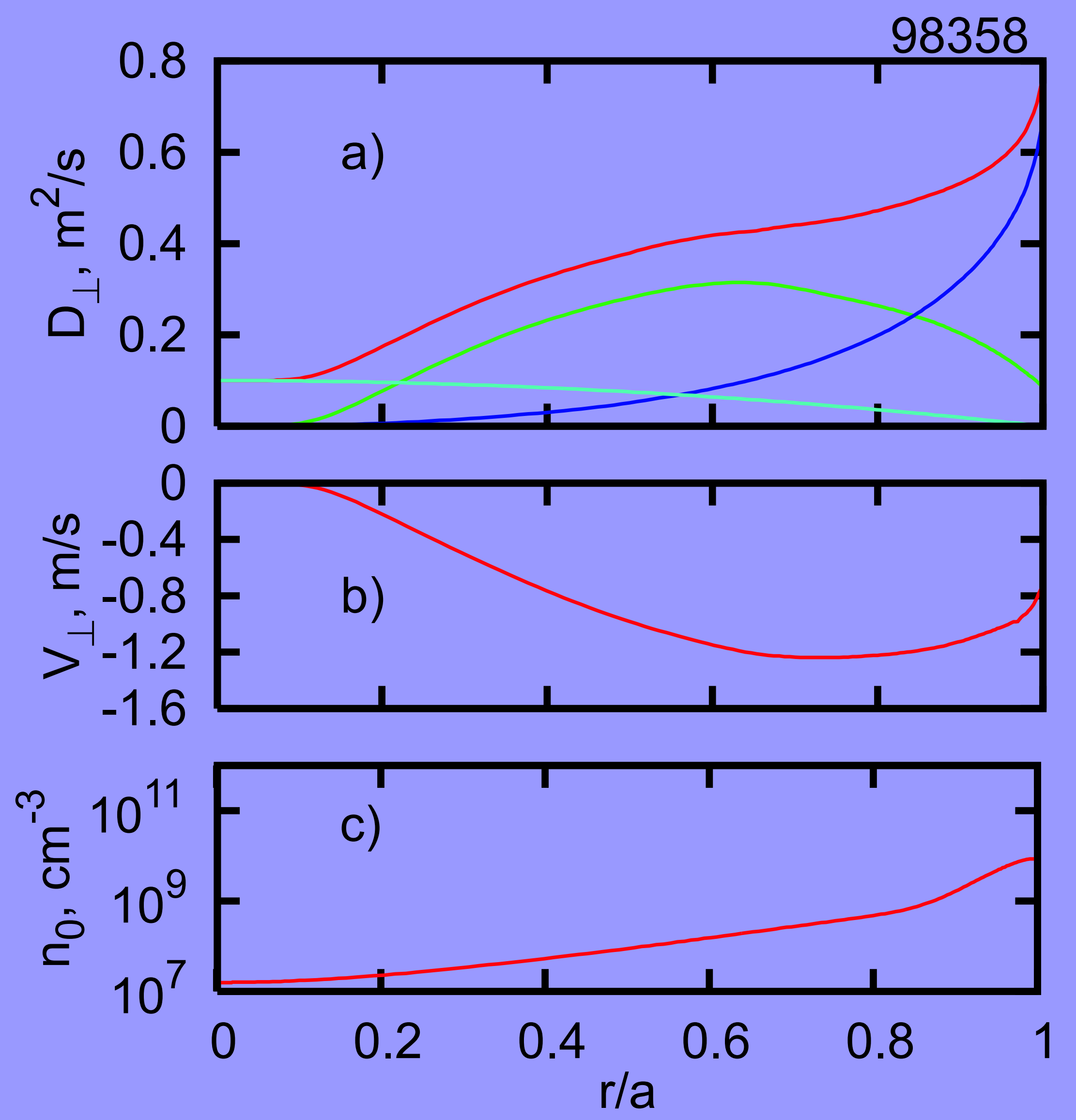
Results from the 2-D He-like argon spectra.

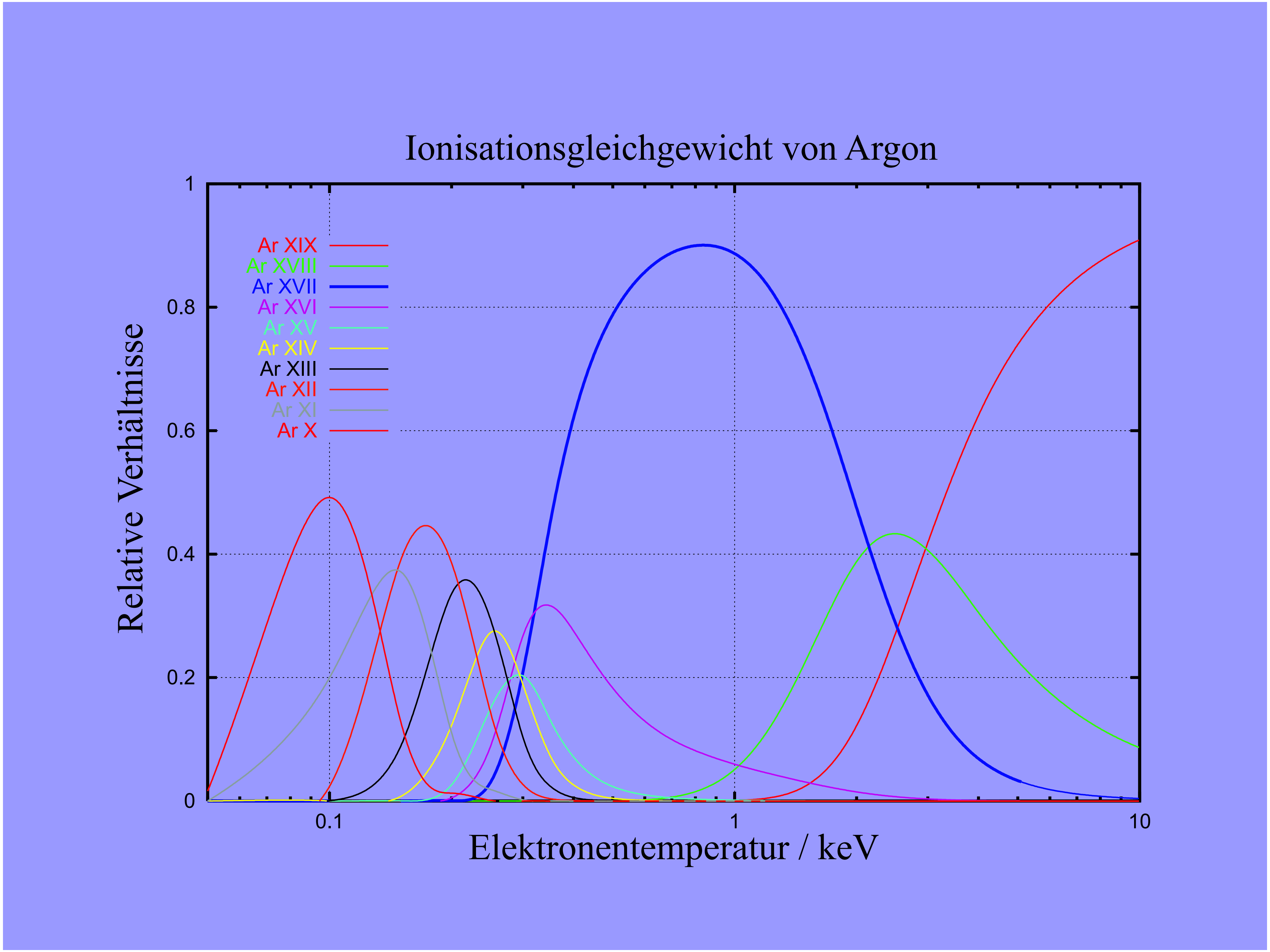




Conclusion

- Routine measurements of T_e, T_i and V_{tor}
- The verified set of atomic data for He-like argon was used to study the CXR and transport porperties of the ohmic plasma.
  - Transport coefficients (~40%)
  - Neutral density (~100%)
- The spectra distinguish between the effect of Transport and CXR as single- and doubly excited states are observed simultaneously.
- The cases with NB-injection need special attention as two neutral species are simultaneously at the plasma and as seen the effect is large !
- It is planned to measure the H-like spectra at TEXTOR with the aim to resolve the cross–sections using the new 2-D spectrometer.


98358
a)
b)
c)
D⊥, m²/s
V⊥, m/s
n0, cm-3
r/a
0.8
0.6
0.4
0.2
0
-0.4
-0.8
-1.2
-1.6
10^11
10^9
10^7
0.2
0.4
0.6
0.8
1


Ionisationsgleichgewicht von Argon
Relative Verhältnisse
Elektronentemperatur / keV
Ar XIX
Ar XVIII
Ar XVII
Ar XVI
Ar XV
Ar XIV
Ar XIII
Ar XII
Ar XI
Ar X
0
0.2
0.4
0.6
0.8
1
0.1
1
10