Population structure of atoms and ions in plasmas

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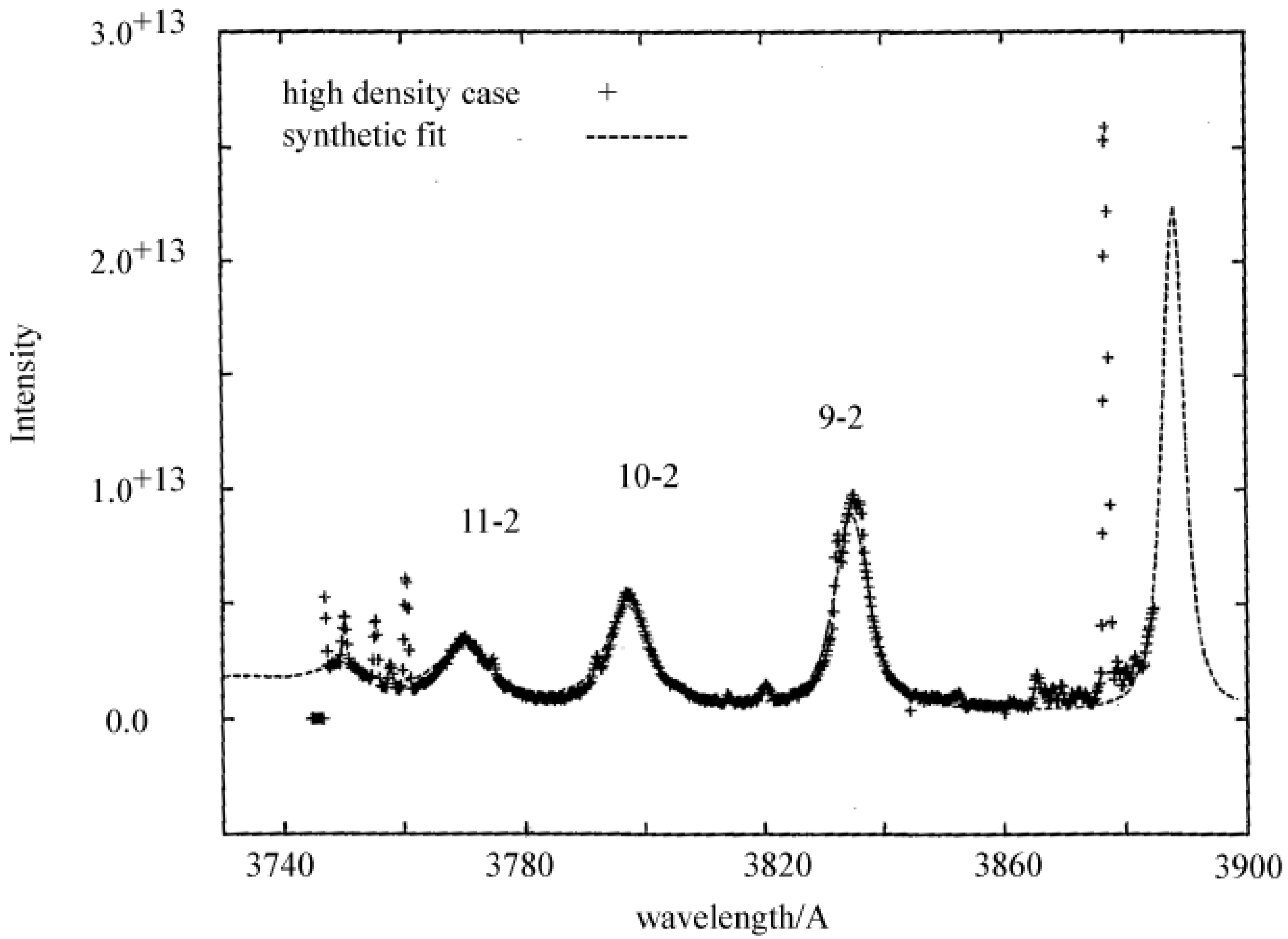
Balmer series spectrum



Fit to JET pulse #43735, Balmer series limit spectrum, track 6, time=18.95s

b and g

Introduce the Saha-Boltzmann population

$$N_i^{SAHA} = N_e N_+ 8\left(\frac{\pi a_0^2 I_H}{kT_e}\right)^{3/2} \frac{\omega_i}{2\omega_+} e^{I_i/kT_e}$$

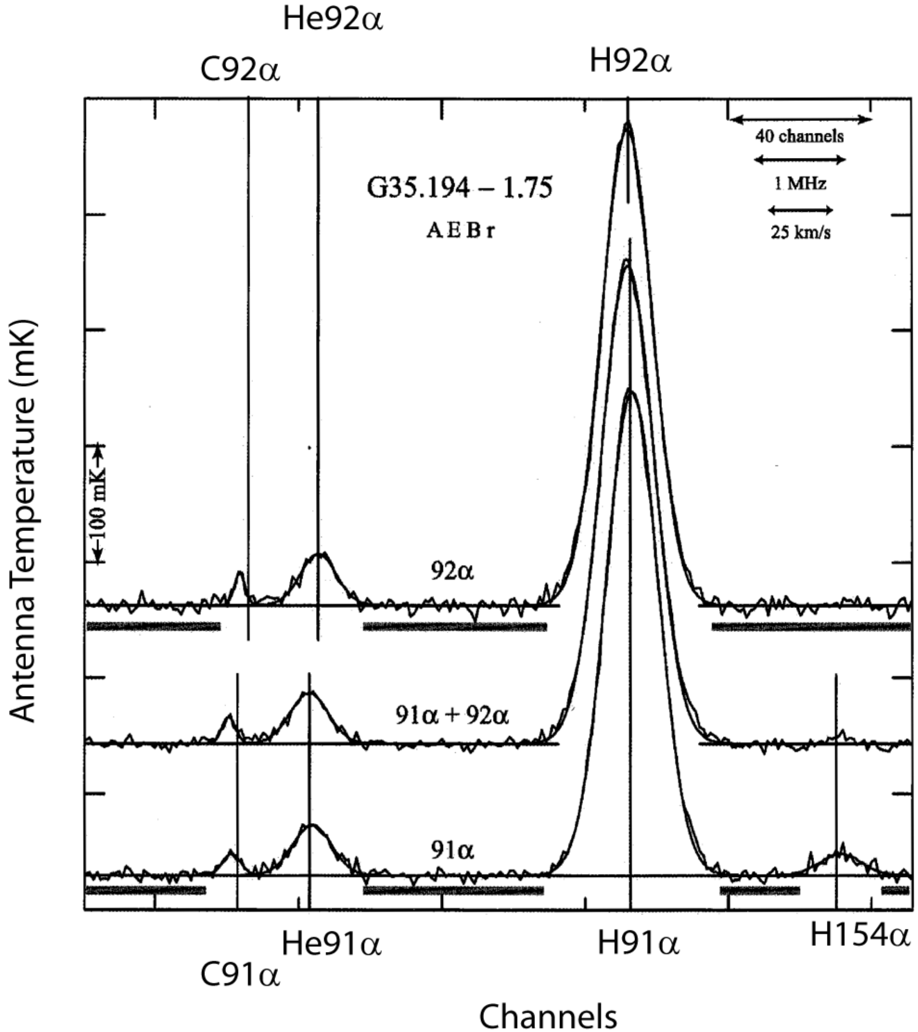
and the Kramer's expression for the oscillator strength

$$f'_{n'\to n} = \frac{2^6}{3\sqrt{3}\pi}\frac{1}{\omega_{n'}}\left(\frac{1}{n'^2} - \frac{1}{n^2}\right)^{-3}\left|\frac{1}{n^3 n'^3}\right|$$

Then the actual populations and oscillator strength are given by

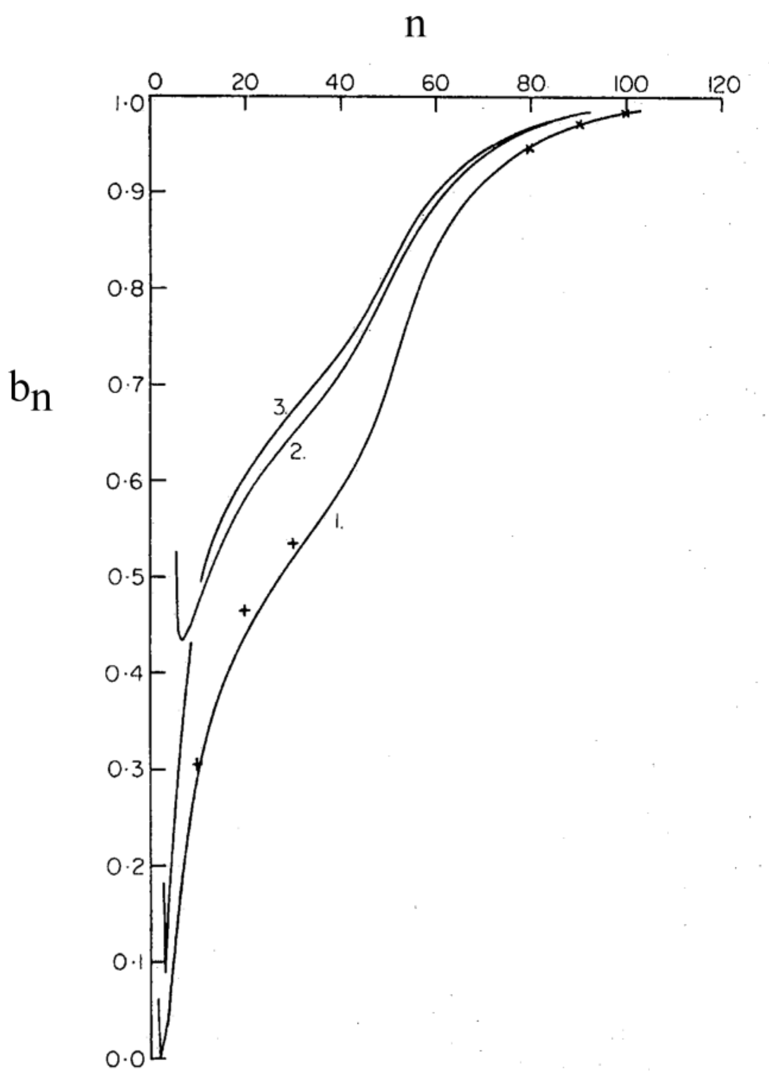
$$N_i = N_i^{SAHA} b_i$$ and $$f_{n'\to n} = f'_{n'\to n} g_{nn'}$$

Observed microwave recombination-line spectra



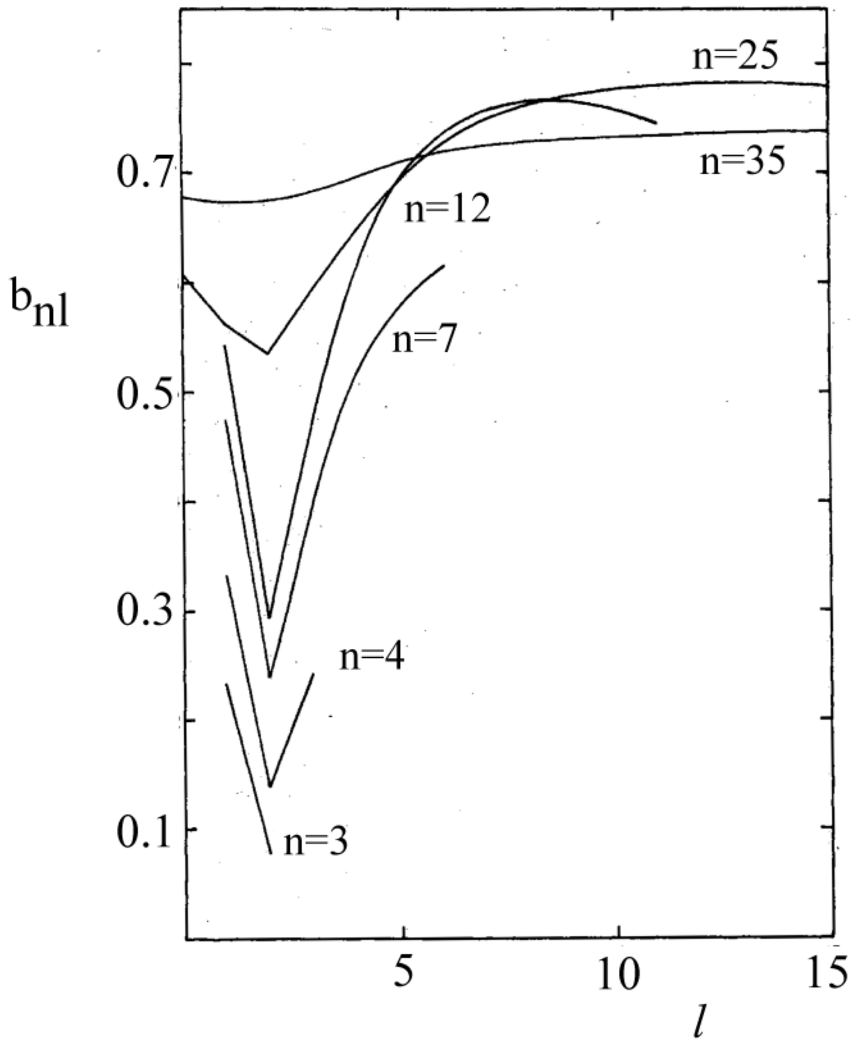
HII region: Quireza et al 2006, Astrophys. J. Supple 165, 338

H population structure: bundle-n



T_e=5x10^3 K, T_r=5x10^3 K, N_e=10^4 cm^{-3}. 1. Case A, W=10^{-16}; 2. Case B , W=10^{-16} ; 3. Case B, W=10^{-12} ; + Seaton radiative; x Hoang-Binh and Dyson

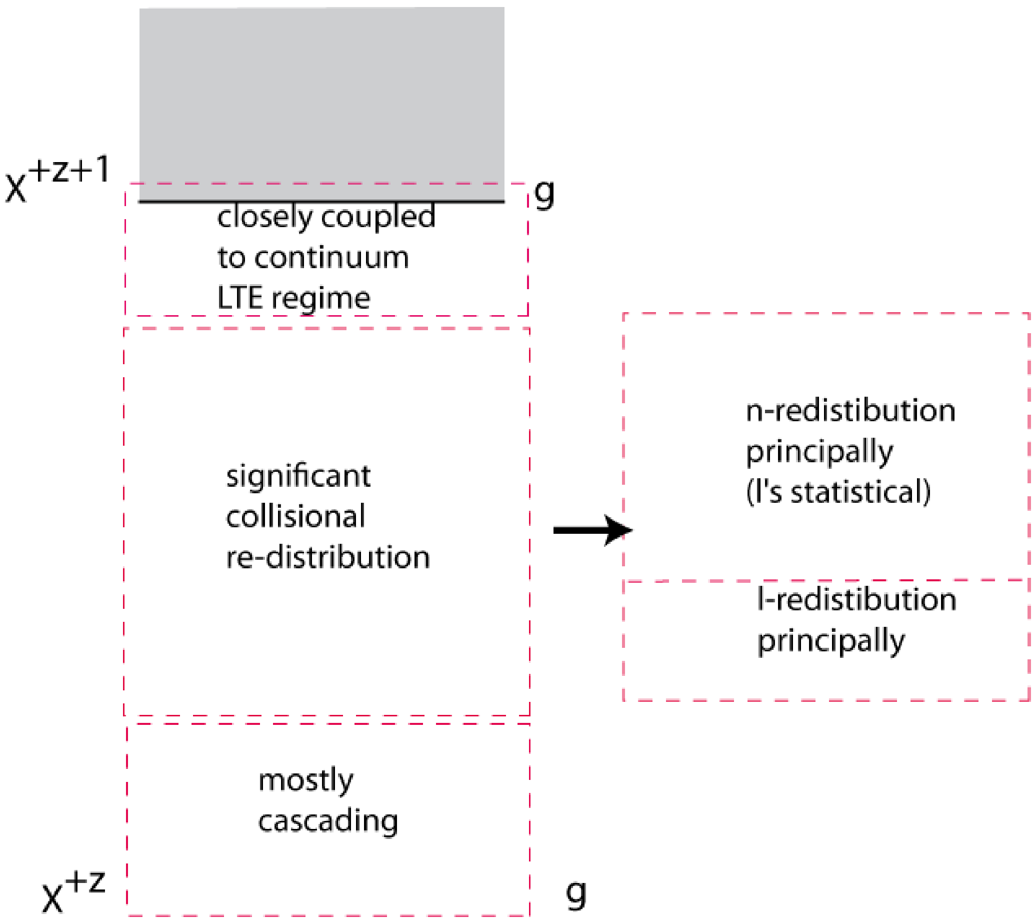
H population structure: bundle-nl



Case B, depopulated n=2 levels. $N_e=1.0^4$ cm^{-3}, $T_e=1.0^4$K, $N_p=N_e$, $T_p=T_e$

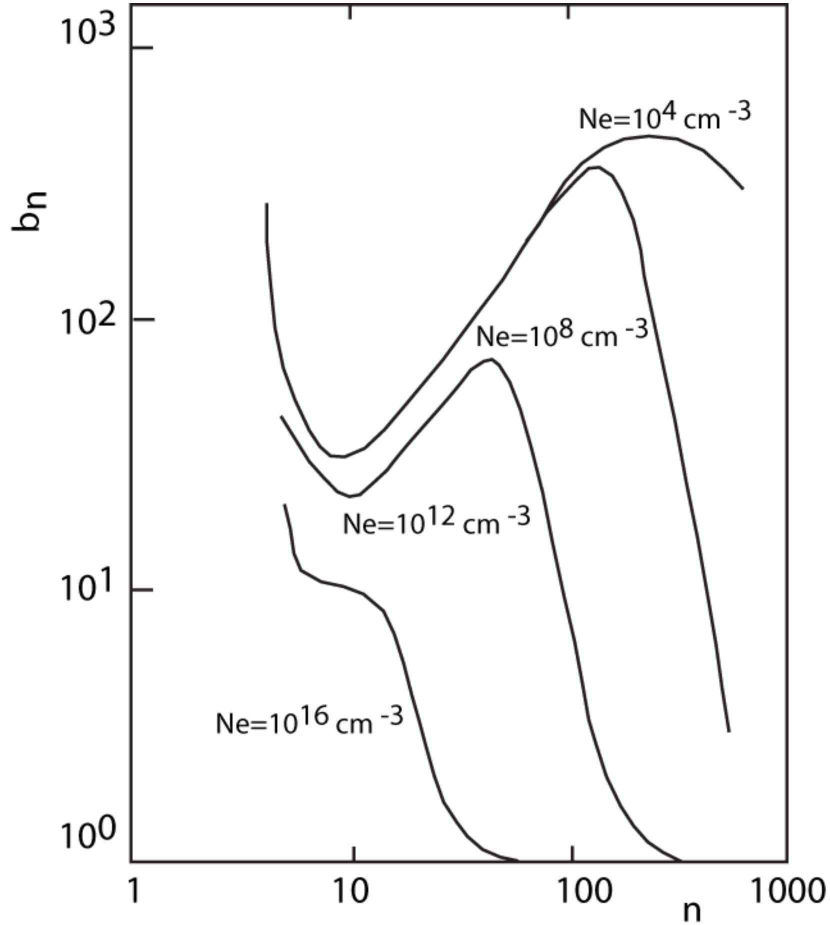
Collisional-radiative modelling schematic

Population regimes



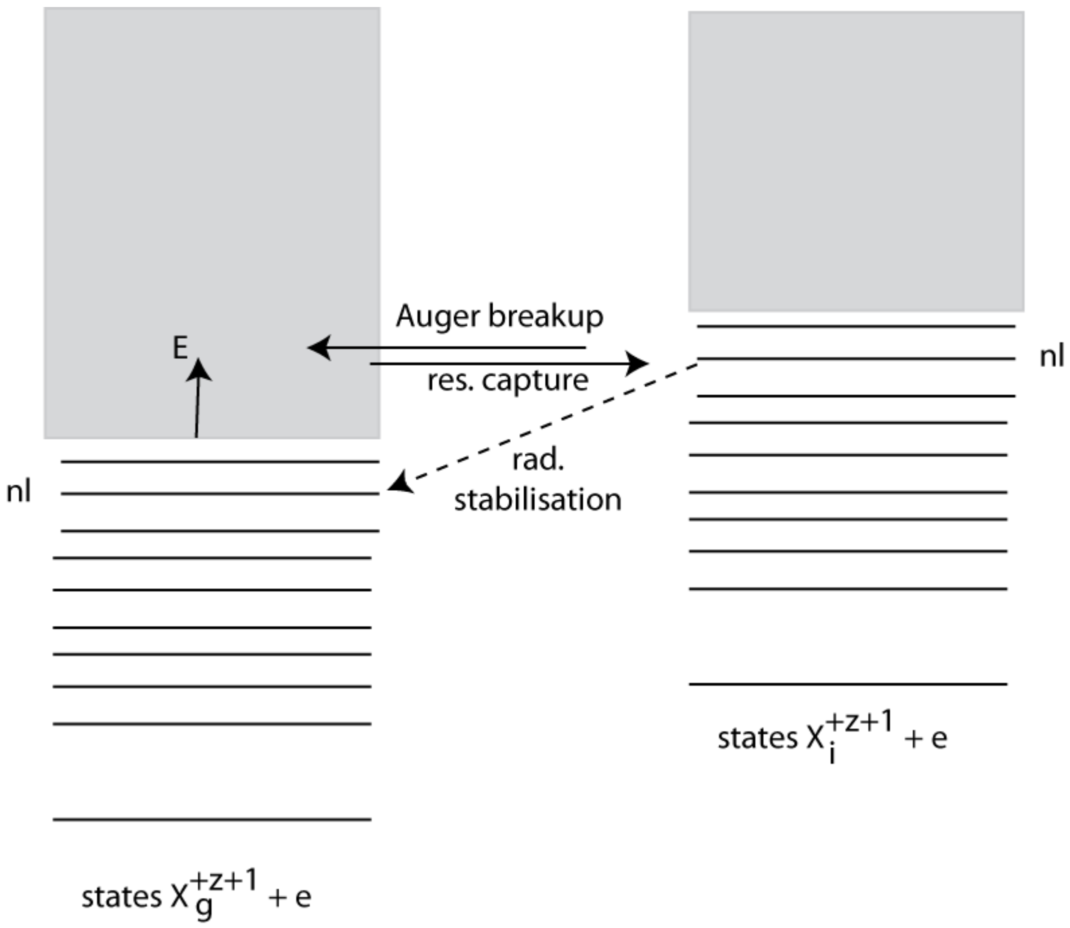
Population structure: bundle-n with DR

singly excited population structure



iron population structure Fe^{+14}

CR modelling schematic : DR doubly excited



Reactions:

$$X_g^{+z+1} + e \underset{Auger\ breakup}{\overset{res.capture}{\leftrightarrow}} X_{i,nl}^{+z}$$

$$X_{i,nl}^{+z} \xrightarrow{rad.stablisation} X_{g,nl}^{+z} + h\tilde{\nu}$$

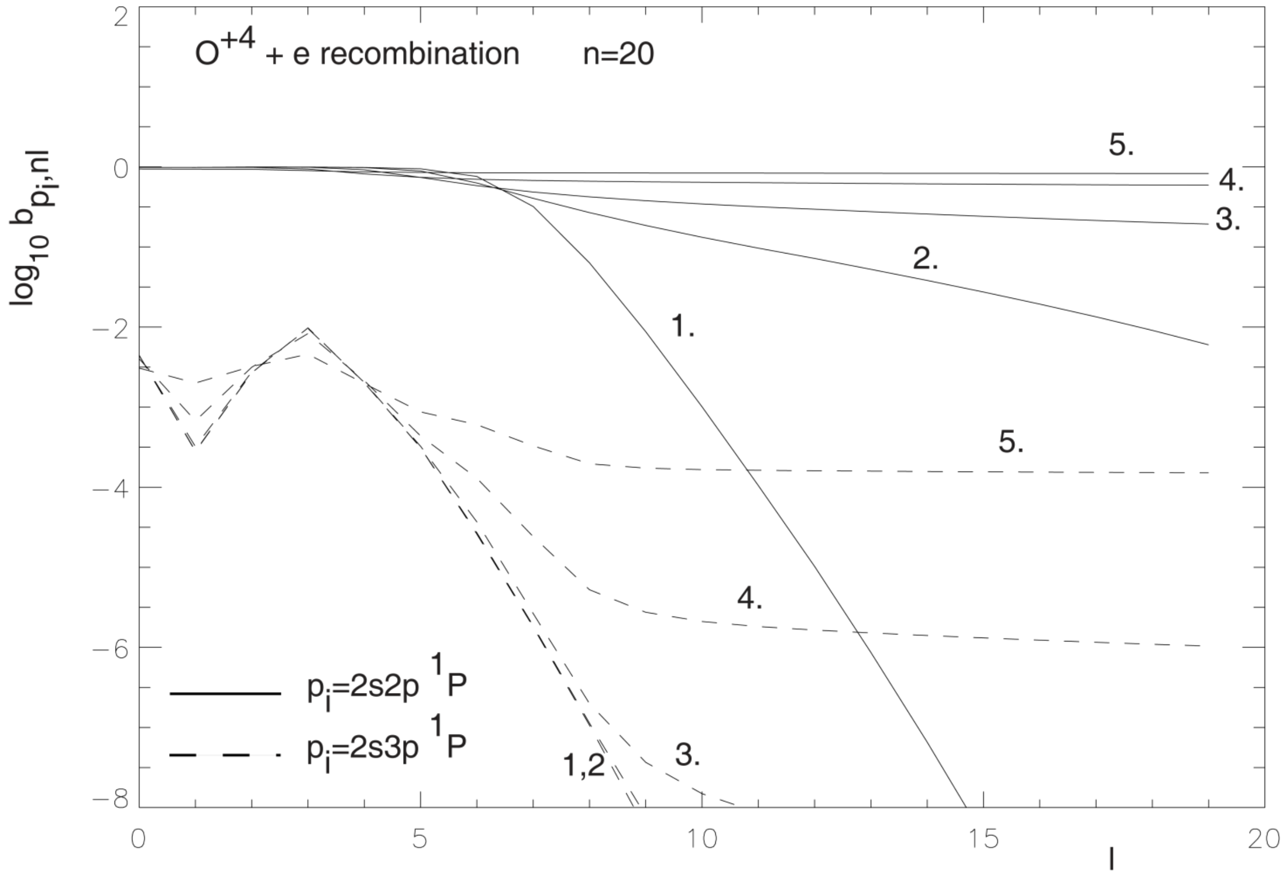
Doubly excited populations:

$$b_{i,nl} = \frac{A_a}{A_a + A_r}$$

$$\alpha_{g,nl}(T_e) = A_r N_{i,nl} / N_e N_g^+$$

At high density there may be re-distribution before stabilisation

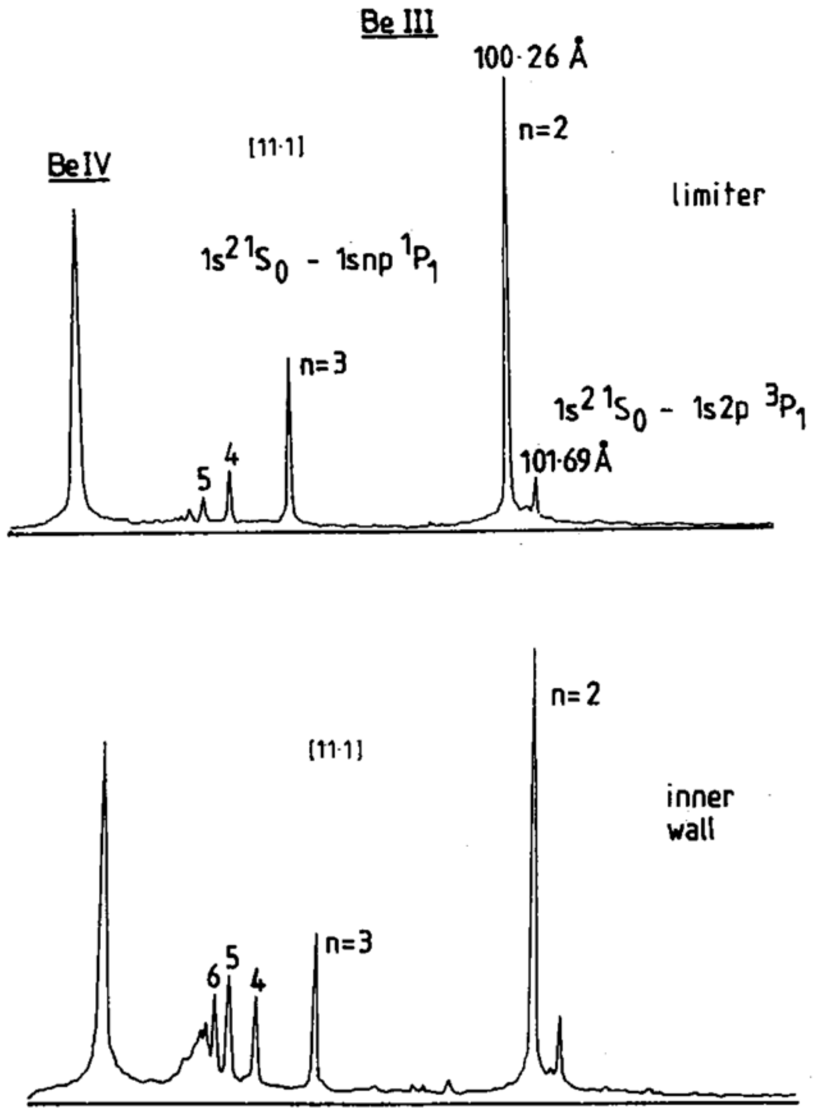
Population structure: bundle-nl, DR doubly excited



1. $N_e=N_p=10^{10}$ cm^{-3}; 2. $N_e=N_p=10^{12}$ cm^{-3}; 3. $N_e=N_p=10^{13}$ cm^{-3}; 4. $N_e=N_p=10^{14}$ cm^{-3}; 5. $N_e=N_p=10^{15}$ cm^{-3}

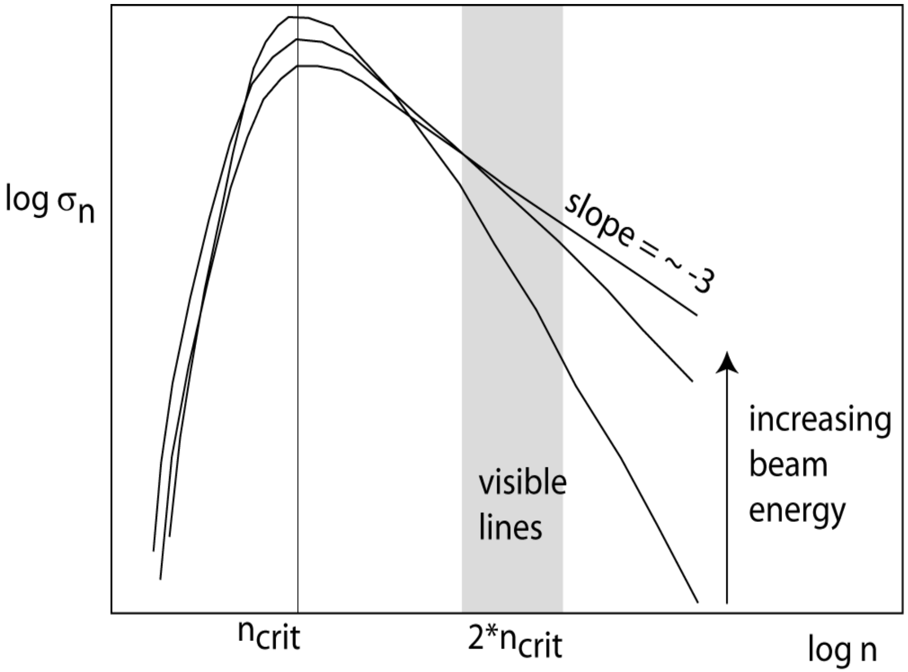
It is ion impact (deuterons in this case) which cause the re-distribution. The population reduction for the 2s3p ^{1}P parent is due to the opening of an alternative Auger channel (--> 2s3s ^{1}S).

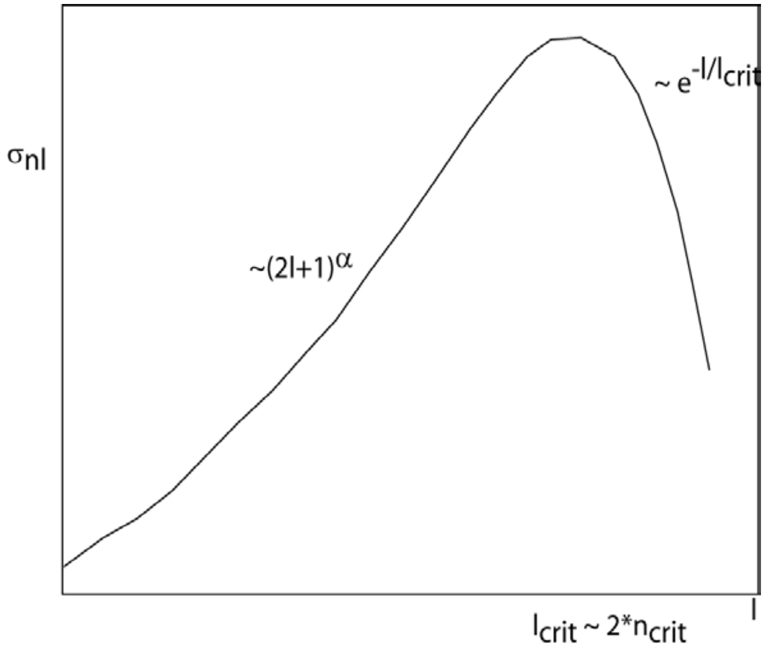
Be XUV spectrum



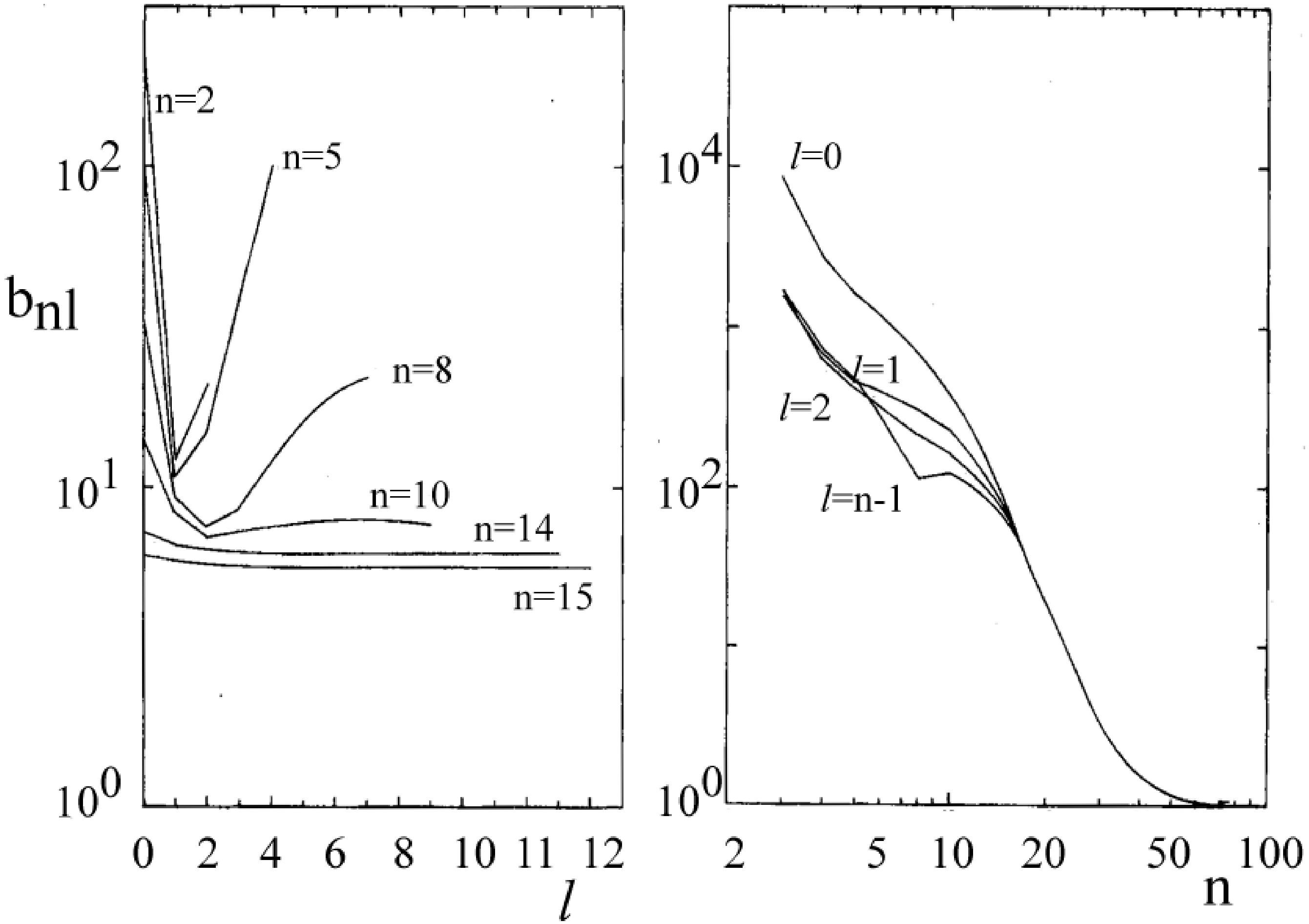
He-like Lyman series decrement as plasma moves into contact with the JET inner wall

Behaviour of partial charge exchange xsects.





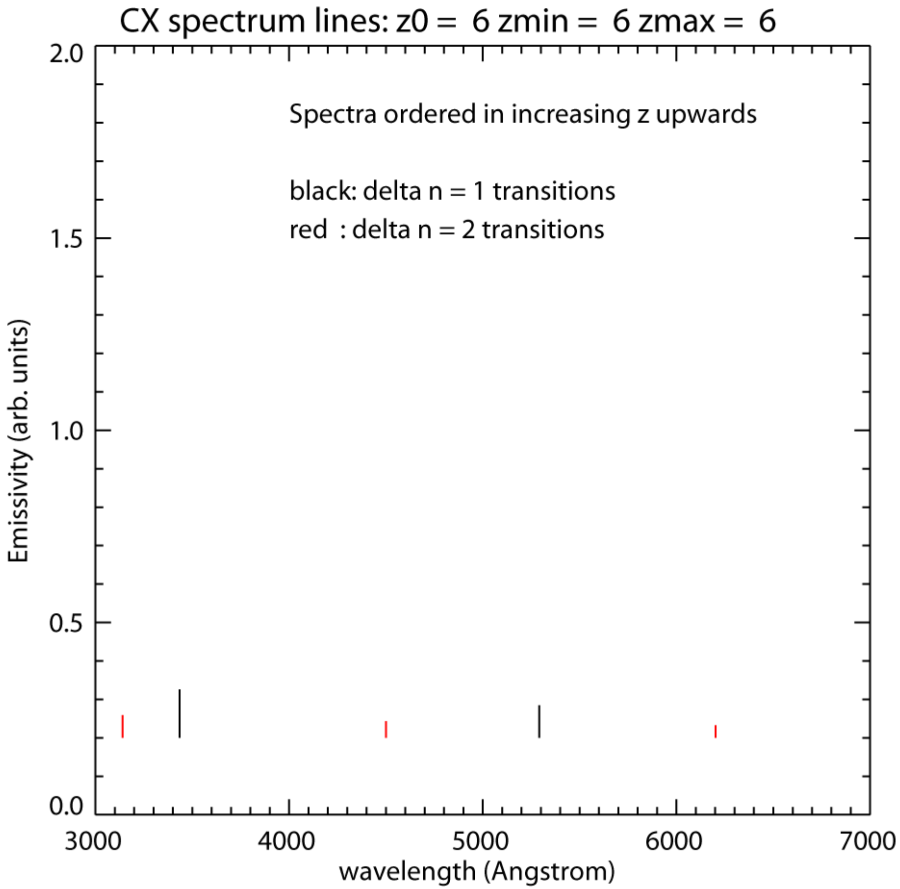
Population structure: bundle-nl with CX

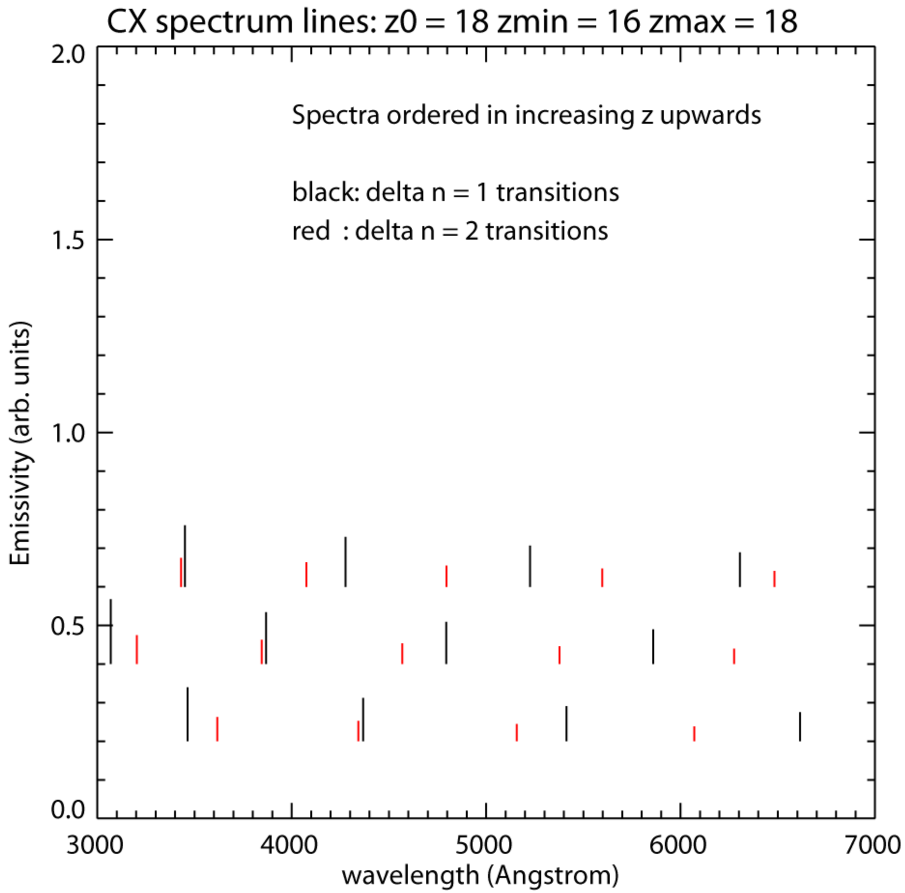


O^{+7} : $T_e=T_p=6.4\times10^6$, $N_e=N_p=5\times10^{13}$ cm^{-3}, E_H=25keV/amu, $N_H=5\times10^7$ cm^{-3}

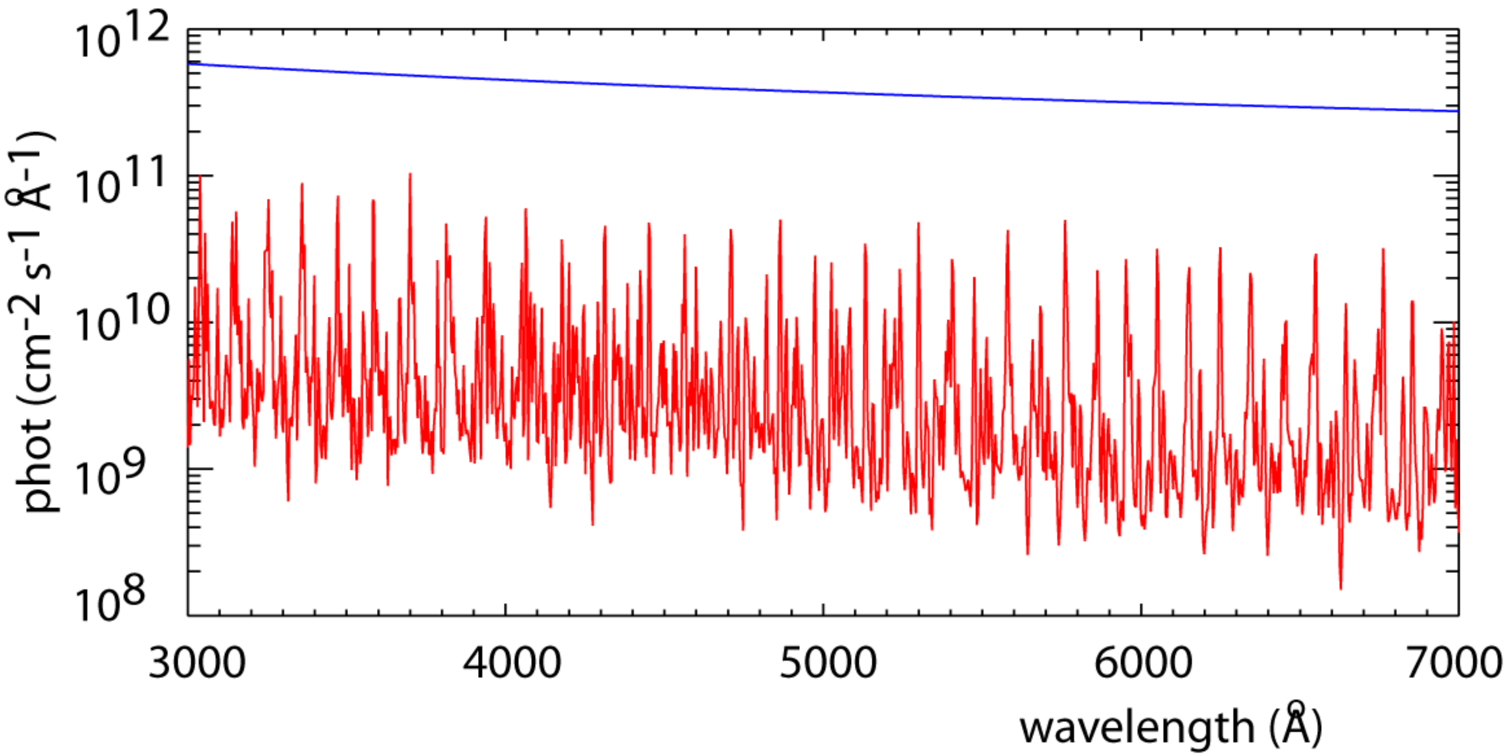
O^{+5} : $T_e=T_p=3.6\times10^6$, $N_e=N_p=5\times10^{13}$ cm^{-3}, E_H=25keV/amu, $N_H=5\times10^8$ cm^{-3}

Patterns of CXS lines in the visible





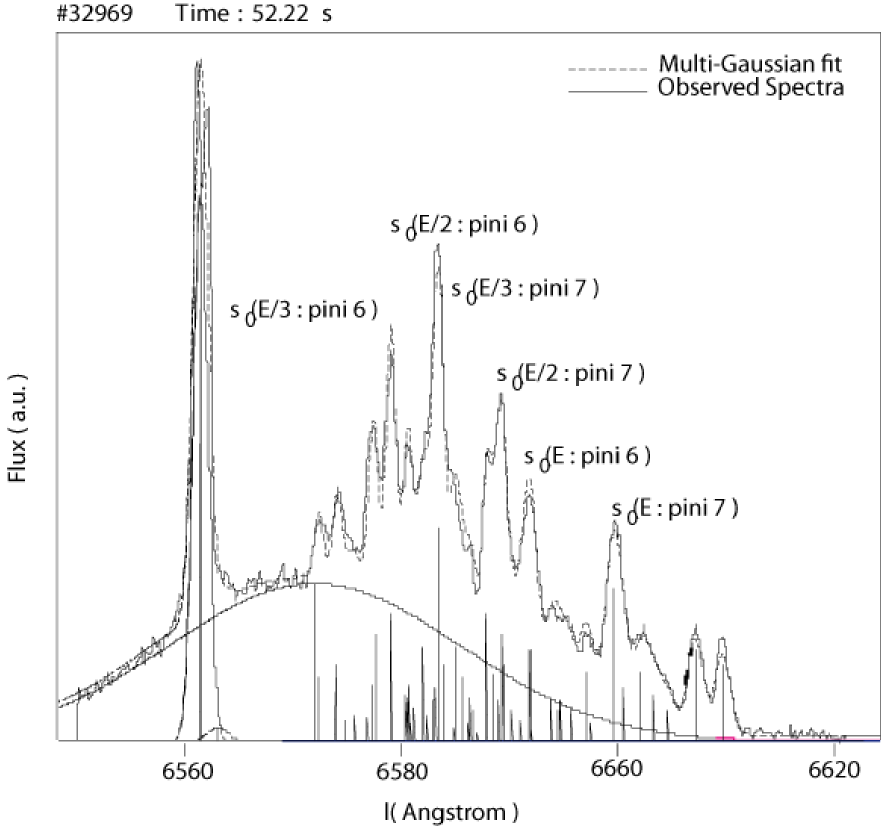
ITER: tungsten CX compared with Bremsstrahlung



- 50 keV/amu D beam (diagnostic NB), JNBI=300A/m2, INBI=60A
- Using ITER scenario 2 (T_e=20keV core, $N_e=1\times10^{14}cm^{-3}$)
- No transport – steady state ionisation balance
- Assume looking vertically down on the beam at the core.
- No beam attenuation effects taken into account.
- W concentration = 1×10^{-6} of N_H

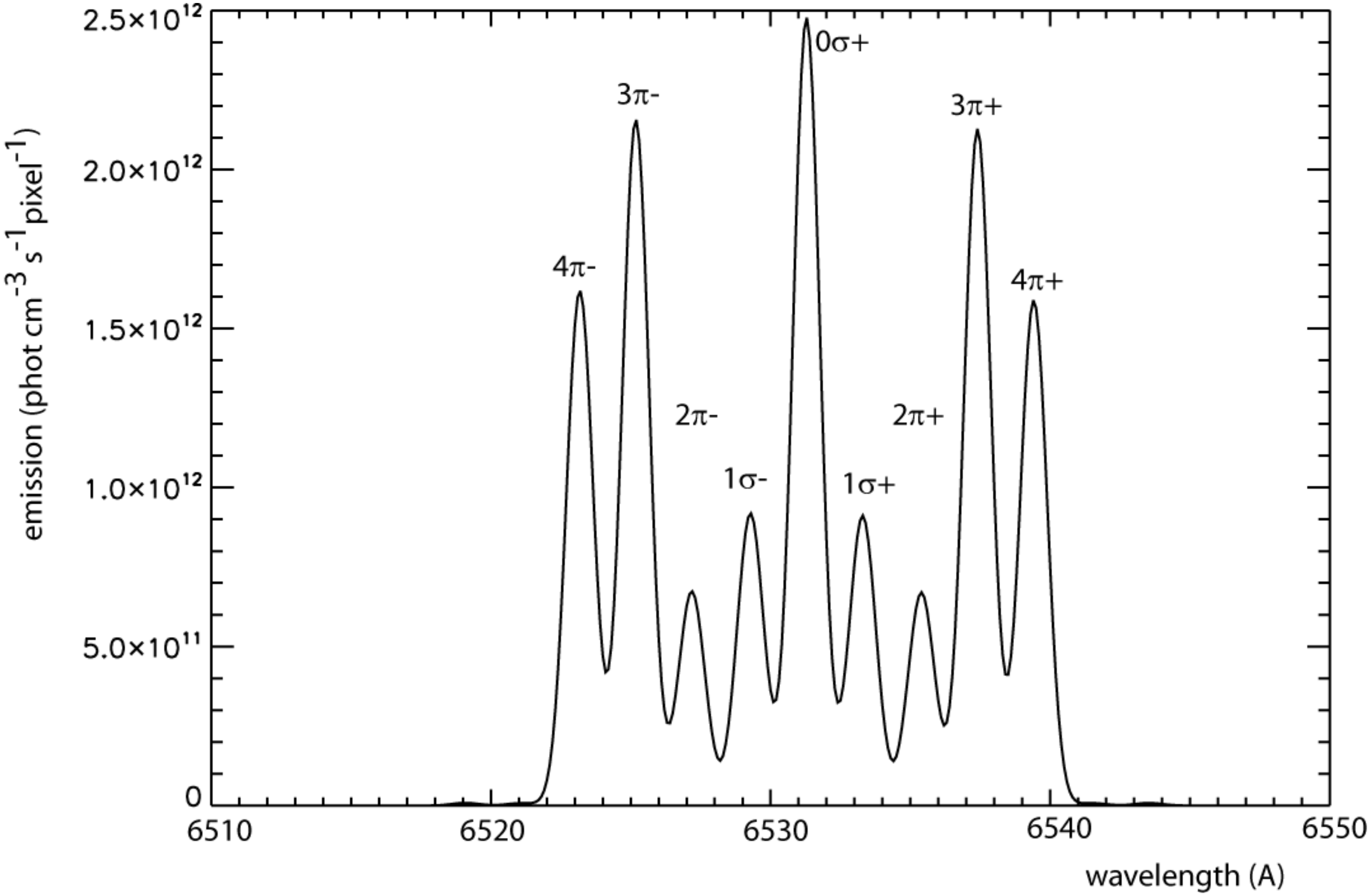
Beam stopping and beam emission

- The beam emission lines appear as Stark multiplets due to the motional electric field in the beam atom frame.



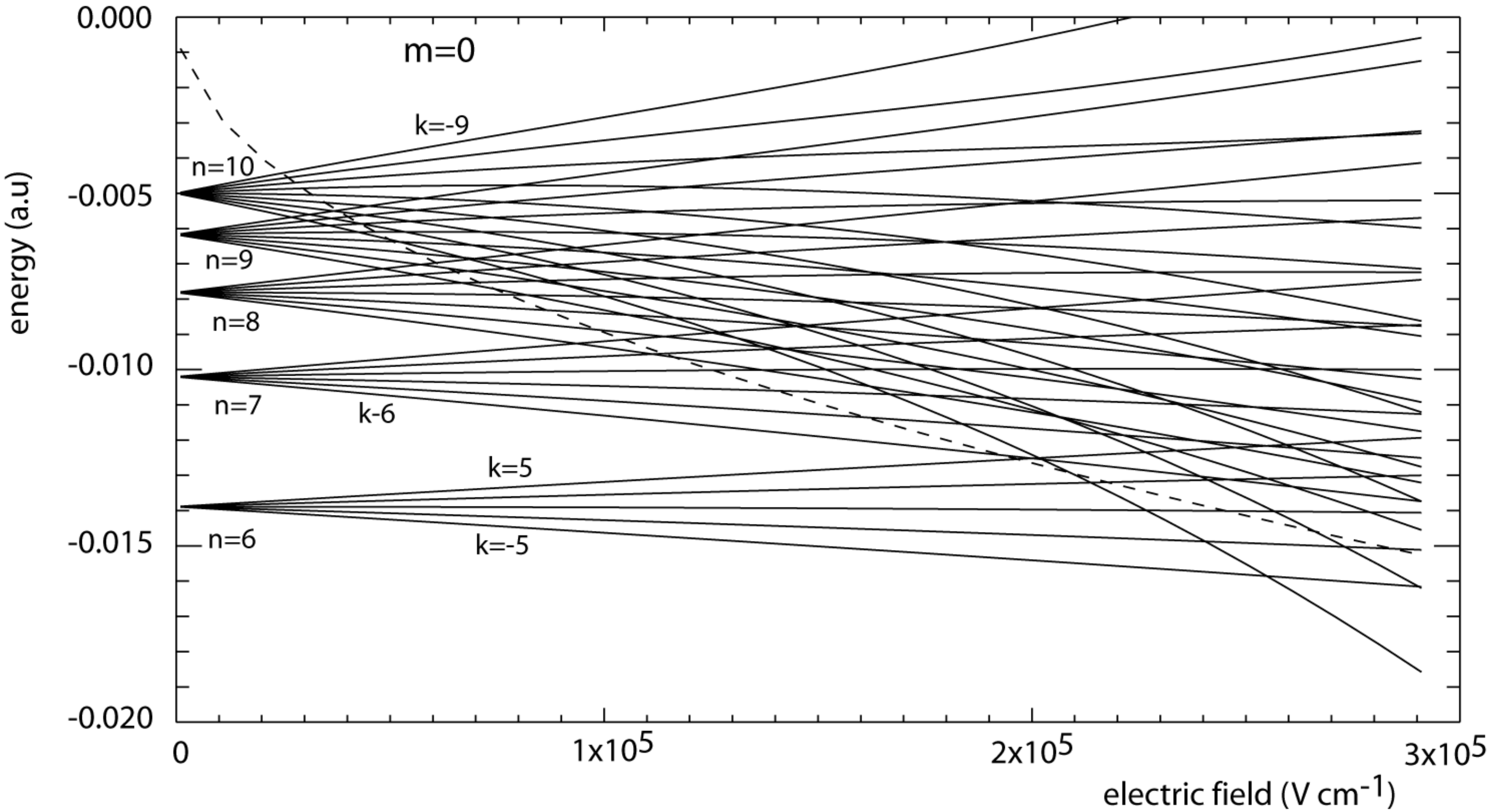
- Stark manifold collisional-radiative models describe the precise wavelengths, the polar distribution and polarisation of emission and the collisional mixing for the low n-shell emission (Balmer and Paschen)

Beam stopping and beam emission

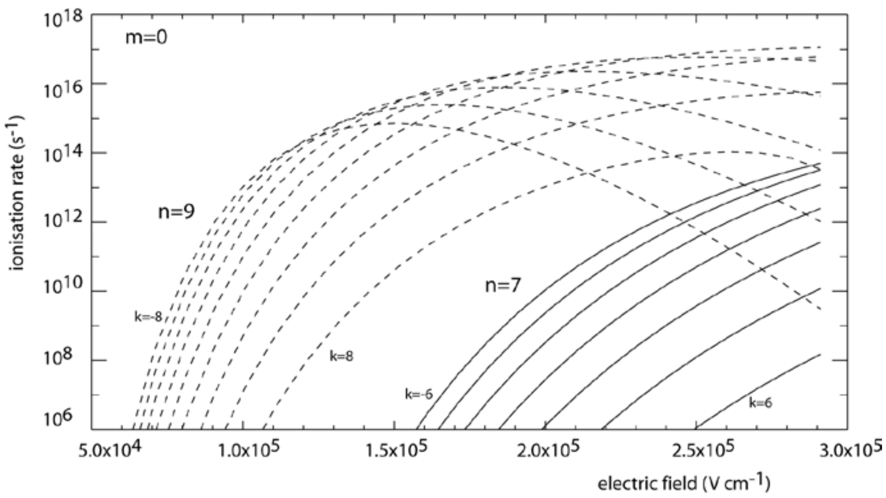


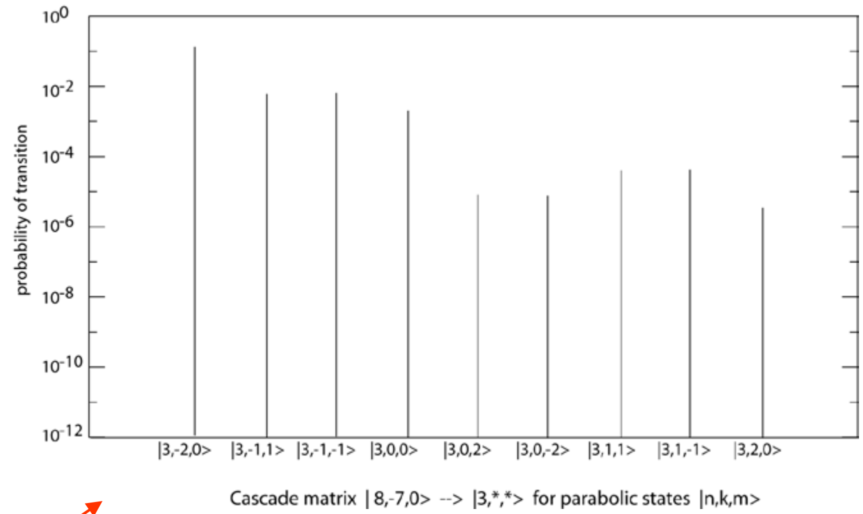
Stark multiplet components of D(n=3-2) beam emission

Stark energy levels

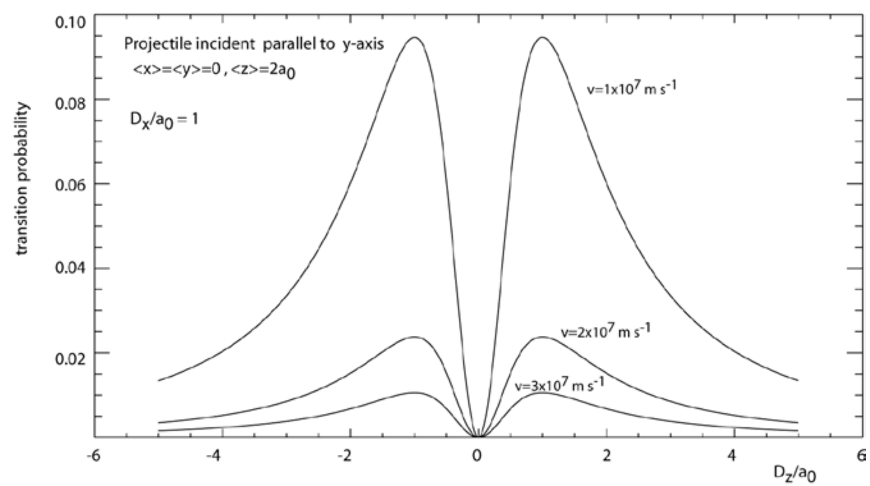


Some issues





1. Field ionisation
2. k-cascade
3. Directional, angular differential cross-sections



Fire and Water
(Susan Gamble & Michael Wenyon)

SOHO CDS : NIS-1 & NIS-2 quiet sun spectrum