Non-thermal time-dependent atomic physics in the interaction of X-ray laser with matter

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Abstract.

In the present work, we study the evolution of laser produced plasmas. We simulate the interaction of X-ray radiation with matter from ultrashort and ultraintense X-ray laser, using a non-thermal time-dependent collisional radiative model. With femtosecond pulse and high intensity lasers, the evolution of free electrons and atomic populations during the interaction has many time-dependent non equilibrium features. However, to speed up processing and to simplify calculations, most of the codes assume thermalized distribution of free electrons when obtaining collisional rates. We present a temporal evolution of an aluminium foil irradiated with high intensity X-ray laser, calculated with the code **BIGBART**, developed by our group.

1.Introduction

- We simulate the interaction of X-ray radiation with matter from ultrashort (140fs) and ultraintense($10^{15} W/cm^2$) X-ray laser, using a **non-thermal time-dependent collisional radiative model**
- Although standard simulations usually assume a M-B or F-D distribution of free electrons, their use might not be fully justified, due to:
  - strong non-equilibrium nature of the interaction of high energy photons with matter
  - thermalization is not instantaneously in these cases
- Therefore, we avoid this assumption and include the thermal treatment of the free $e-$ distribution with a Fokker-Planck approximation
- In order to reduce time computing of CRM calculations we use:
  - similar model based on superconfigurations [3,4]
  - some atomic data from **FAC** code [5]

2.Ion population

- In time-dependent CRM, atomic level populations are determined from the solution of atomic rate equations of the form:

$$\frac{dn_i}{dt} = \underbrace{\sum_{j\neq i} n_j A_{ji}^{se} - n_i \sum_{j\neq i} A_{ij}^{se}}_{\text{Spontaneous emission}} + \underbrace{n_e\Big(\sum_{j\neq i} n_j R_{ji}^{rr} - n_i \sum_{j\neq i} R_{ij}^{rr}\Big)}_{\text{Radiative recombination}} + \underbrace{\sum_{j\neq i} n_j A_{ji}^{ai} - n_i \sum_{j\neq i} A_{ij}^{ai}}_{\text{Autoionization}}$$
$$+ \underbrace{n_e\Big(\sum_{j\neq i} n_j D_{ji}^{dc} - n_i \sum_{j\neq i} D_{ij}^{dc}\Big)}_{\text{Dielectronic capture}} + \underbrace{\sum_{j\neq i} n_j R_{ji}^{pi} - n_i \sum_{j\neq i} R_{ij}^{pi}}_{\text{Photoionization}} + \underbrace{n_e\Big(\sum_{j\neq i} n_j I_{ji}^{ci} - n_i \sum_{j\neq i} I_{ij}^{ci}\Big)}_{\text{Collisional ionization}}$$
$$+ \underbrace{n_e\Big(\sum_{j\neq i} n_j C_{ji}^{ce} - n_i \sum_{j\neq i} C_{ij}^{ce} + \sum_{j\neq i} n_j C_{ji}^{cd} - n_i \sum_{j\neq i} C_{ij}^{cd}\Big)}_{\text{Collisional excitation and de-excitation}}$$

- n_i is the population density of the atomic state i
- Rij and Rji are the rates connecting different atomic states
- M is the total number of atomic states considered

3.Electron population

- We include the thermal treatment of the distribution with a Fokker-Planck approximation:

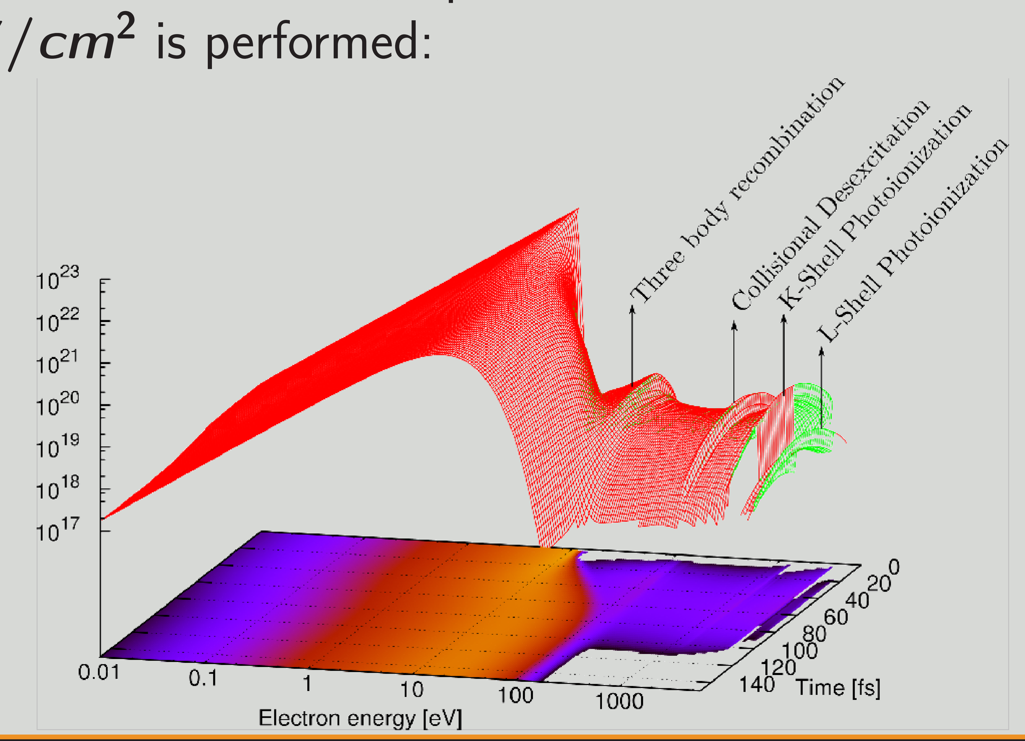
$$\frac{\partial f}{\partial t} = -\frac{\partial}{\partial E}(a(E)f(E)) + \frac{1}{2}\frac{\partial^2}{\partial E^2}(D(E)f(E)) + S(E) + I(f)$$

- a, electron-electron drift coefficient
- D, electron-electron diffusion coefficient
- S, the source electron term (photoionization and Auger electrons)
- $I(f)$, inelastic term, that includes all creation and destruction of electron population in each energy bin, due to collision with ions

This allows us to obtain more consistent atomic data by averaging with the real energy distribution

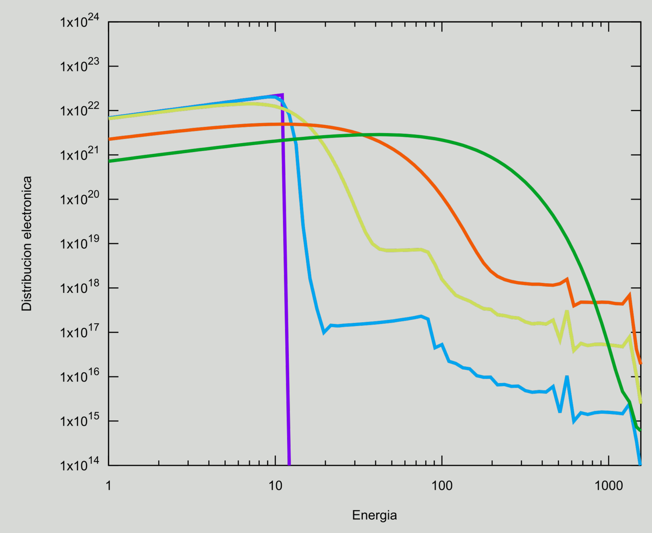
4.Simulations

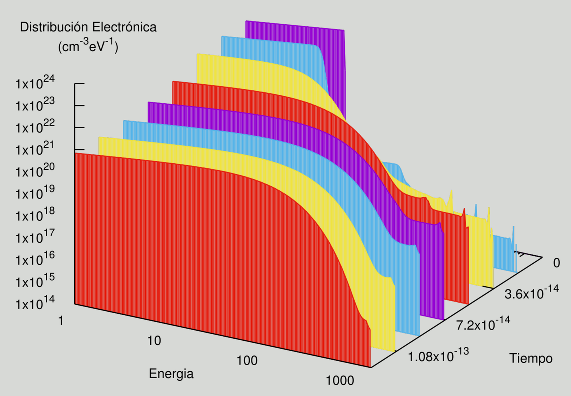
- A simulation with Al at 3 keV, a pulse duration of 140 fs and intensity of $\mathbf{3.7x10^{15}}$ W/cm^2 is performed:



5.Electrons distribution function

- Initially, the sample has not time to heat up, so the quantum effects are very important
- Thermalization of high energy electrons takes ∼20fs

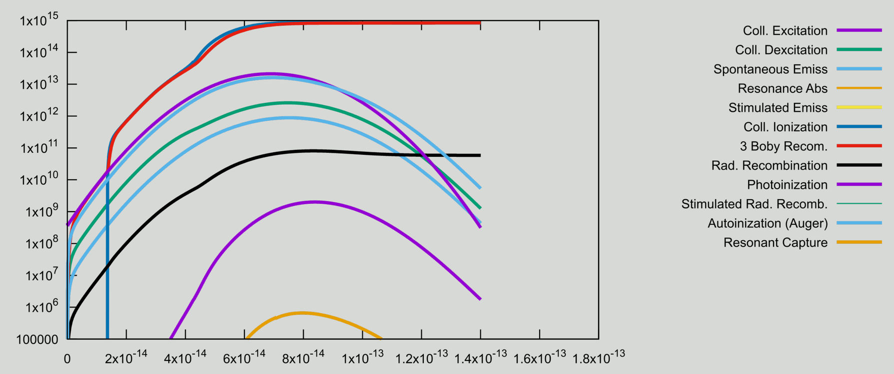




- The electron distribution evolves from F-D to M-B with a very high energy tail
- Therefore, during a significant part of the pulse will exist more energetic electrons than in the one would exist in the thermal distribution

6.Rates

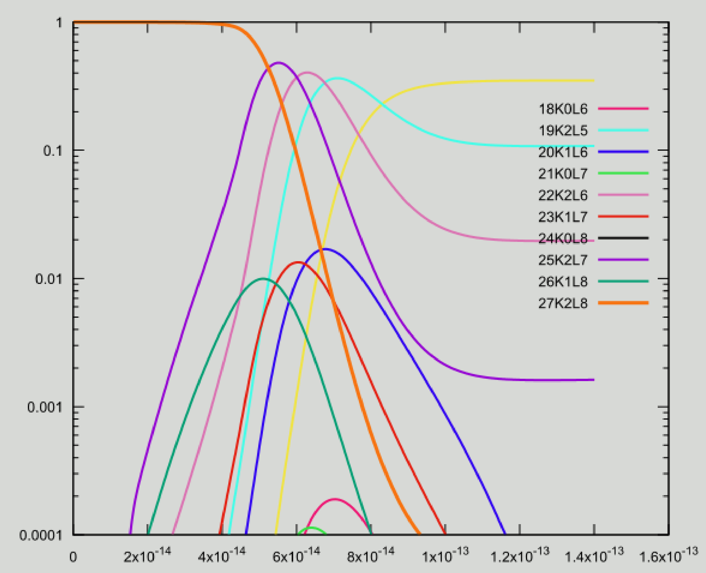
- As a result of the changes in the electron distribution, the rates of all different processes considered, also change:



- As expected, it can be observed a close evolution between:
  - collisional ionization and 3-body recombination
  - photionization and autoionization

7.Conclusions

- Not considering the evolution of the free electron distribution lead to big differences in:
  - collisional rates
  - evolution of ionic populations if the dynamics of the ionic populations are driven by collisional processes or, at least, these are not negligible



8. References

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9.Acknowledgements

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