Non-local electron parallel heat transport in divertor plasmas and atomic physics rates

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overview

I) Parallel electron heat transport when classical kinetic ordering is violated.

- (Usual flux limiter approach.)
- Non local approach.
  - Delocalization formula for the flux.
  - Delocalization formula for $f_0(x, v)$ and non Maxellian effects on the electron distribution function

II) Atomic physics when the distribution function is non Maxwellian.

- Effect on the elementary rates.
- Effect on the effective rates.

III) Conclusion.

Domain of validity of classical kinetic theory.

- If $\lambda_e > 5.3\ 10^{-2}\ L_T$

•Classical thermal conductivity is wrong for parallel transport.

When do we have: $\lambda_e > 5.3\ 10^{-2}\ L_T$?

In divertor plasmas, mainly near the neutralization plate,

especially in the detached regime.

How do we correct the parallel heat transport ?

Usual flux limit correction

- Classical Sptizer Harm flux:

$$q_{SH} = \kappa T_e^{5/2} \frac{dTe}{dx}$$

- Free streaming flux:

$$Q_{FS} = n_e Te\, v_t \qquad v_t = \sqrt{\frac{Te}{m_e}}$$

- Flux limiter model:

$$q_{FL} = \min(q_{SH}, f q_{FS}) \qquad f: 0.1 - 0.2$$

or

$$\frac{1}{q_{FL}} = \frac{1}{q_{SH}} + \frac{1}{f\, q_{FS}}$$

Non local heat flux formula

$$q(x) = \frac{1}{\beta(x)} \int_{-\infty}^{\infty} w\left[\xi(x,x')\right] \frac{q_{SH}(x')}{\lambda_e(x')} \, dx'$$

Convolution over the classical heat flux

$$\lambda_e(x) = \frac{T_e(x)}{4\pi\sqrt{2}\, n_e(x) \ln\left[\Lambda_{ei}(x)\right]}$$

Local electron mean free path

$$\beta(x)$$

Normalization function

$$\xi(x,x') = \frac{1}{\lambda_e(x)} \left| \int_{x}^{x'} \frac{n_e(x'')}{n_e(x')} \, dx'' \right|$$

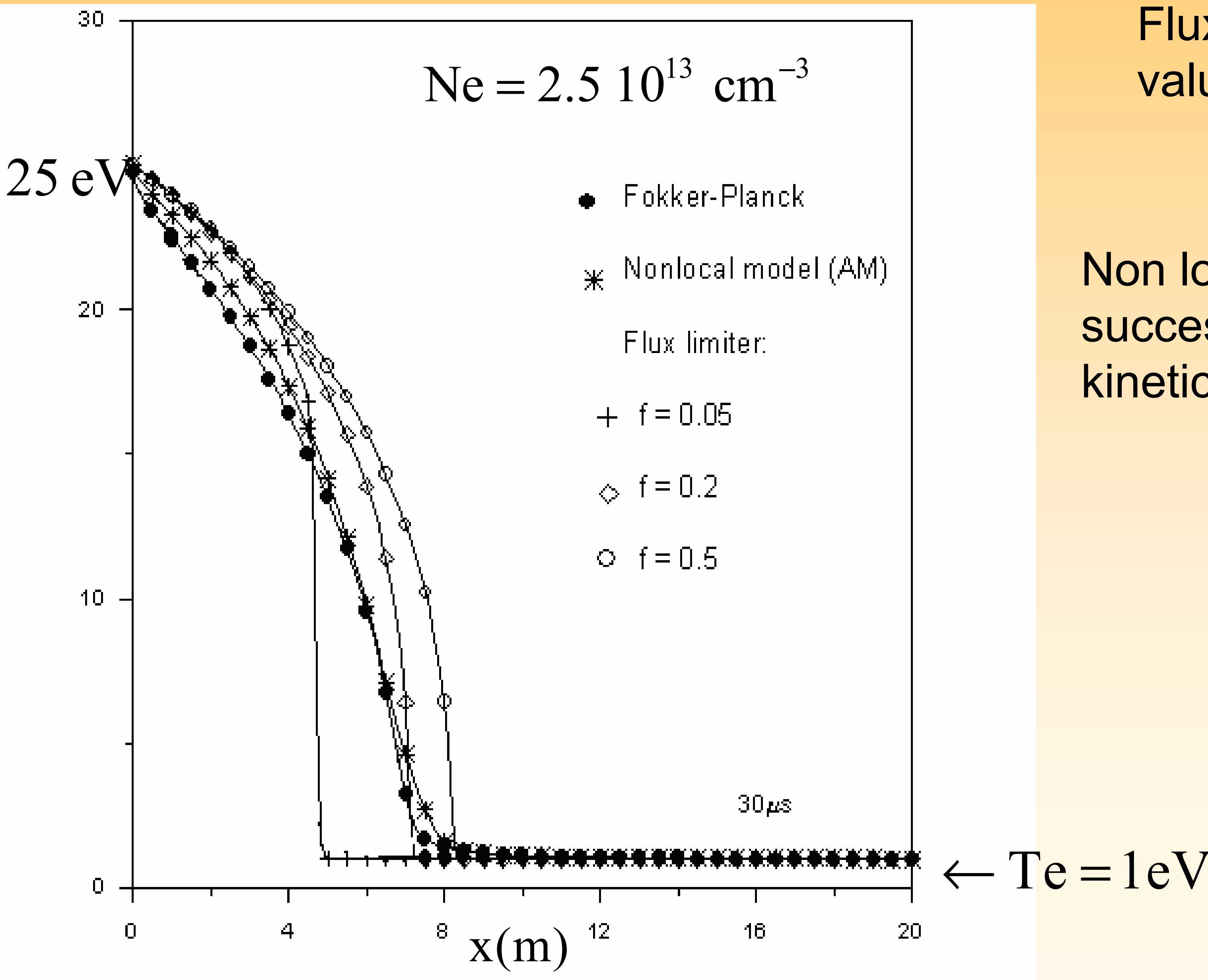
Normalized distance

$$W(\xi)$$

Non local propagator, computed with the help of our kinetic code FPI

Comparison of heat flow models to kinetic simulation

Advancing heat front $\rightarrow$



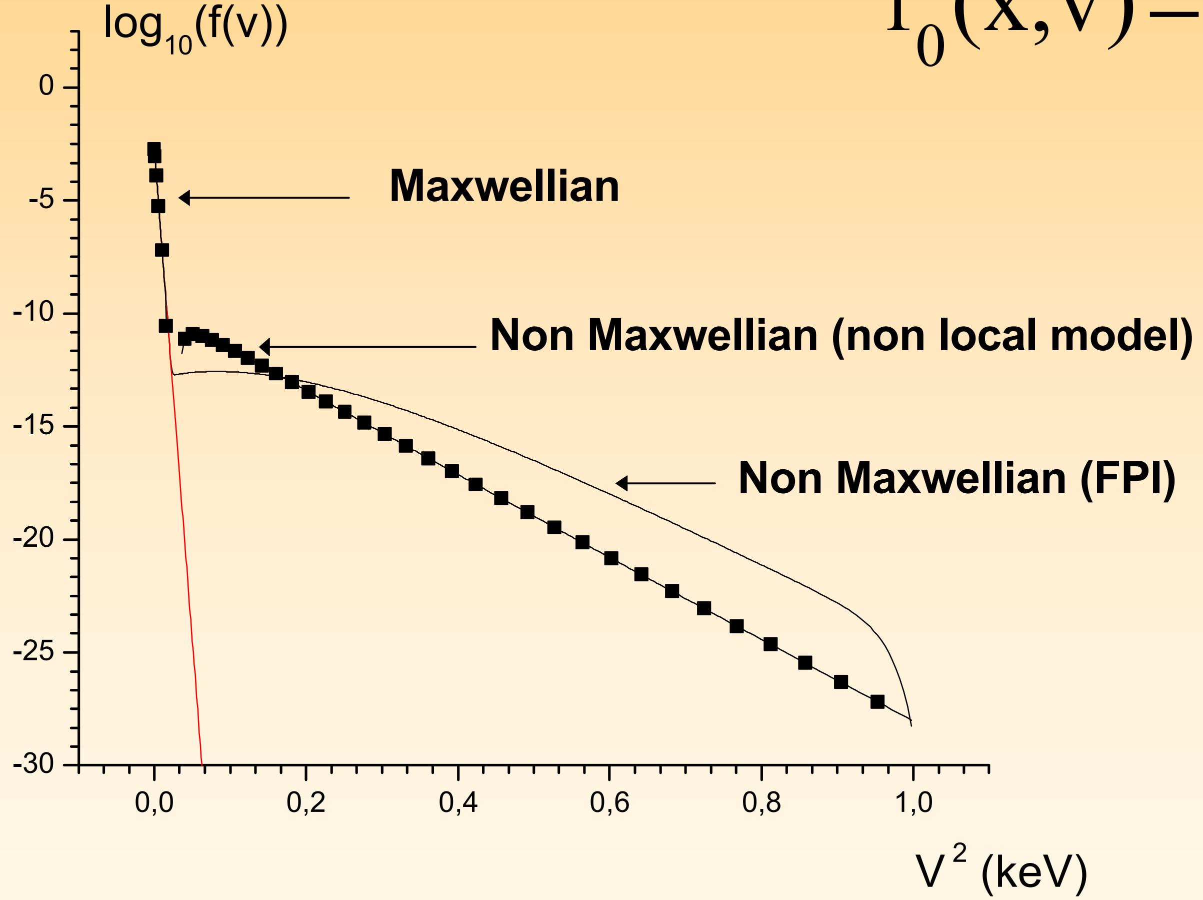
Flux limiting fails for any value of f.

Non local model (AM) successfully reproduces the kinetic Te profile.

Progress toward a non local formula for f_0

Convolution formula analogous to the one for the heat flux

$$f_0(x,v) = \int_{-\infty}^{\infty} f_{max}(x',v)\frac{g[\xi(x,x');v]}{\lambda_e(x')}dx'$$



II) Atomic processes

Ionization: $e + H(n) \rightarrow e + e + H^{+}$ Rate: S_m ($cm^3\ s^{-1}$)

Three body recombination: $e + e + H^{+} \rightarrow H(m) + e$ Rate: a_m ($cm^3\ s^{-1}$)

Radiative recombination: $e + H^{+} \rightarrow H(n) + h?$ Rate: $ß_m$ ($cm^3\ s^{-1}$)

Radiative desexcitation : $H(m) \rightarrow H(n) + h?$ Rate: A_{mn} (s^{-1})

Excitation and desexcitation:

$e + H(n) \rightarrow e + H(m)$ $m > n$ Rate: C_{mn} ($cm^3\ s^{-1}$)

$e + H(m) \rightarrow H(n) + e$ $m > n$

HOW TO COMPUTE THE ELEMENTARY RATES

- FOR $S_m \ , \ \alpha_m , \beta_m , C_{mn}$

$$\text{rate} = 4\pi \int_{V_{inf}}^{\infty} dv\ v^3 \sigma(v)\ f(v)$$

- With: f(v) Maxwellian (DEGAS)
- f(v) Non Maxwellian (FPI)
- f(v) Non Maxwellian (non local theory)

$\sigma(v)$ R.K Janev and J.J Smith

From the elementary rates to the effective rates: The collisional radiative model (CRM)

Master equation (solved numerically)

$$\left(\frac{dN_i}{dt}\right)_{atomic} = -N_e N_i S_i - N_e N_i \sum_{j\neq i}^{30} C_{ij} - N_i \sum_{j=1}^{i-1} A_{ij} + N_e \sum_{j\neq i}^{30} N_j C_{ji} + \sum_{j=i+1}^{30} N_j A_{ji} + (\beta_i + \alpha_i N_e) N_e^2$$

$$i = 1, 2..30$$

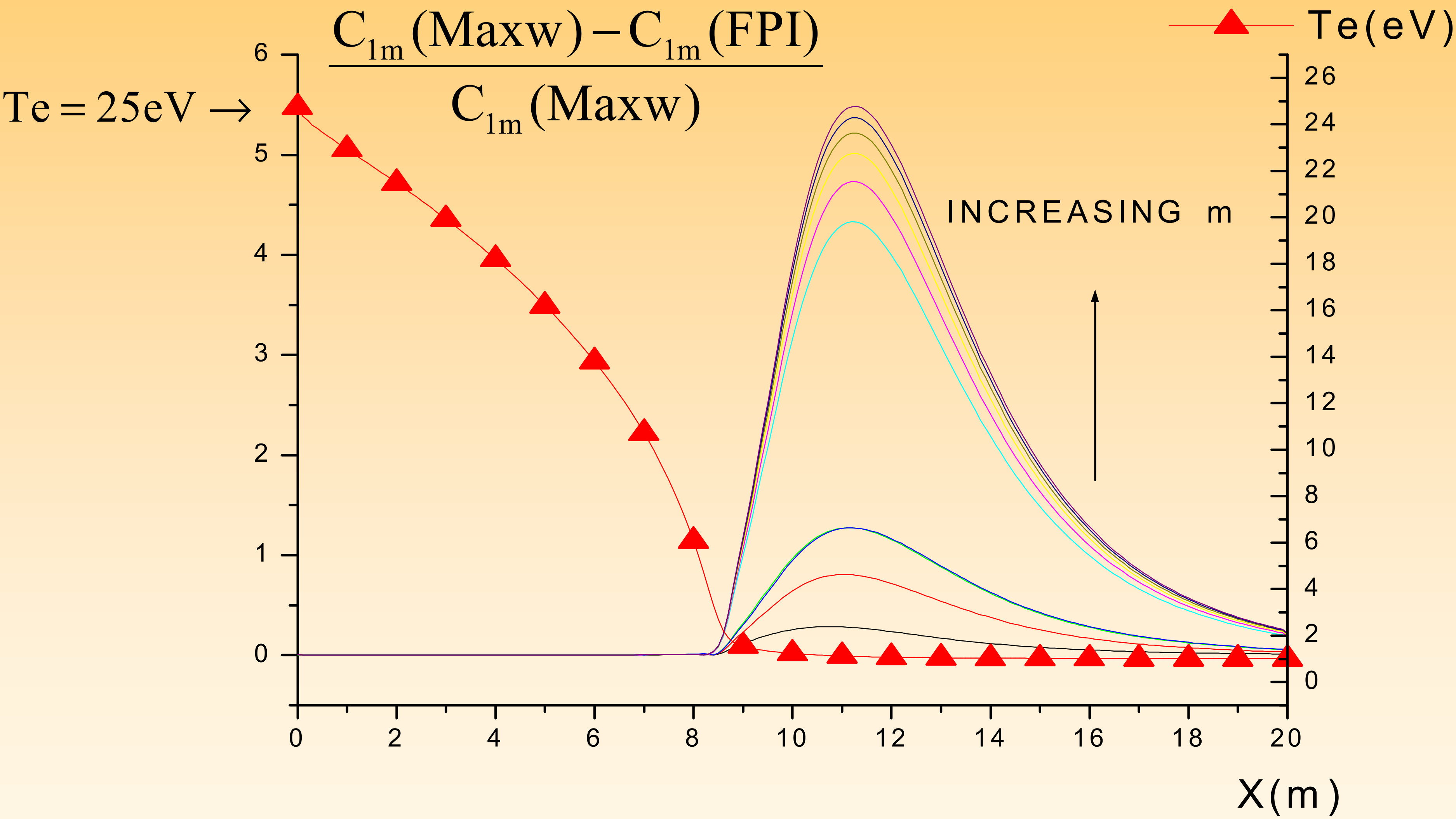
CRM hypothesis

$$g_1 << g_i \qquad N_i = T_i^0 + T_i^1 \, N_1 \qquad \frac{\mathbf{dN_{i>1}}}{\mathbf{dt}} \approx 0$$ **on the slow time scale**

Reduced equation (used by UEDGE and DEGAS)

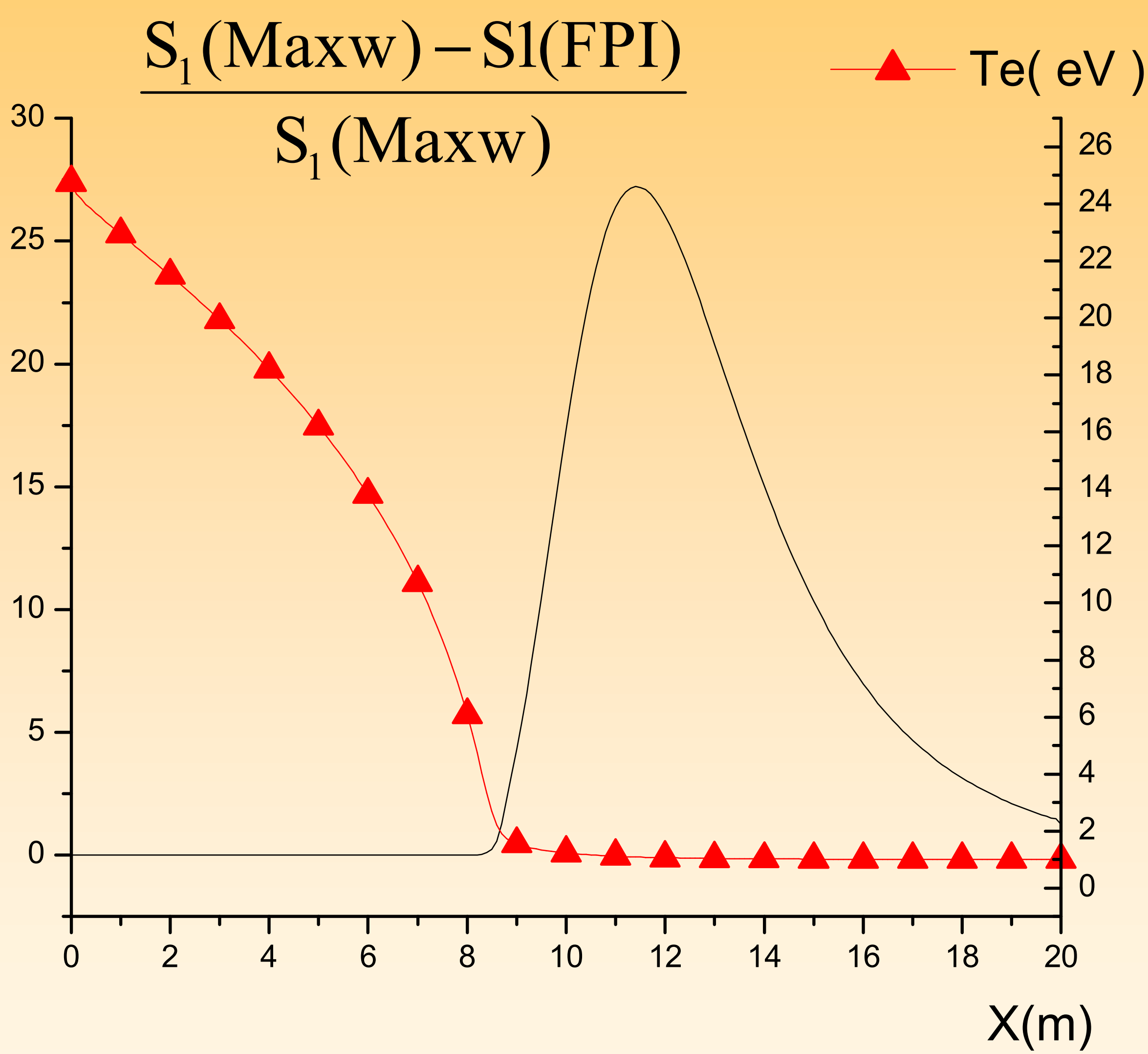
$$\frac{dN_1}{dt} = -S_{eff} N_1 N_e + R_{eff} N_e^2 \qquad \text{with} \qquad N_1 + N_e = N_0$$

Effect of the non locality on the excitation rate from the ground state



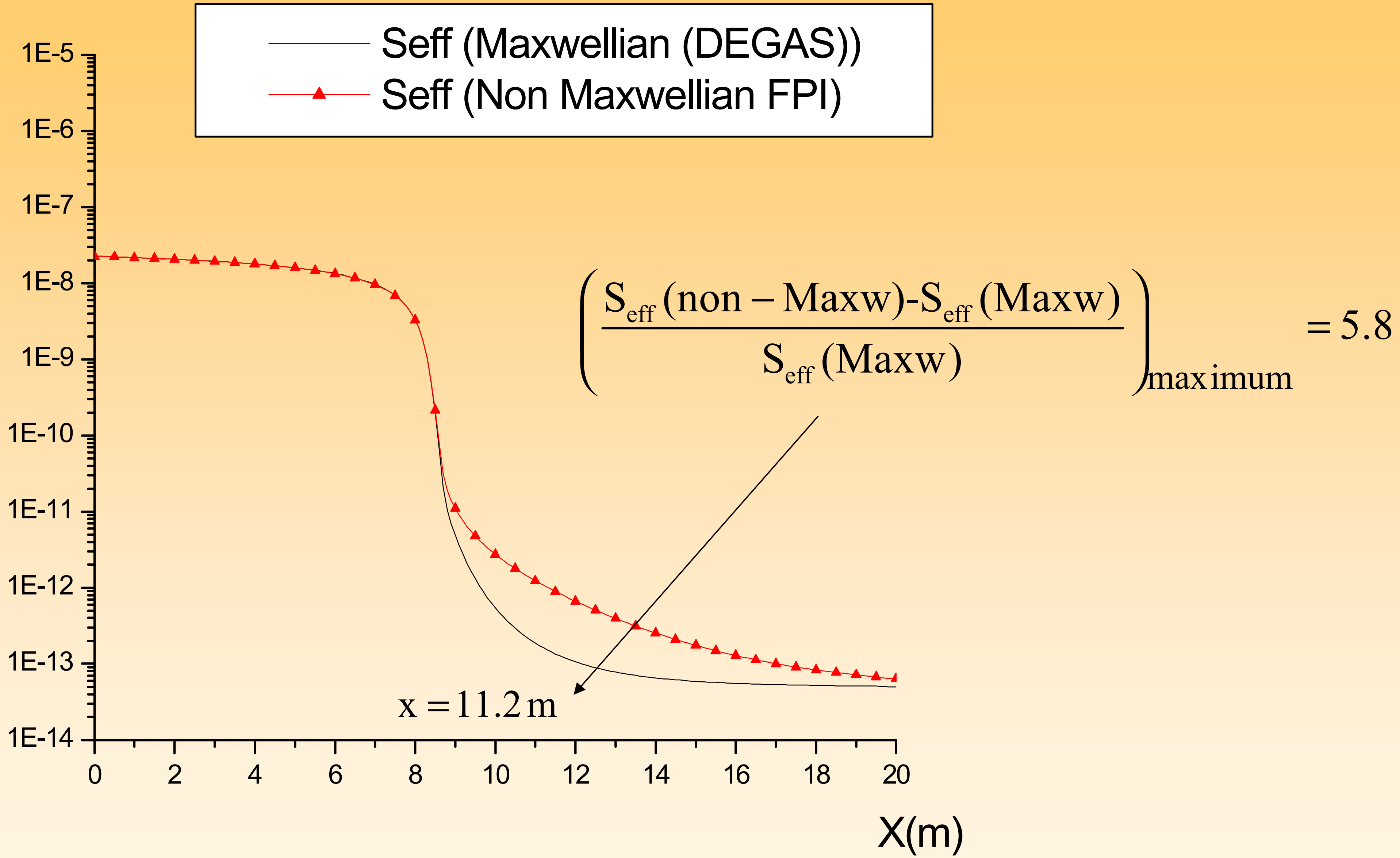
Negligible effect for excitation from upper states (not shown) : $C_{ij} \quad 1 < i < j$

Effect of the non locality on the ionization rate from the ground state



Negligible effect for ionization from excited states (not shown)

Effect of the non locality on the effective ionization rate



Negligible effect on the effective recombination rate
(not shown).

EFFECTIVE IONIZATION AND NONLOCAL MODEL

Seff Maxwellian	FPI Non Maxwellian	Non Local model for f_0 Non Maxwellian
0.162157E-12	0.107674E-11	0.185317E-11

X = 11.2 m maximal effect

Conclusion

- Non local approach have been validated with the heat flux.
- Demonstration of significant non Maxwellian effects on Seff in the cold region.

$\mathbf{f_0}$

Future work

- Improvement of the formula for $\mathbf{f_0}$
- Include the effects of the atomic physics on $\mathbf{f_0}$ in our kinetic code.
- Include the physics of recycling
- Implementation in fluid code (UEDGE…)