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Tungsten surface temperature calculated by means of PIC simulations: bifurcation and space charge limited regime

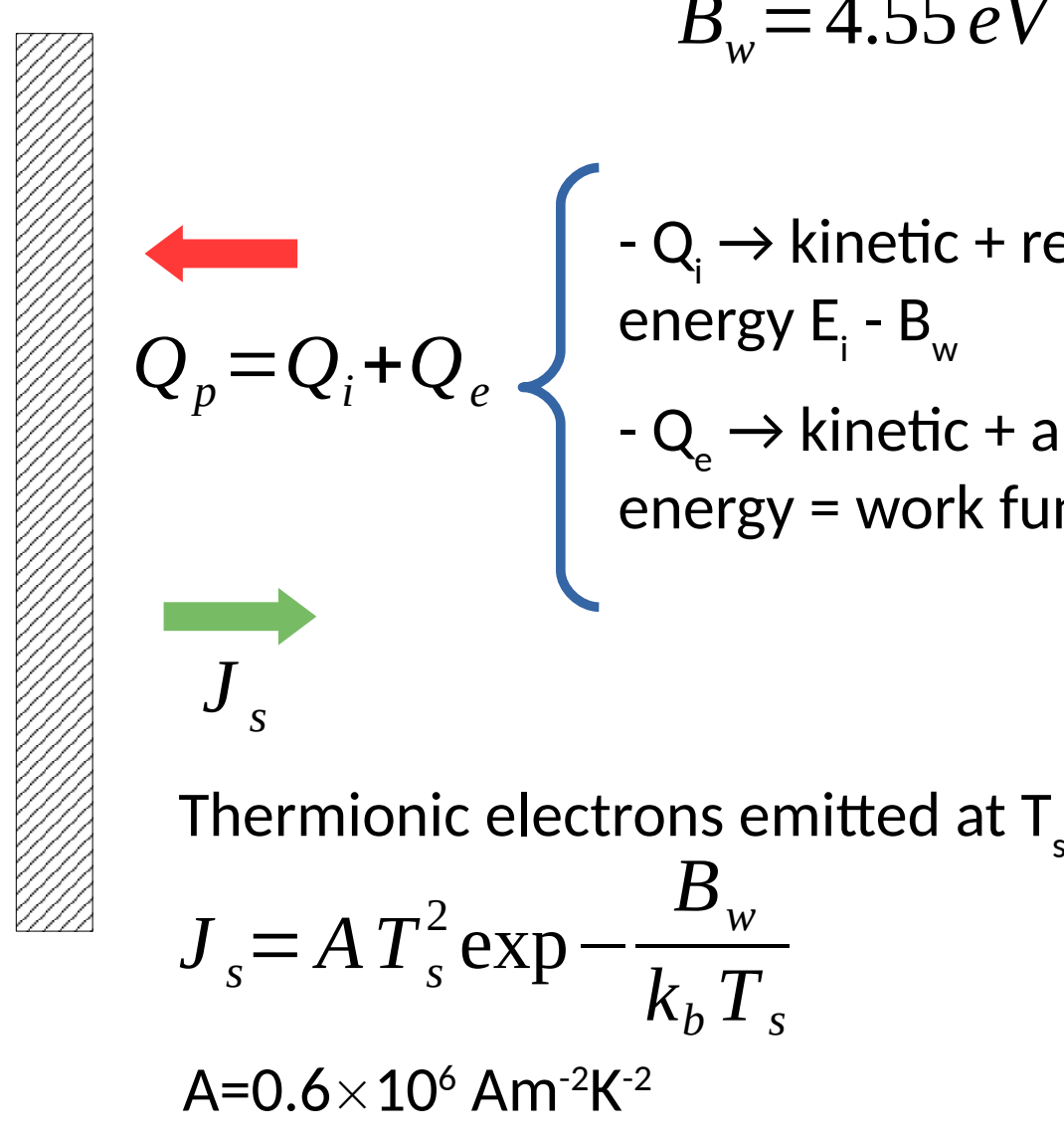
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Context of the Simulations

- 1d/3V PIC simulations ($L=100L_d$)
- Tungsten surface with $\epsilon=0.25$
 $B_w=4.55\text{ eV}$



- $Q_p \rightarrow$ kinetic + recomb. energy $E_i - B_w$
- $Q_e \rightarrow$ kinetic + absorp. energy = work function B_w

- Heat flux balance at the wall at each iteration

$$Q_p = Q_c$$

$$\text{With [1]} \quad Q_c = J_s (2k_b T_s + B_w) + \epsilon \sigma T_s^4 + \frac{K}{l} (T_s - T_0)$$

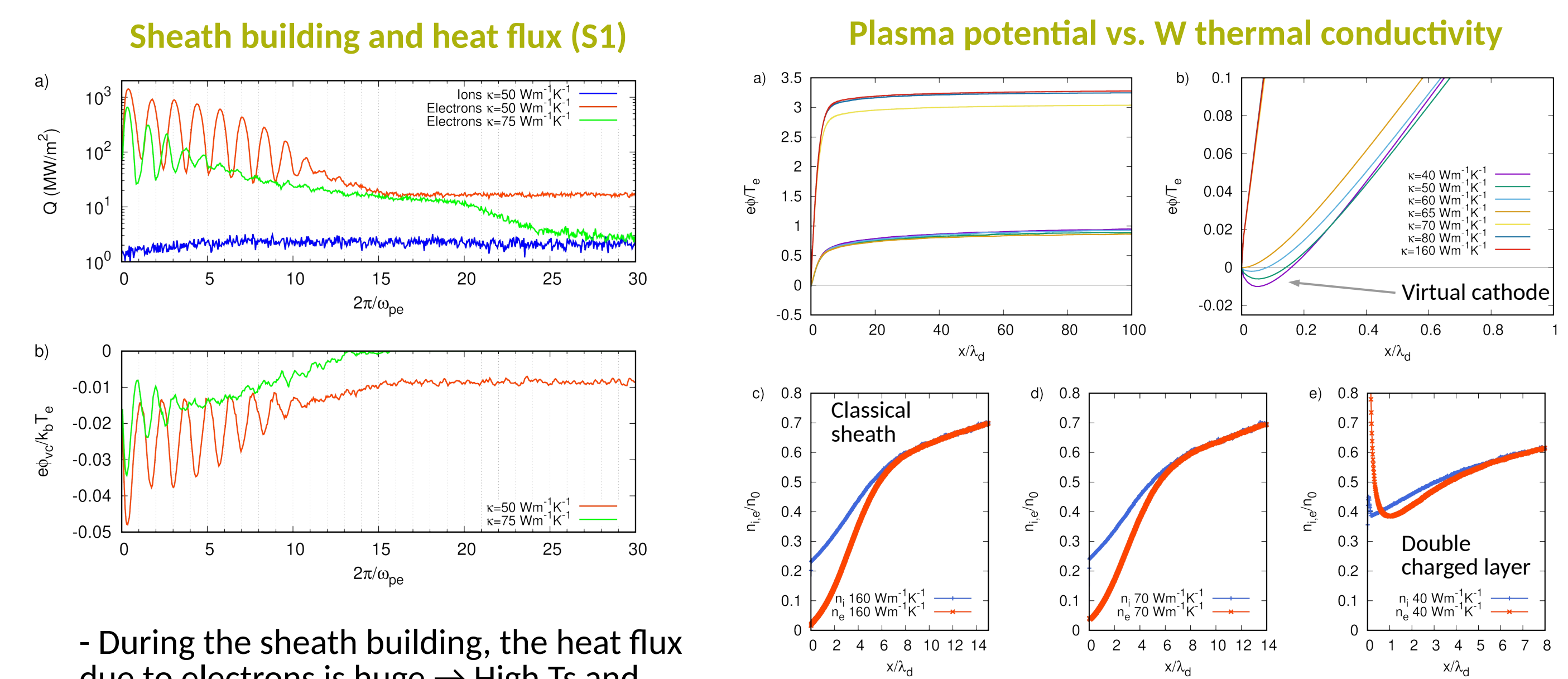
\rightarrow gives T_s and then J_s to be injected + loop until the steady state ($T_0 = 300\text{ K}$ and wall thickness $l=1\text{ cm}$).

- 2 Simulation scenarios:

S1: The routine calculating T_s and J_s is run at the beginning of the simulations. During the establishment of the sheath, the surface receives a very large heat flux due to the electrons \rightarrow high T_s . Then the wall eventually cools down to the steady state.

S2: The routine calculating T_s and J_s is launched after 10 plasma periods (*waiting time*) for the sheath to be established. The cathode can then be cold before the steady state is reached contrary to scenario 1.

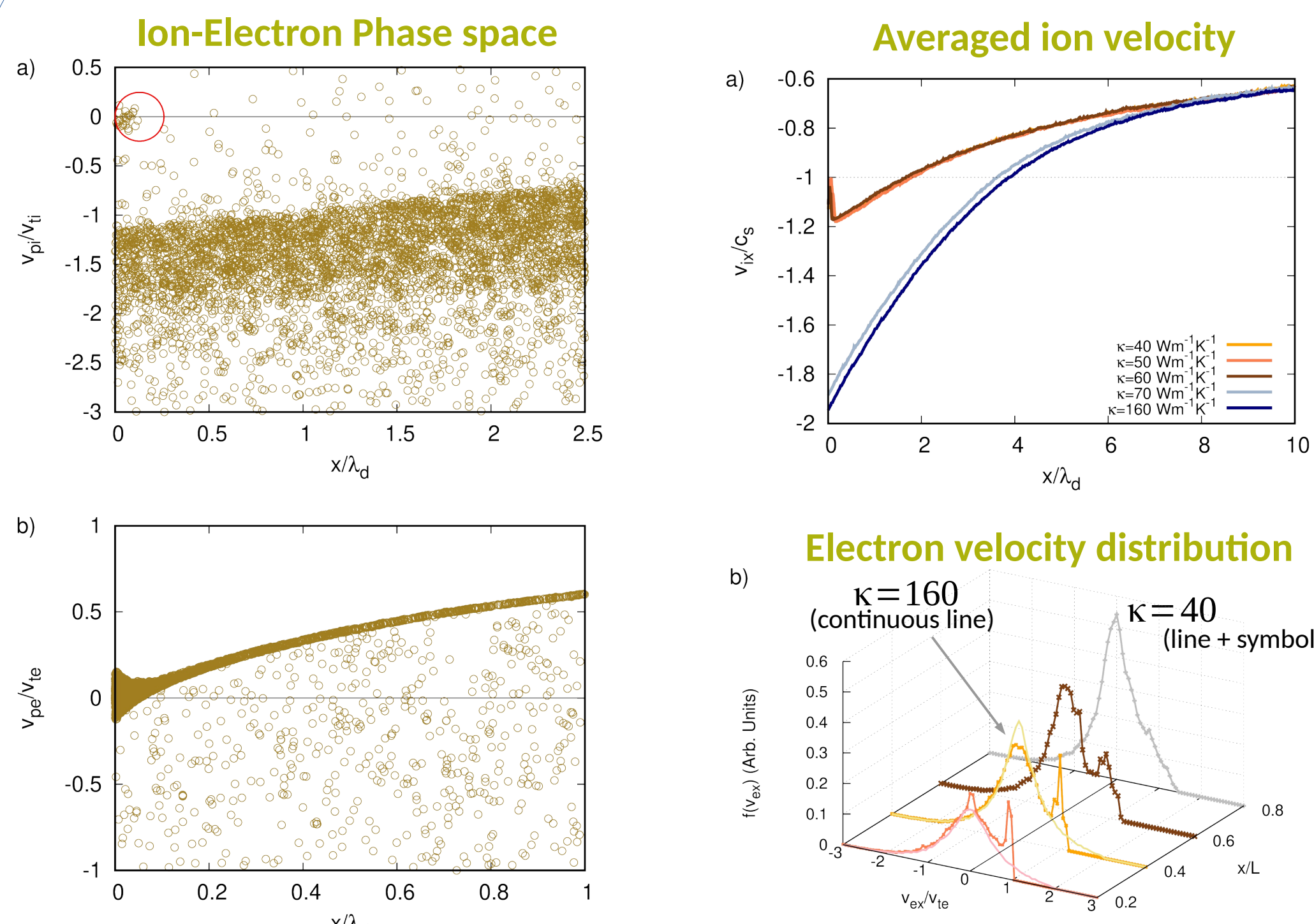
Sheath building & Space potential + plasma density



- During the sheath building, the heat flux due to electrons is huge \rightarrow High T_s and strong $J_s \rightarrow$ Virtual cathode on several plasma periods (but can be temporary and cancels if further heat flux not large enough)

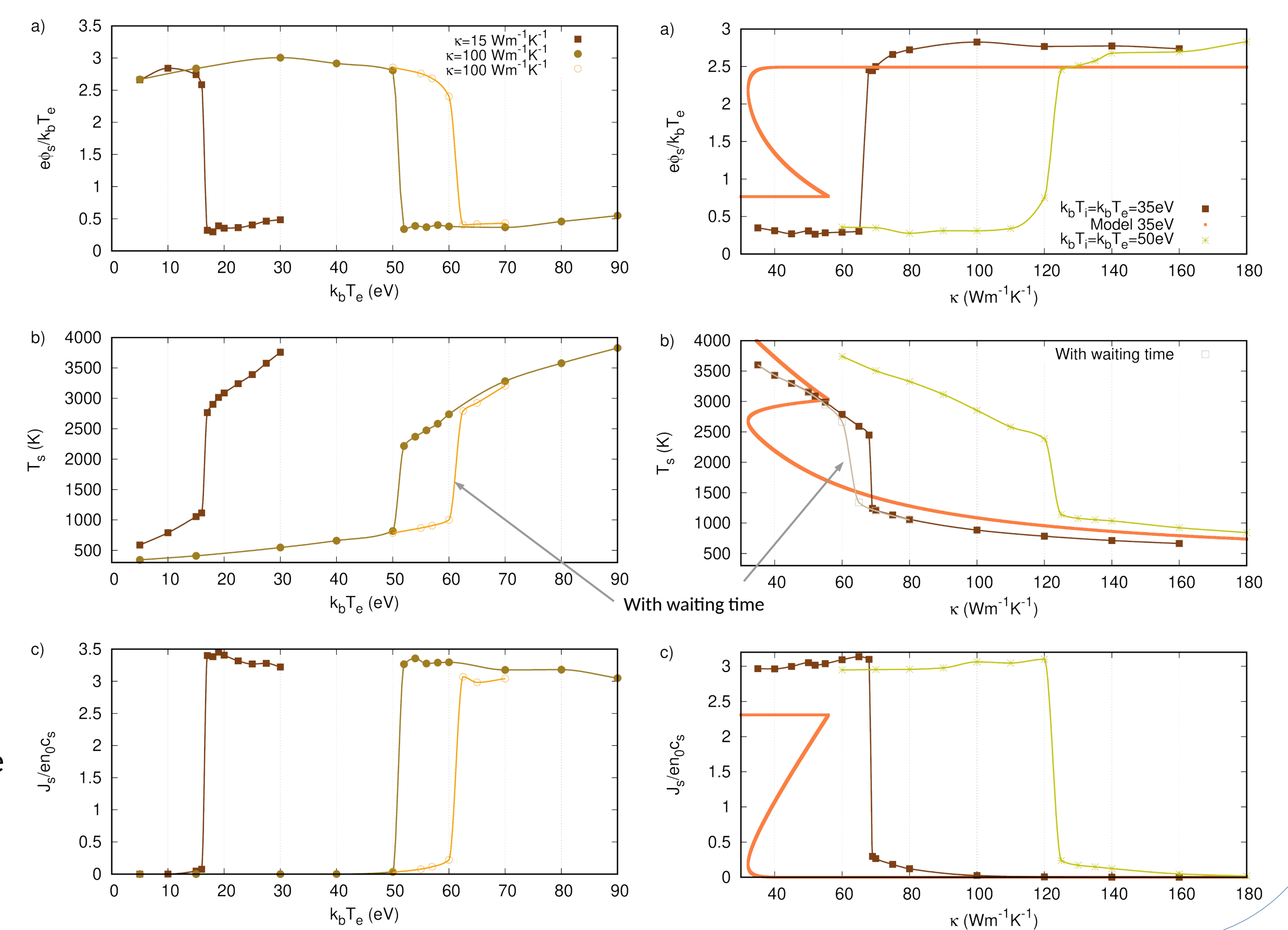
- The reduction of κ makes the surface temperature increase with a larger thermionic emission \rightarrow sheath shrinking and double layer occurs = virtual cathode

Phase space and Velocity distribution

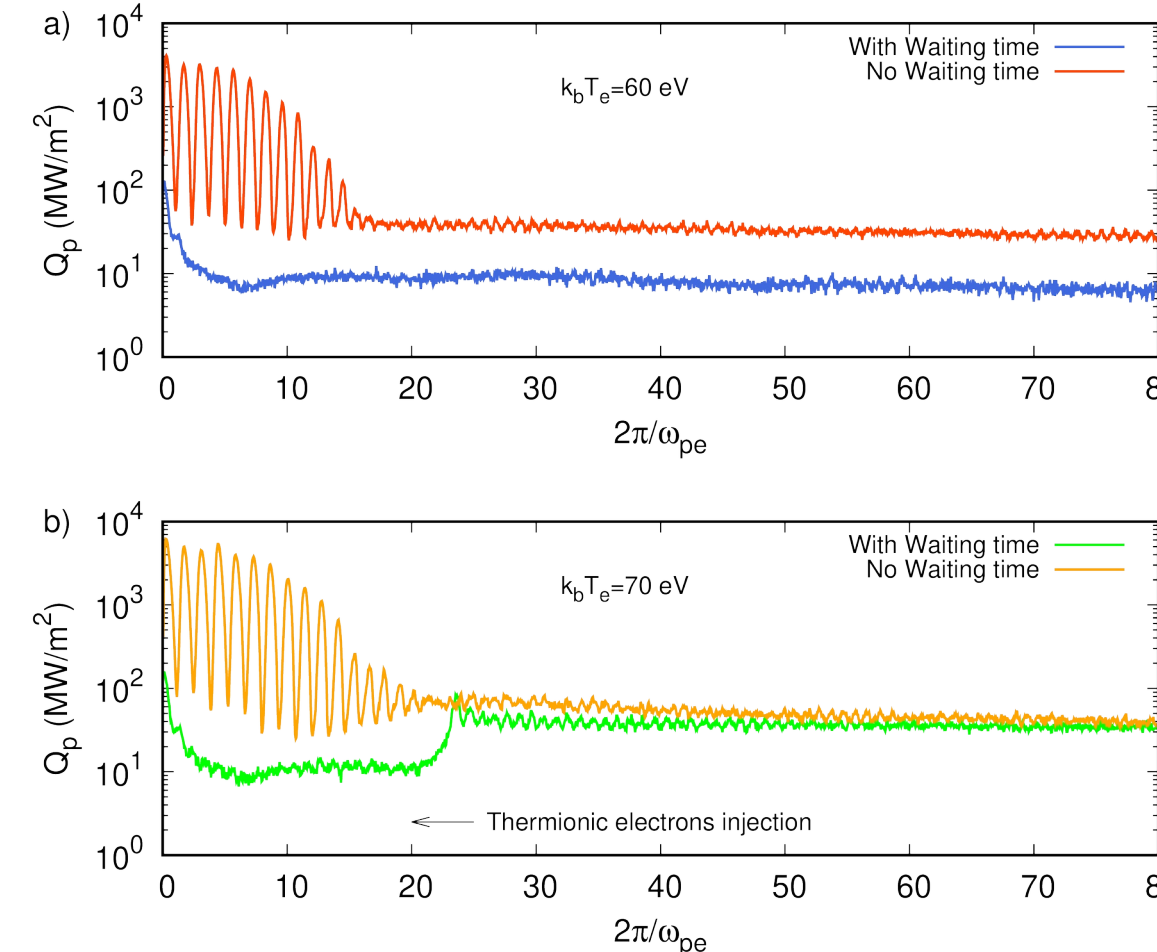


- Electrons accelerated through the sheath or reflected onto the virtual cathode when $J_s > J_s^*$
- Ions can be trapped into the potential dip [2,3]

Parametric studies & hysteresis



Scenario S1 vs. S2: Heat Flux

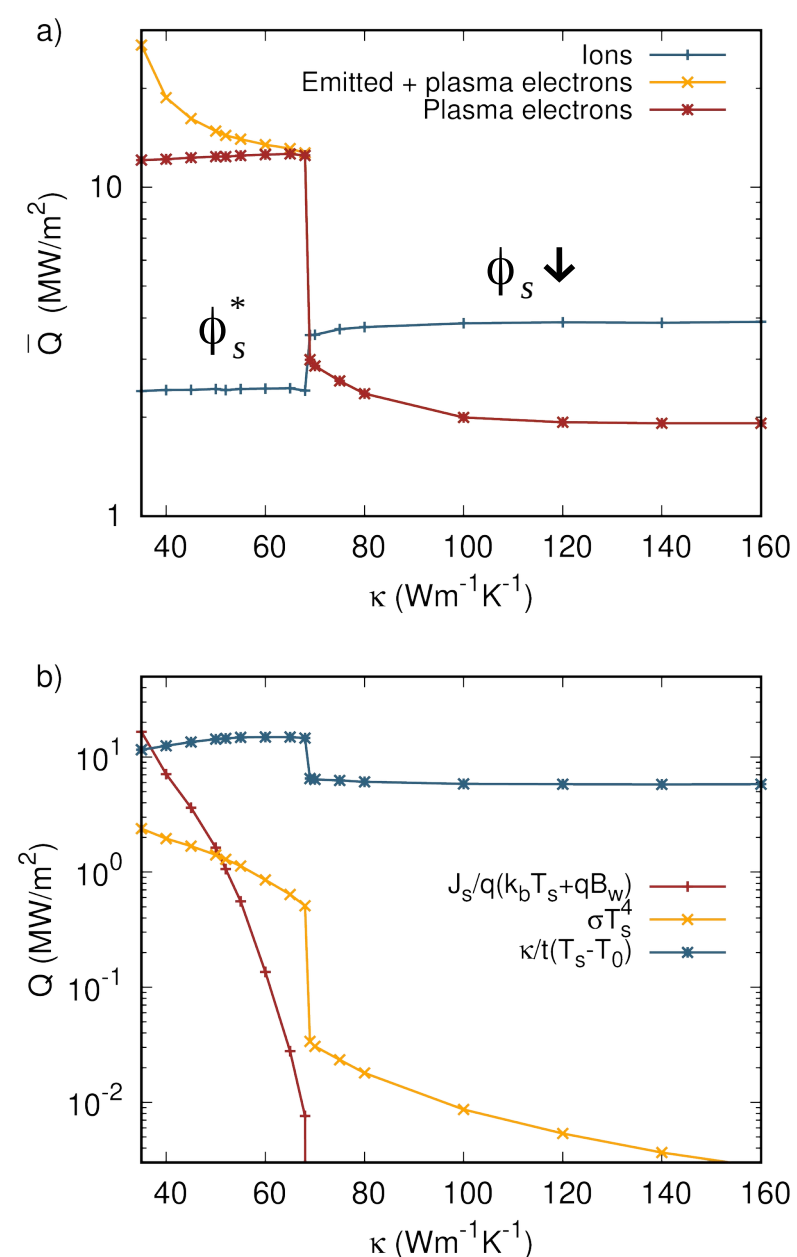


- The final state of the cathode depends on its initial one in the expected bifurcation regime (similar behavior in experiments [6])

- The critical temperature ranges between 2500-3000K for the space charge limited regime to be reached

Heat Flux & Fluid Approach and bifurcation

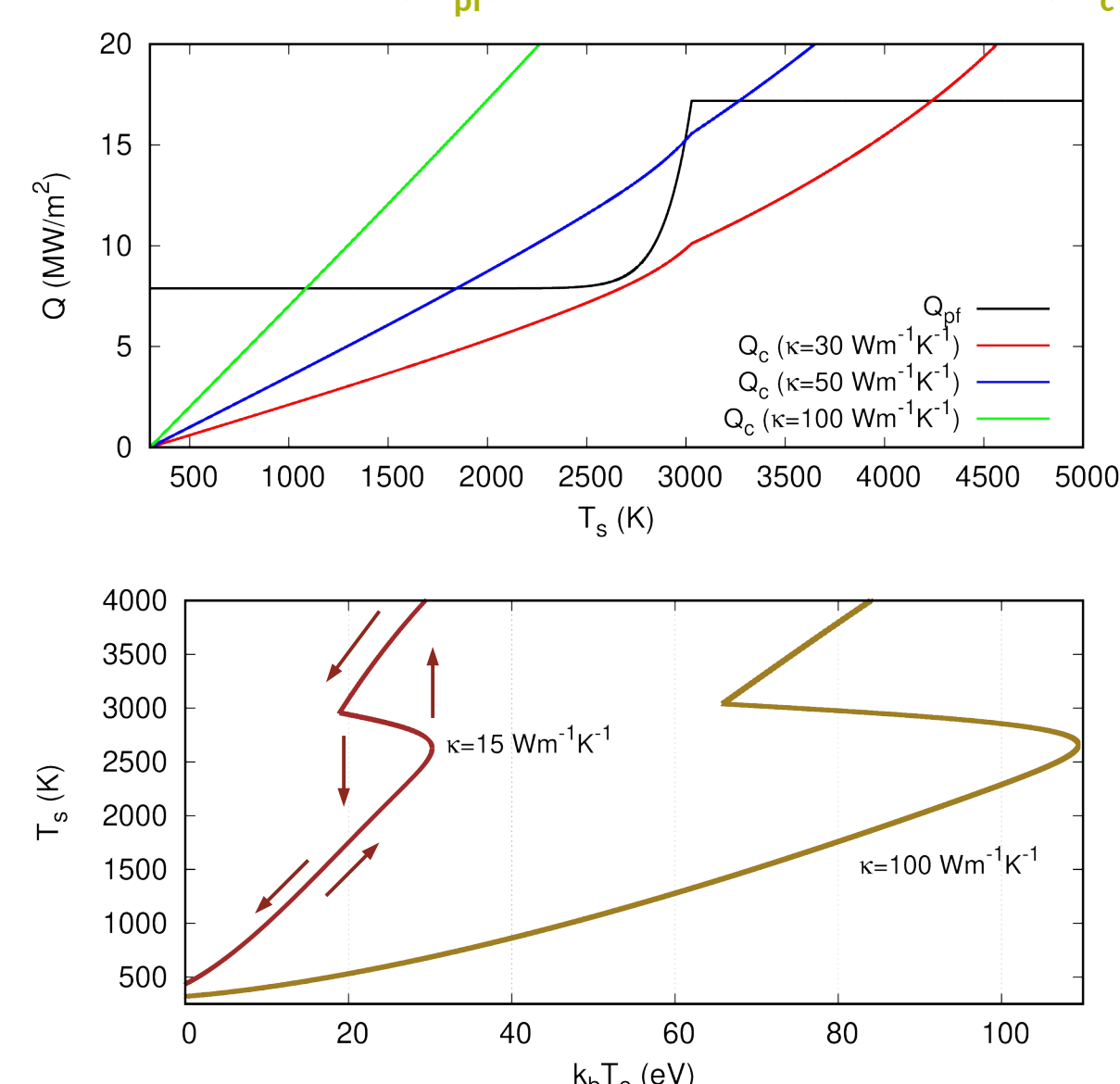
PIC Heat flux to the surface



- The heat flux on the surface depends on the sheath potential.
- In the strong emission regime, the current is limited + reflected electrons increase the heat flux
- The heat flux carried away from the surface \rightarrow mostly conduction for all the range of κ investigated

PIC Heat flux from the surface

Heat flux to (Q_p) and from the surface (Q_c)



$$Q_c = J_s (2k_b T_s + B_w) + \epsilon \sigma T_s^4 + \frac{K}{l} (T_s - T_0)$$

$$Q_p = n_s c_s (2k_b T_i + E_i - B_w + e \phi_s) + \frac{n_s c_e}{4} \exp\left(-\frac{e \phi_s}{k_b T_e}\right) (2k_b T_e + B_w)$$

$$e \phi_s = e \phi_f - k_b T_e \log\left(1 + \frac{J_s}{en_s c_s}\right) \text{ until the electric field at the surface cancels [4,5] then } J_s = J_s^*, \phi_s = \phi_s^*$$

- There is a regime of the thermal conductivity where a bifurcation occurs \rightarrow the final temperature of the surface depends on its history = hysteresis phenomenon

- The history in the PIC simulation is related to the scenario run \rightarrow coming from a high or a low temperature before reaching the steady state

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- [2] Campanelli and Umansky, Phys. Rev. Lett. 116, 085003 (2016)
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- [6] Ye, Takamura and Ohno, J. Nucl. Mater. 241, 1243 (1997)

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