The Lithium Vapor Box Divertor

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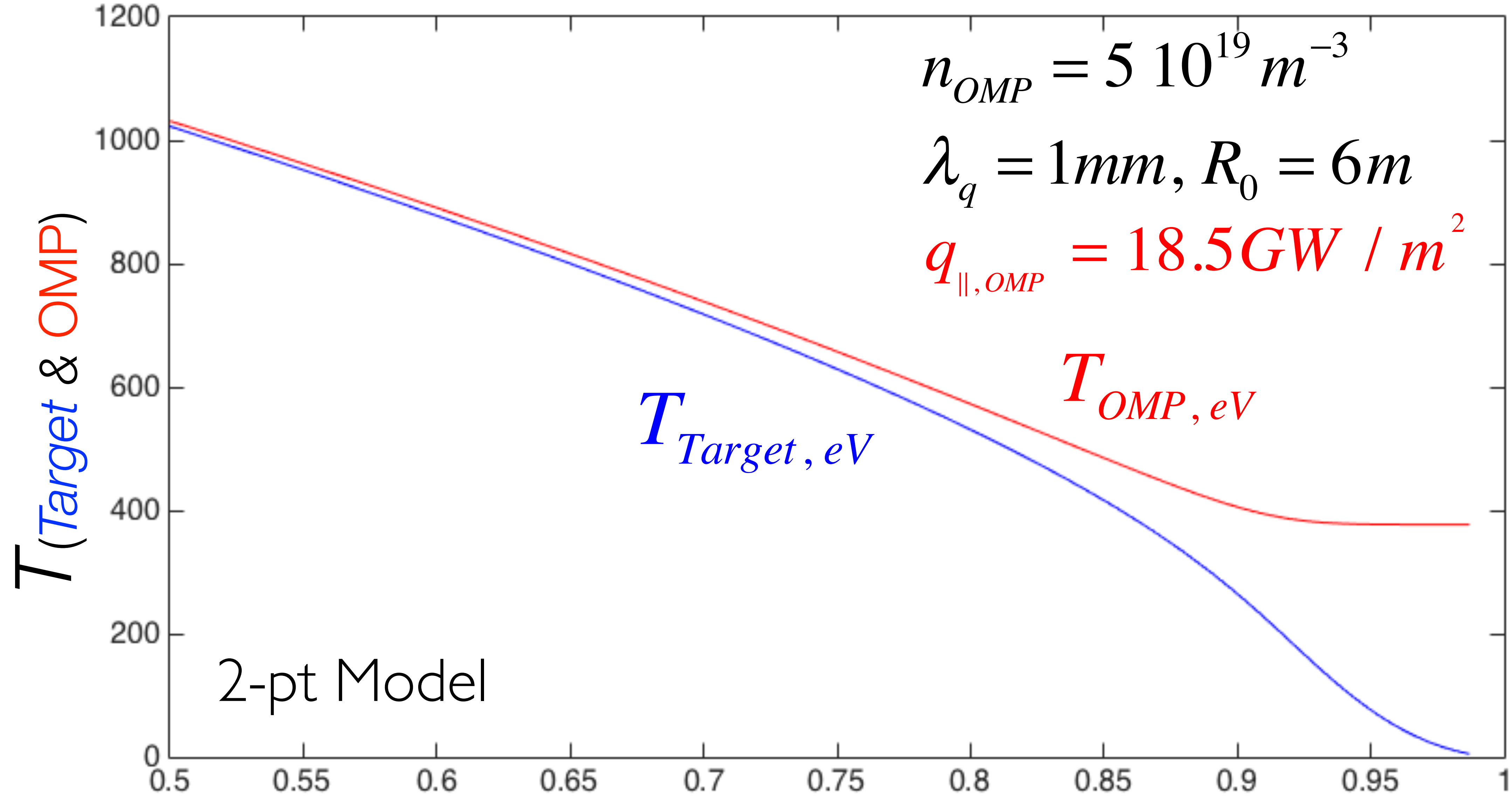
PPPL

Demo Needs Very High Dissipated Power

(Transport, Radiation, CX)



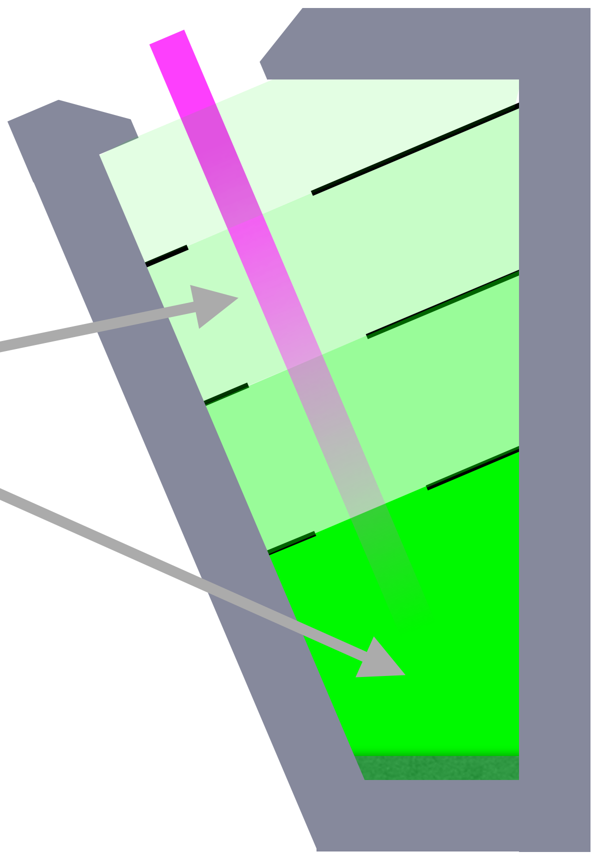
$p_{OMP} =$
$6300\,Pa$

$f_{power} = P_{dissipated} / P_{upstream}$

$q_{\perp,\,Target} = 300\,MW/m^2$

$q_{\perp,\,Target} = 10\,MW/m^2$

Continuous Lithium Vapor Shielding



- Provide a localized cloud of Li vapor away from main plasma
  - Evaporation at ~ 700° C
  - Condensation at ~ 400° C
- Return liquid lithium via capillary porous material.
- An inside-out heat pipe – with the heat source inside the pipe!
- Vapor gradient ⇒ resiliency to variable heat flux.
- Cannot be done with gaseous impurities.
- Use low-Z impurity to maximize radiation in SOL.

Lithium Modeling

- Using SPARTA Monte-Carlo Direct Simulation code
- Li collision model based on known viscosity vs. T.
- Model evaporation and condensation based on known equilibrium Li pressure vs. T, and Langmuir fluxes from/to surfaces.
- "Not bad" agreement with simple model based on choked flow and conservation of enthalpy.
- Plasma absorption, however, is a very big effect, reducing vapor efflux from baffled region.
  - Assuming 100% absorption of lithium at plasma boundary. Recombination at plasma detachment point.

Lithium Modeling

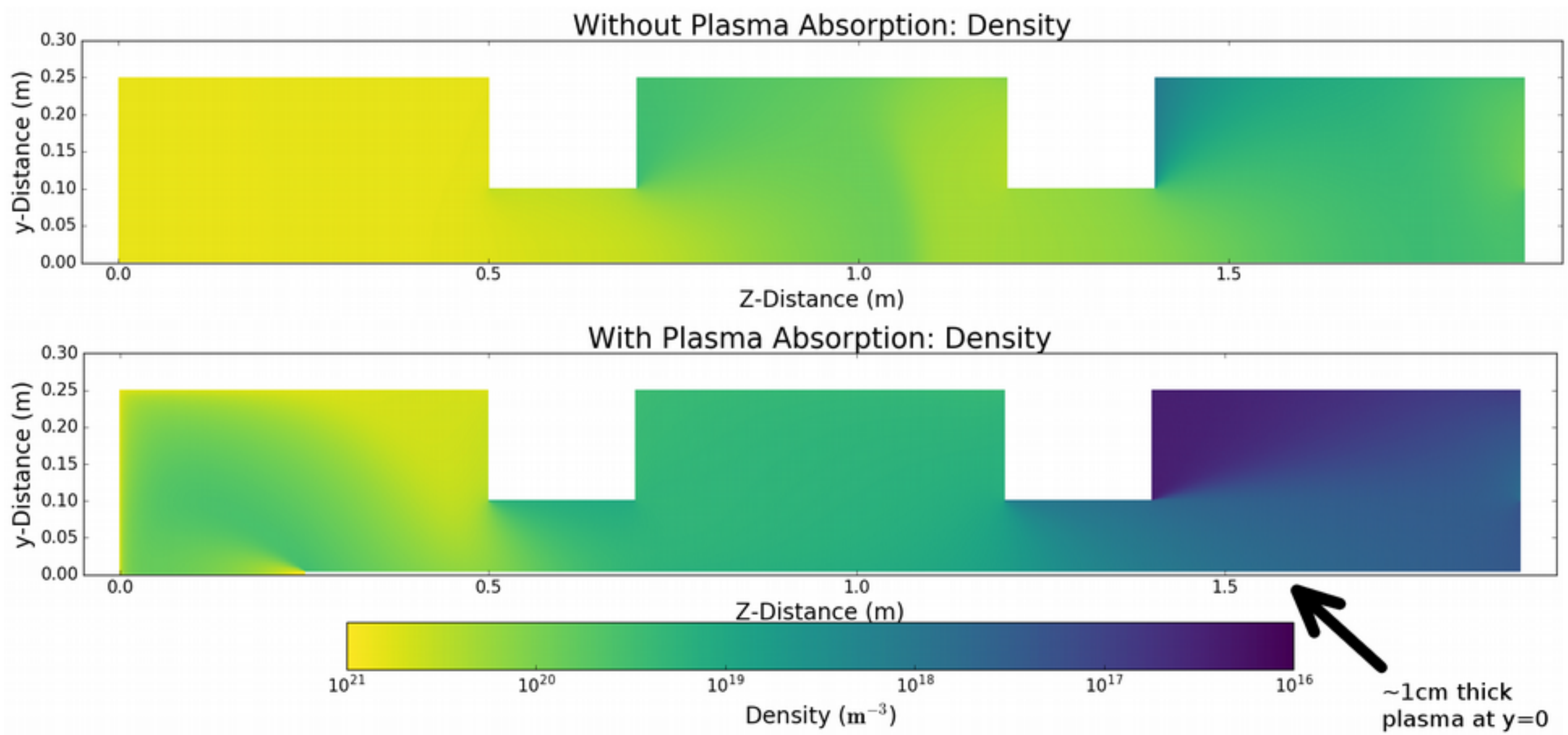


Figure 2: Effect of plasma on lithium density.

UEDGE Modeling

- UEDGE has very different, diffusive model for lithium transport, and very different geometry.
  - Based on collisions of lithium atoms with residual plasma in SOL, far SOL.
  - Short divertor leg, no baffling or vapor box yet.
- Transports lithium and calculates radiation self-consistently.
  - Issues with thermal force model at high impurity fraction.
- Achieves detached plasma in FNSF with nearly 100% lithium radiated power.
  - About 60 eV radiated per lithium ionization, but 1/2 of ionization is in far SOL.

UEDGE Modeling

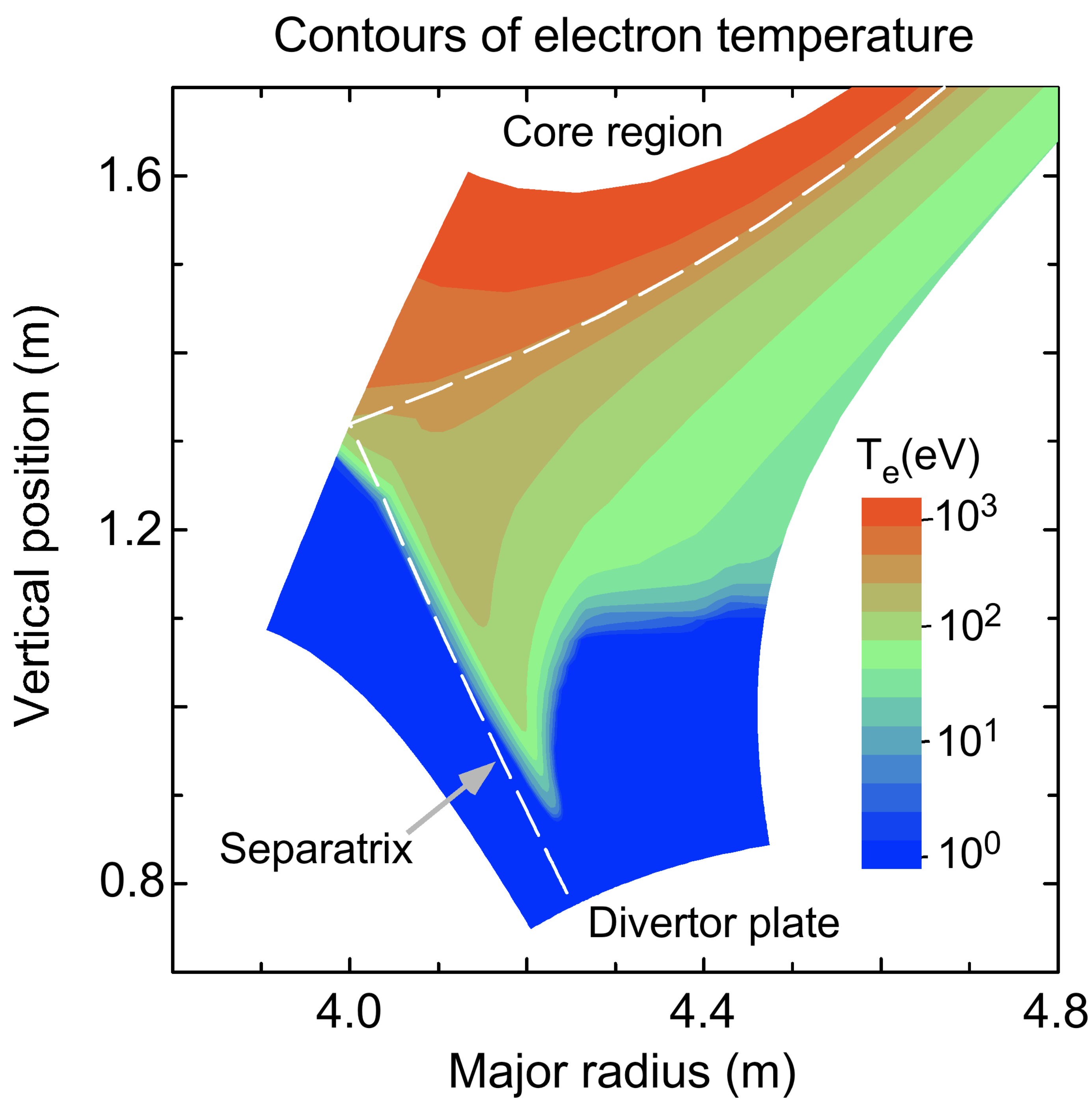
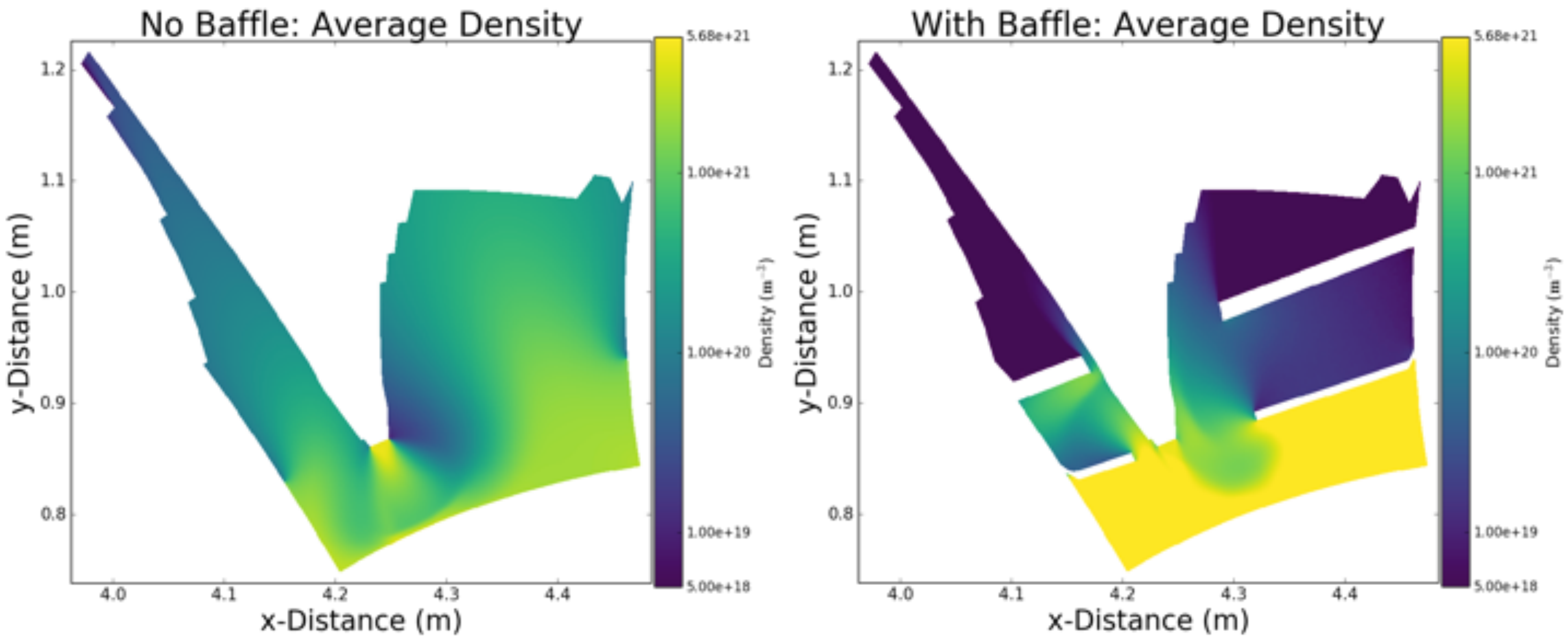


Figure 1. Detached FNSF plasma.

Lithium Modeling in UEDGE Geometry

- **Using UEDGE plasma contours, have shown dramatic decrease in lithium to far SOL with baffles.**



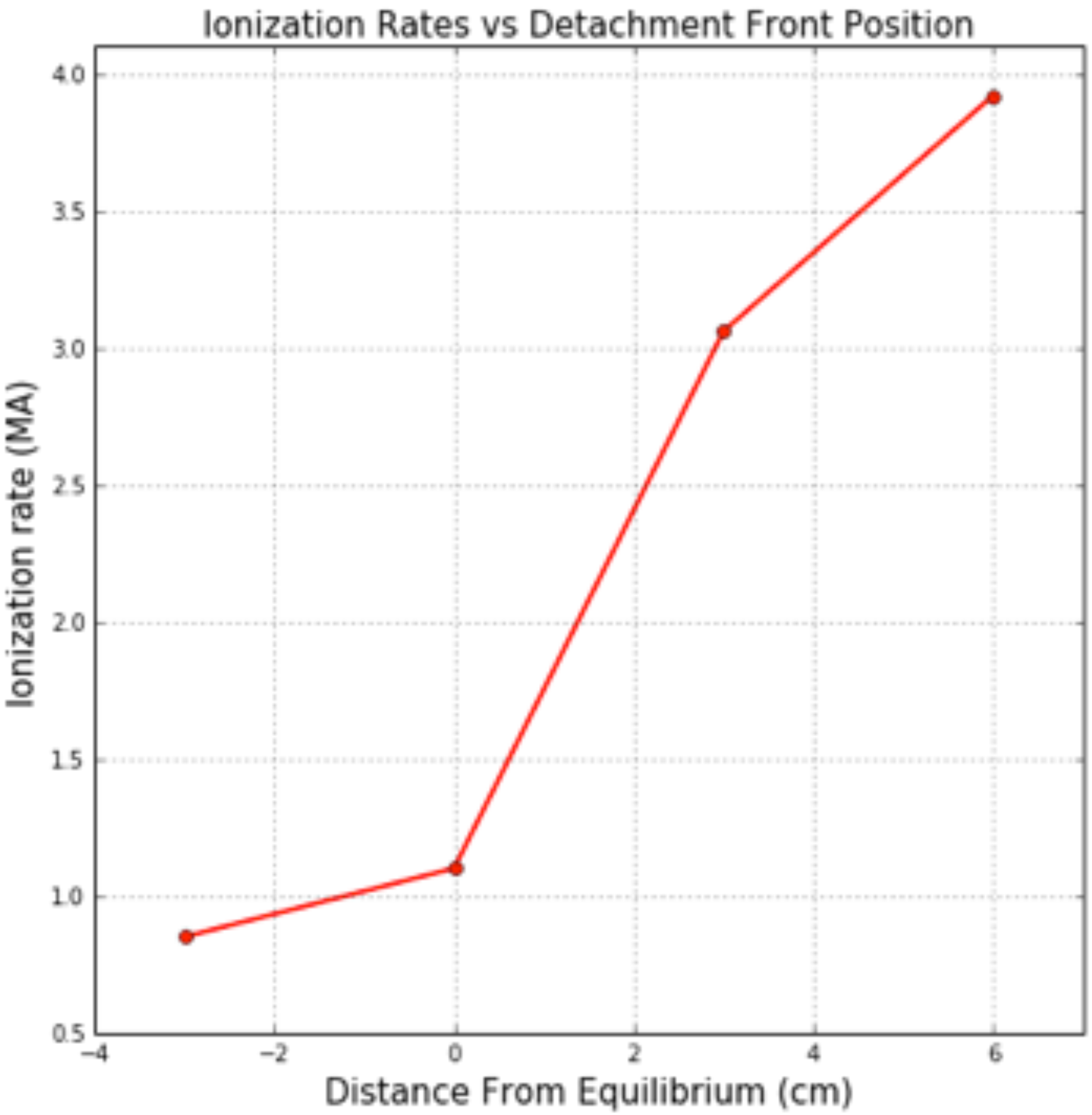
Lithium Modeling in UEDGE Geometry

- **Using UEDGE plasma contours, have found dramatic decrease in lithium to far SOL with baffles.**

Quantity	Without Baffle (MA)	With 2 Baffles (MA)	
Lithium Evaporated from the Walls	2.59	11.8	x4
Lithium Condensed on the Walls	2.59	11.8	
Ionization in Far SOL	0.56	0.003	
Ionization in baffled region	0.25	1.07	x4
Total Ionization	1.1	1.1	

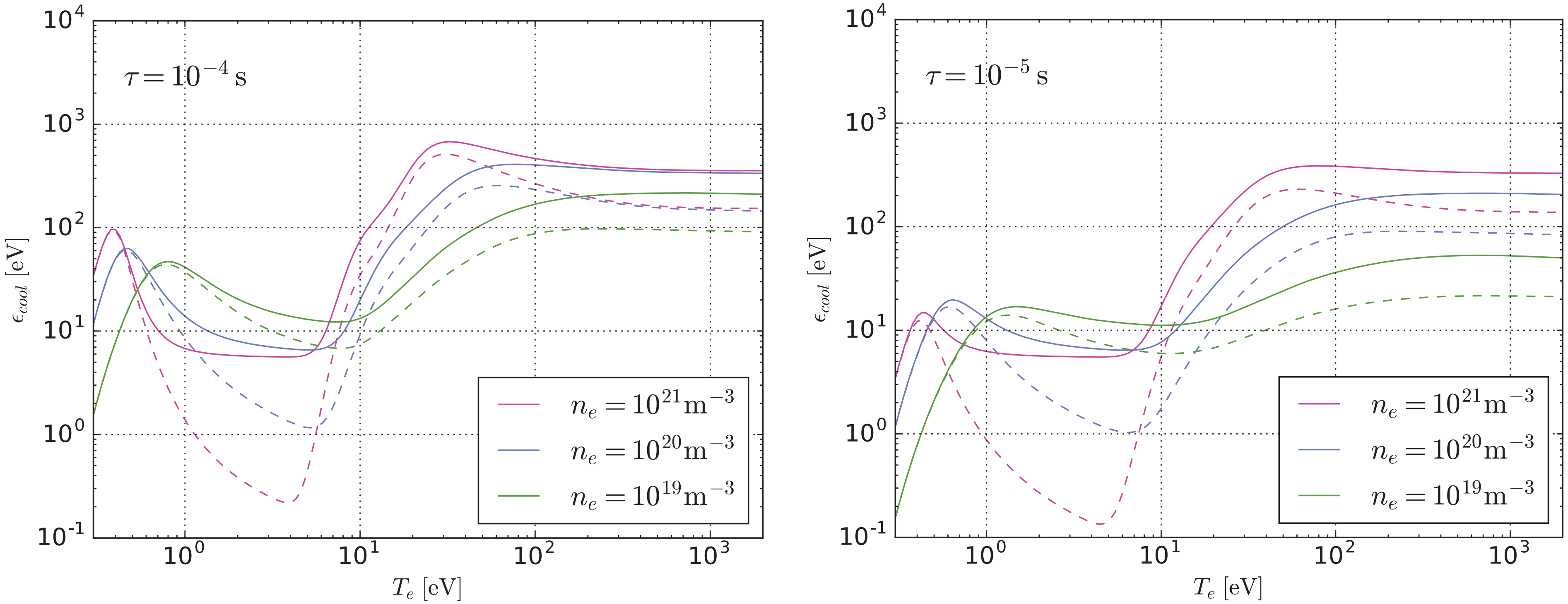
Resilience

- **Moved UEDGE contours into and out of baffled region.**
- **For fixed lithium evaporation rate, ionization in plasma increases dramatically as plasma penetrates highest density region.**
- **Should provide very substantial robustness against variable power flux.**



Simpler and More Complex Questions

- **Simpler question: How much energy is lost from upstream plasma due to Li influx?**
- **ADAS answer for Li atoms**



- **More Complex Question: What are the mechanisms of detachment with high Li content?**

From Paper by I. Murakami

I. Murakami et al. / Fusion Engineering and Design 85 (2010) 854–857

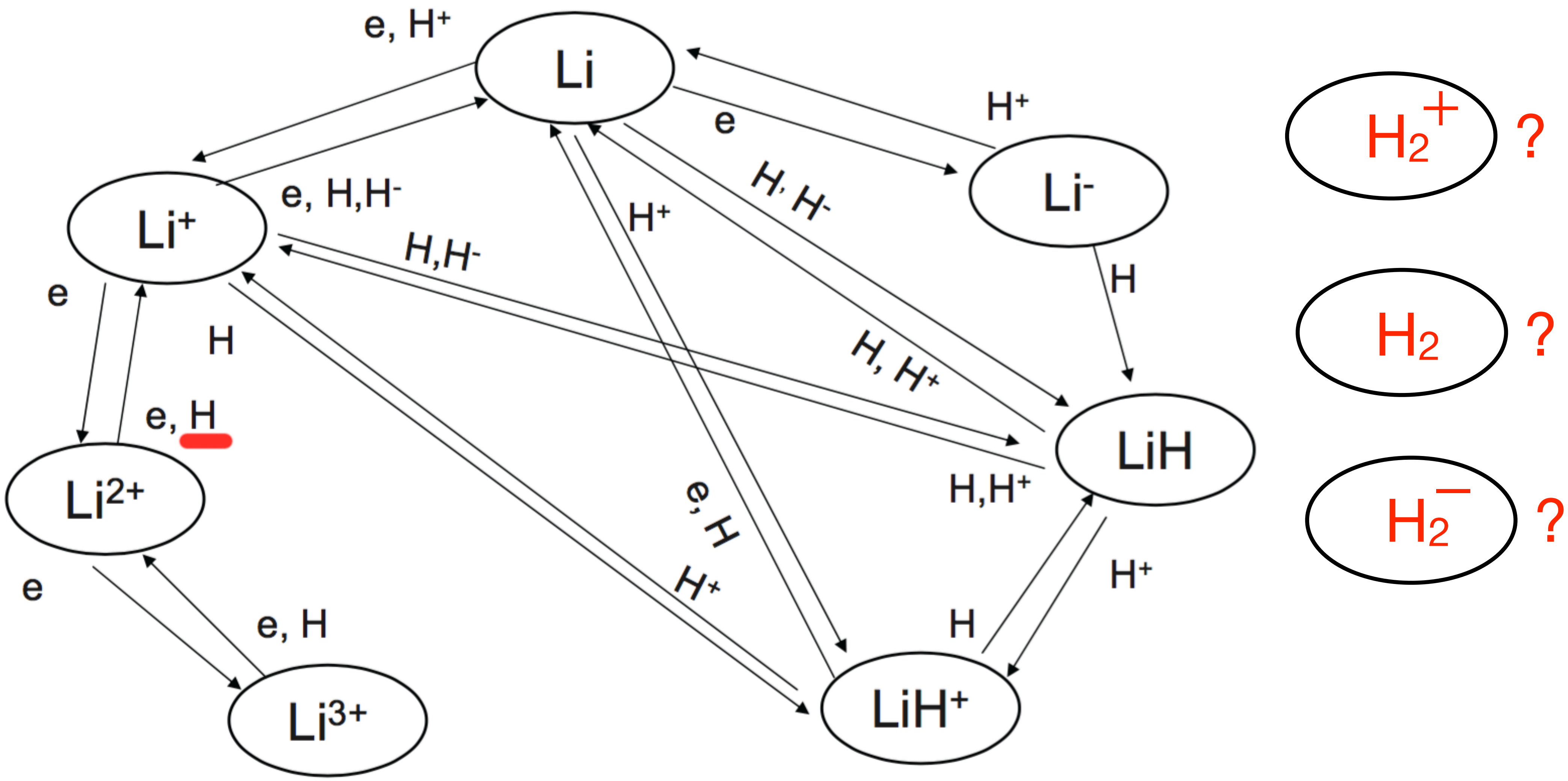


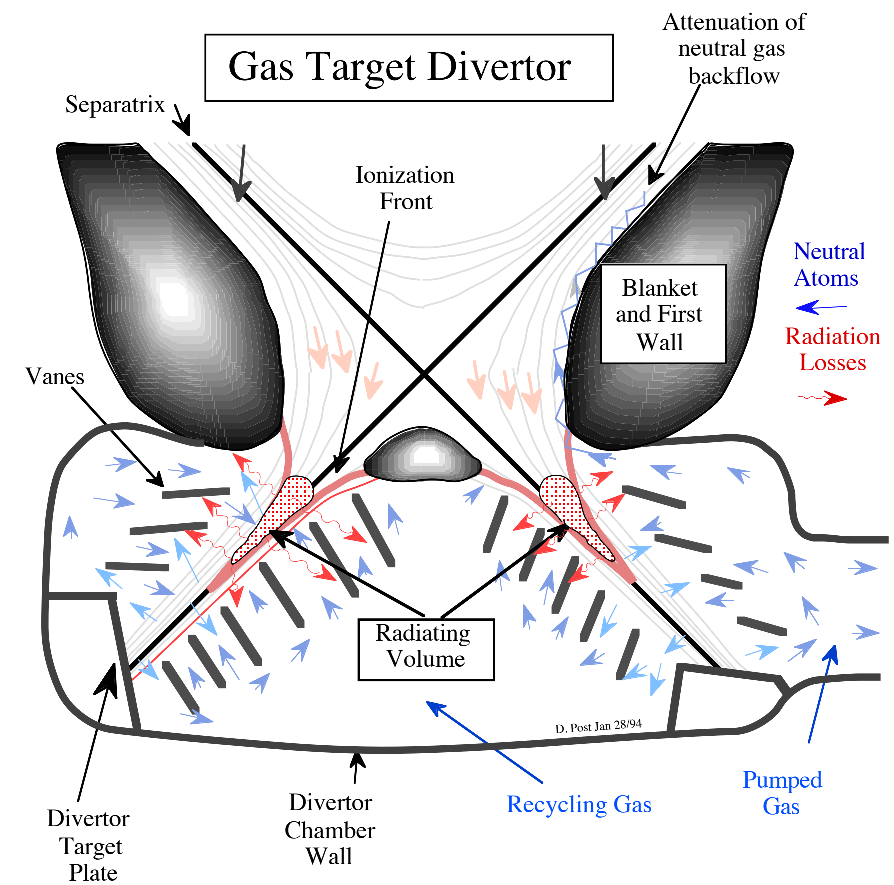
Fig. 1. Chemical reaction network for lithium considered in the model.

Need data down to energies ~ 0.1 eV (?).

What do We Need to Know?

- **Current model is that lithium is rapidly ionized at plasma edge, even in UEDGE. Many processes are not included, e.g., CX incl. Li, molecular interactions: H_2, LH**
- **A more detailed model is needed to understand how much upstream loss is needed (and how to get it) vs. dissipation in the detachment region.**
- **As plasma recombines there should be much H, H_2 and perhaps LH co-located with much Li vapor. CX effects?**
- **How does Li in its various charge and excitation states interact with H atoms and with H_2 and LH molecules in their various charge and excitation states, at energies down to ~ 0.1 eV?**
- **Is photon opacity an issue?**

References



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