# Lithium as a radiative edge-plasma component, snowflake ELM heat-flux reduction, and blob wall-fluxes

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# Focus

- **Understand/control heat-flux distribution to PFCs**

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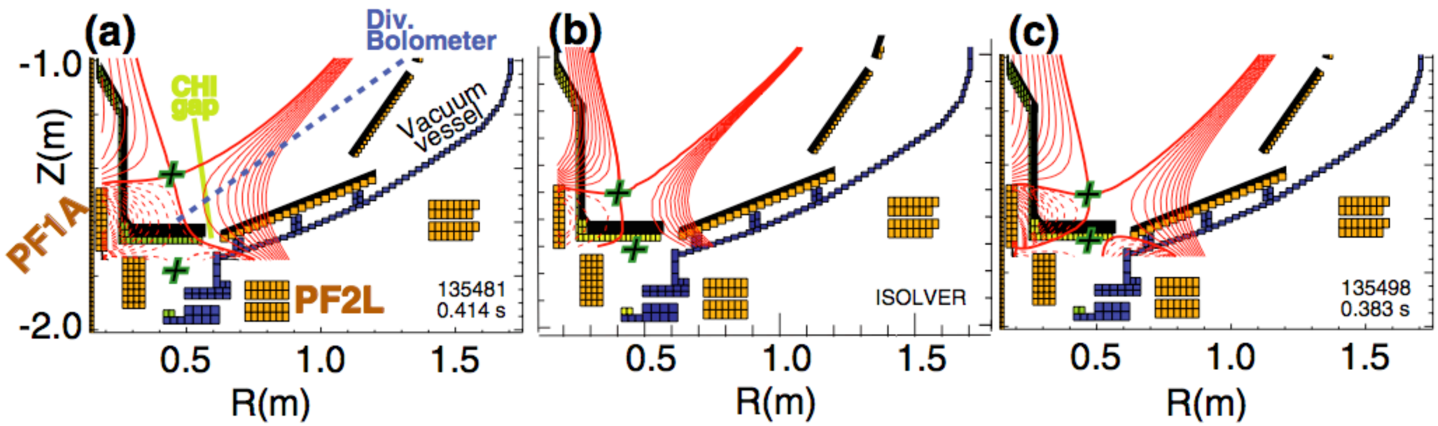
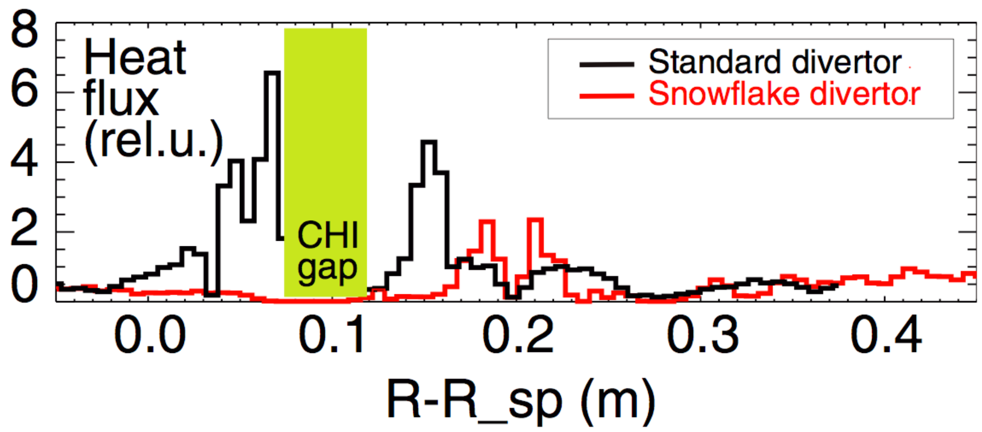
- **Assessing impact of sputtered/evaporated material on edge plasma properties**

# 1. NSTX shows substantial divertor heat-flux reduction with snowflake configuration and Li

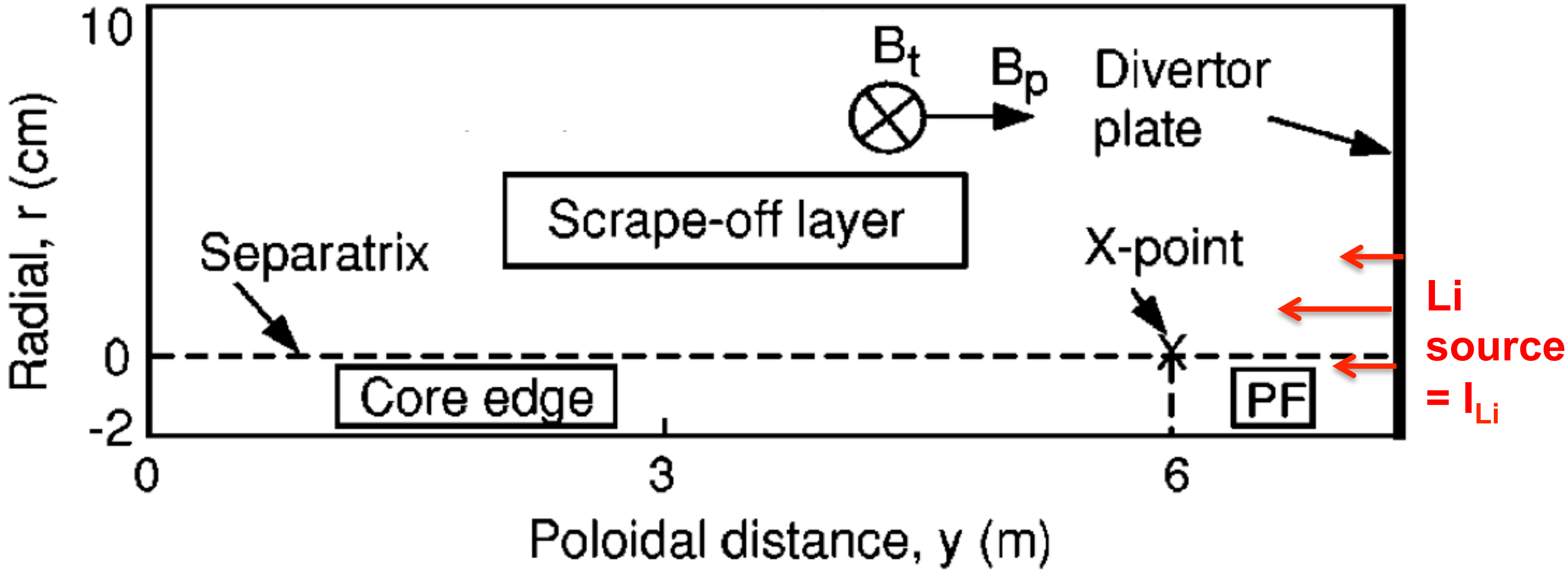
**NSTX: factor of 3 heat-flux reduction on the divertor plate [V.A. Soukhanovskii et al, Nucl. Fusion 51 (2011) 012001]**



# Simple slab model of scrape-off layer/divertor used to show strong effect of lithium source near strike point

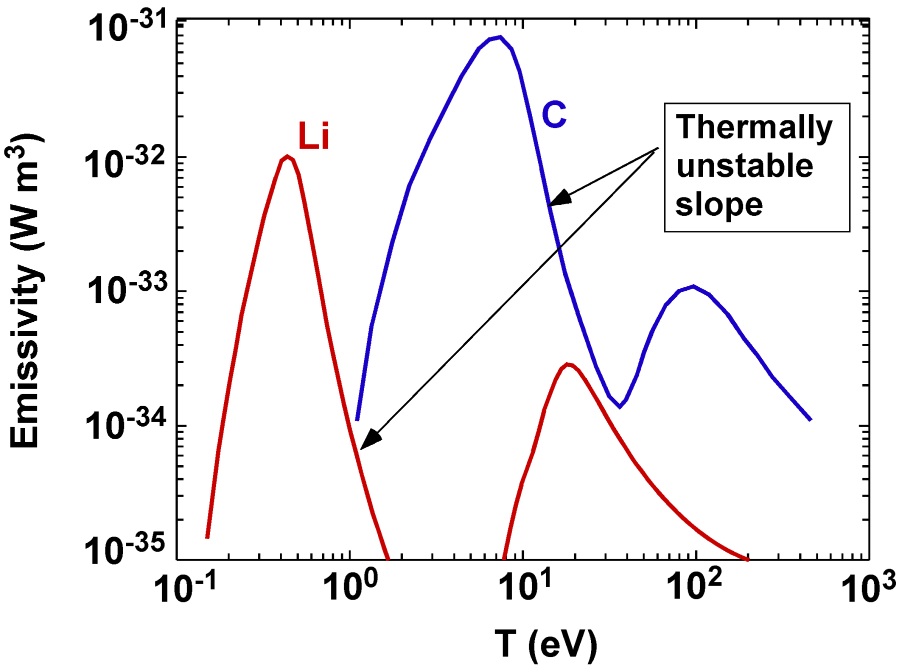
**Here only consider effect of Li on detachment; snowflake adds an additional effect**

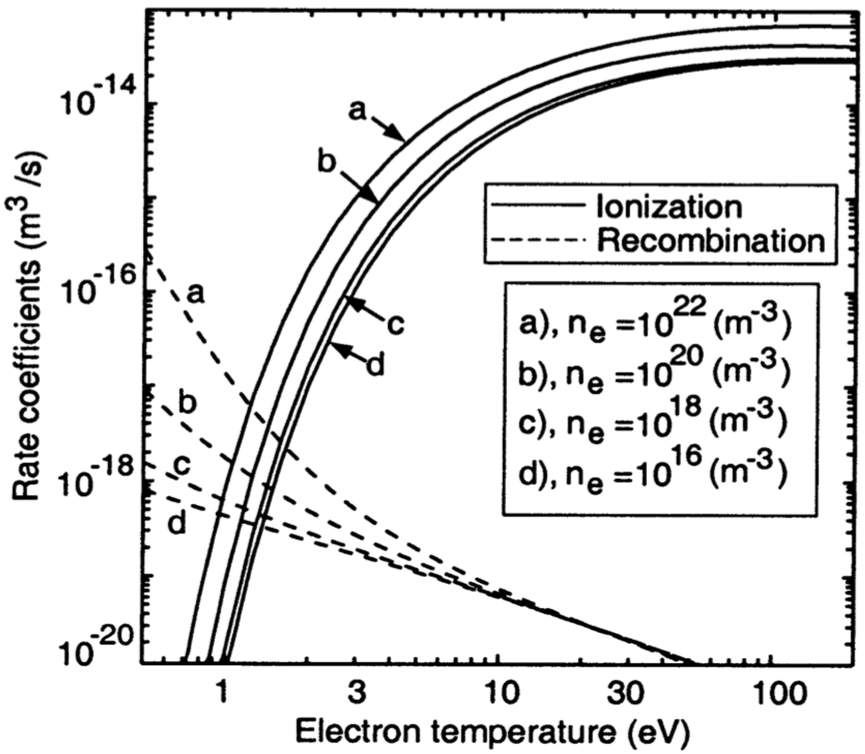



**Simulations to follow use 2D UEDGE with noncoronal, multi-charge-state lithium and deuterium**

# Low-energy peak in lithium emissivity has an important impact on hydrogen divertor plasma

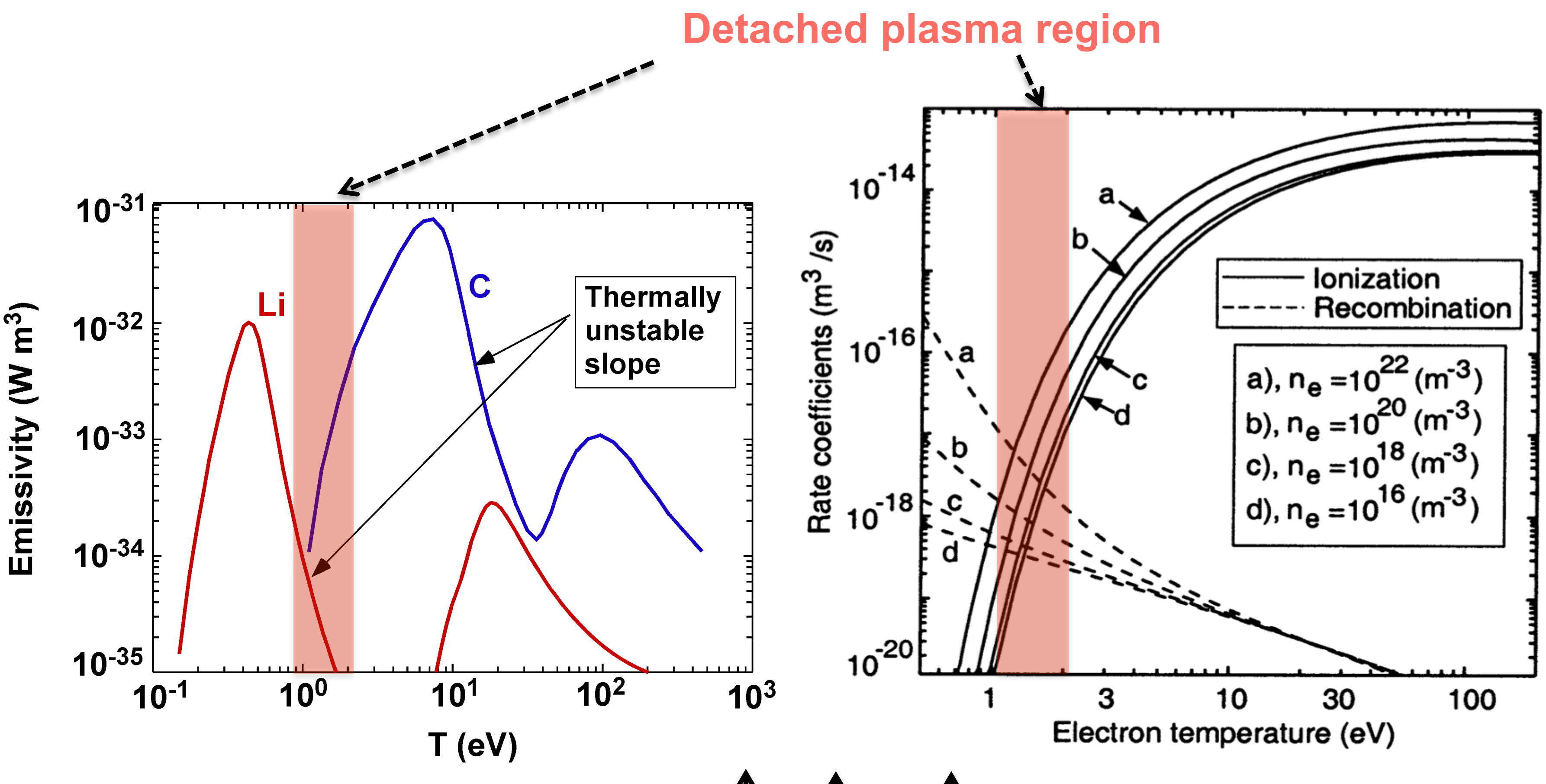
Coronal equilibrium model
for qualitative argument




**Radiated power: $P_{rad} \sim n_e \times n_{Li} \times$ Emiss**

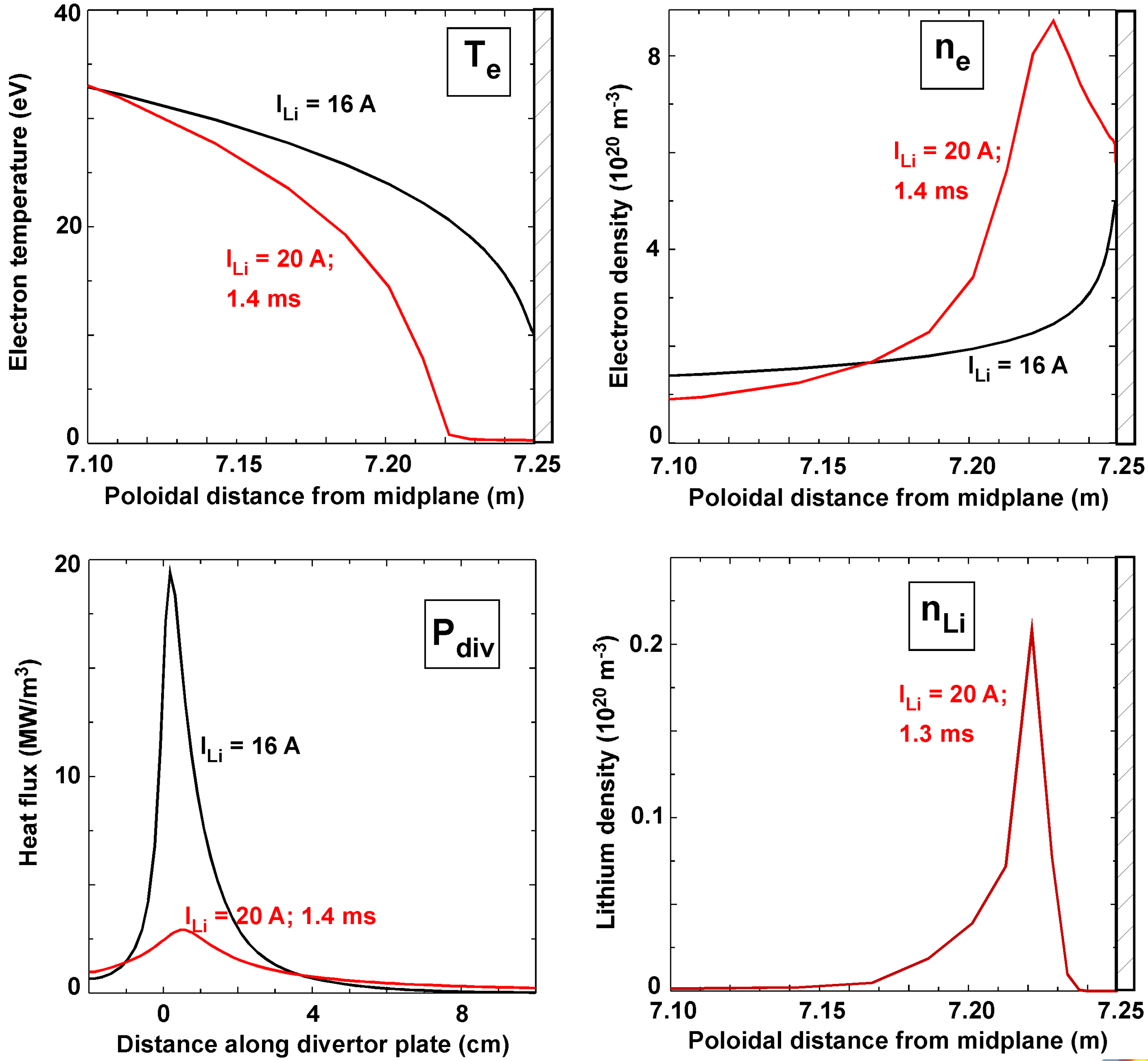
# Low-energy peak in lithium emissivity has an important impact on hydrogen divertor plasma




**Radiated power: $P_{rad} \sim n_e \times n_{Li} \times$ Emiss**

# Increasing Li plate source from 16 A to 20 A yields detached divertor in ~1 ms; not steady-state

**UEDGE simulations**




**Radiated Li power increases ~50 times to about match the input power**

# 2. ELM heat load for snowflake: depends on both time of energy deposition time ($\tau_{dep}$) and radial spreading

- **Temperature rise on divertor scales as**

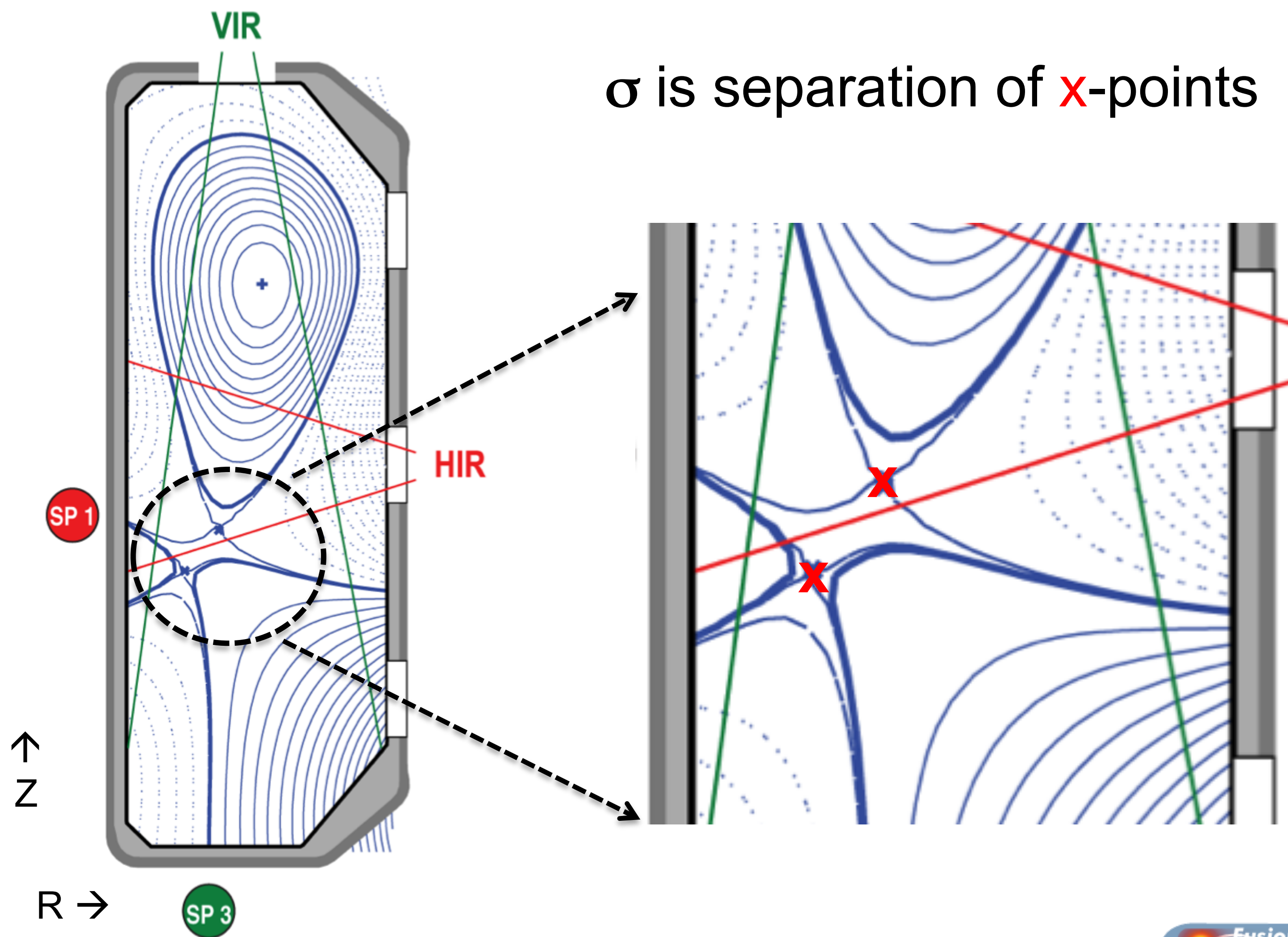
$$\text{Energy}/(\text{Area}*\tau_{dep}^{1/2})$$

- **Snowflake divertor predicted to have**
  - **larger $\tau_{dep}$ owing to longer midplane-divertor connection length**
  - **larger divertor deposition area from radial spreading**

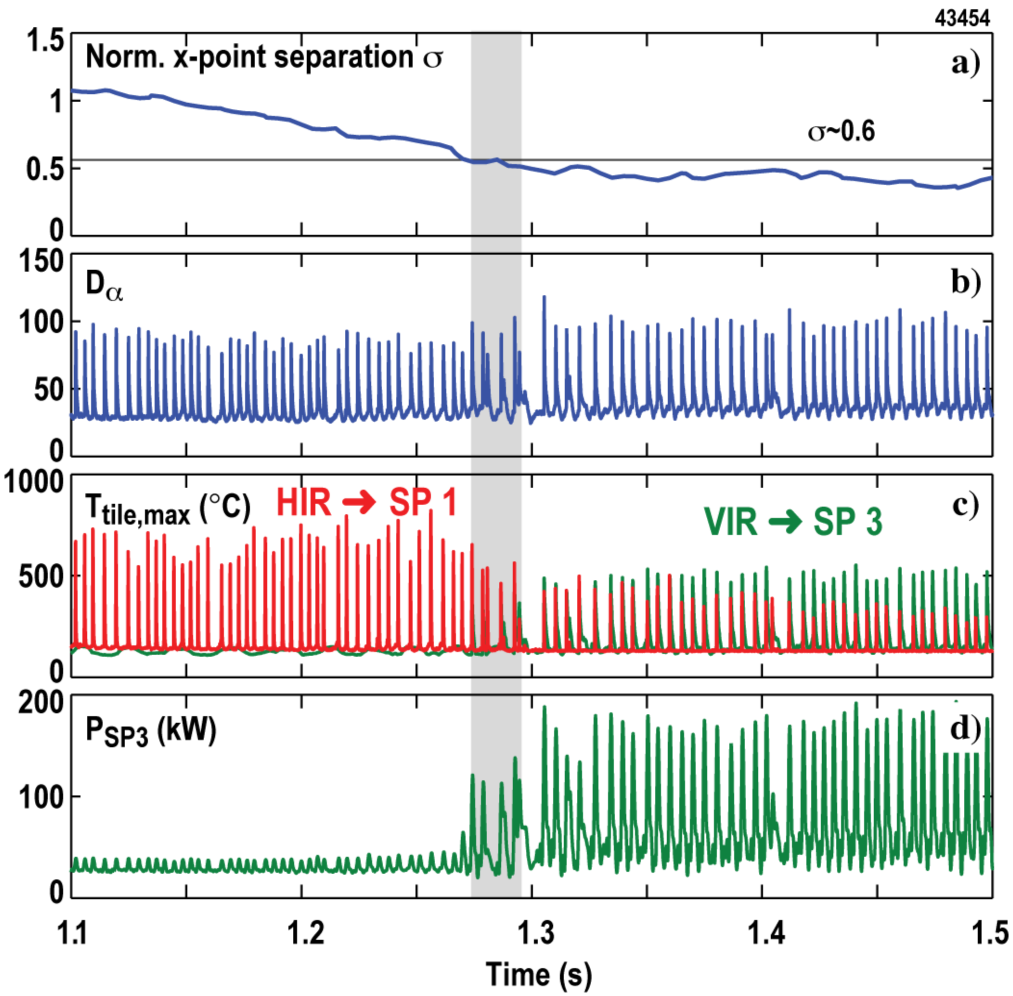
# TCV has also formed snowflake divertor & shows ELM power being spread to additional divertor leg

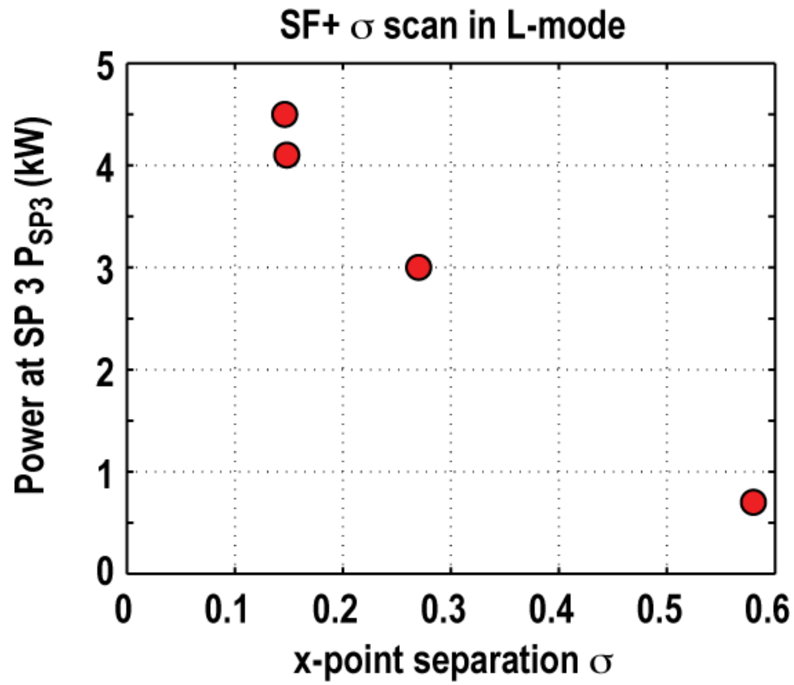
**TCV results from H. Reimedes et al., APS-DPP 2011, and PSI 2012**

σ is separation of x-points



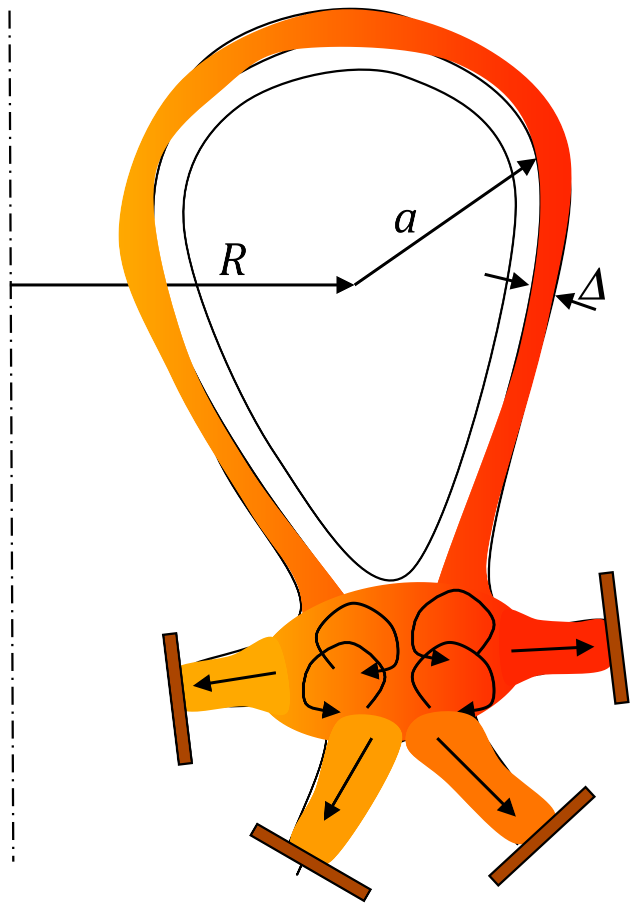
# TCV shows ELM power being spread to additional divertor leg as snowflake configuration is approached




- **L-mode: activation of SP3 at σ ~ 0.2 ($P_{SP3}/P_{SP1}$~10%)**
- **H-mode: in continuous sigma scan (from previous session), activation of SP3 during ELMs at a larger value of σ than in L-mode**

# Enlarged region with small $B_{pol}$ near magnetic null point removes usual toroidal stabilizing effect




See D. Ryutov et al., Contrib. Plasma Physics 52 (2012) 539

Flute mode growth rate

$$\Gamma \sim [(\partial P/\partial r)/(m_i n_i R)]^{1/2} ,$$

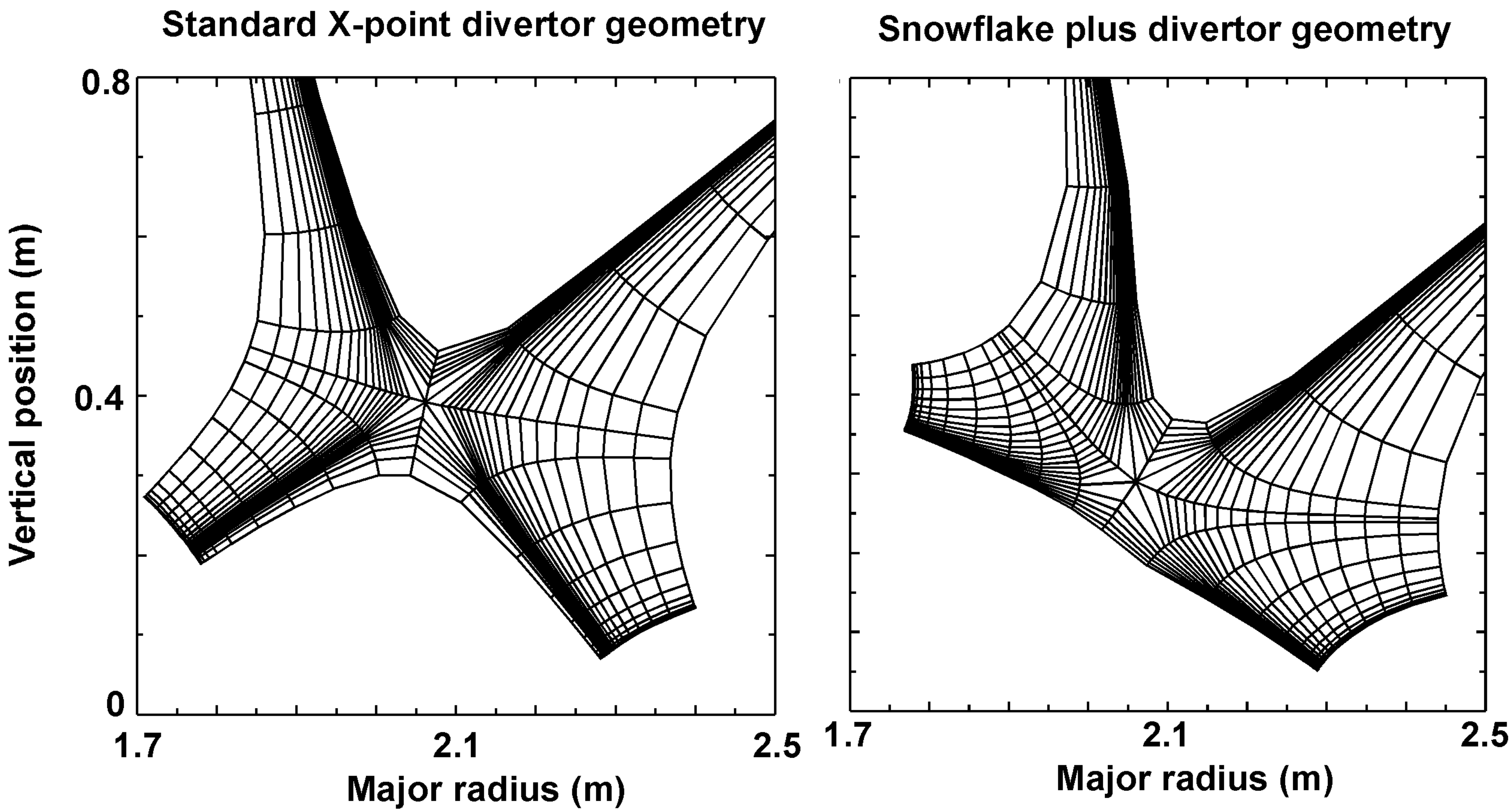
$m_i$, ion mass; P, pressure; $n_i$, ion density.

Turbulence eddy turn-over time $\tau_e$ & parallel convection time $\tau_{||}$, give

$$\tau_{||}/\tau_e \sim (B_T/B_{pm})(a^2/R\Delta)^{1/2} ,$$

$B_T$, $B_{pm}$ are toroidal & poloidal magnetic fields at midplane

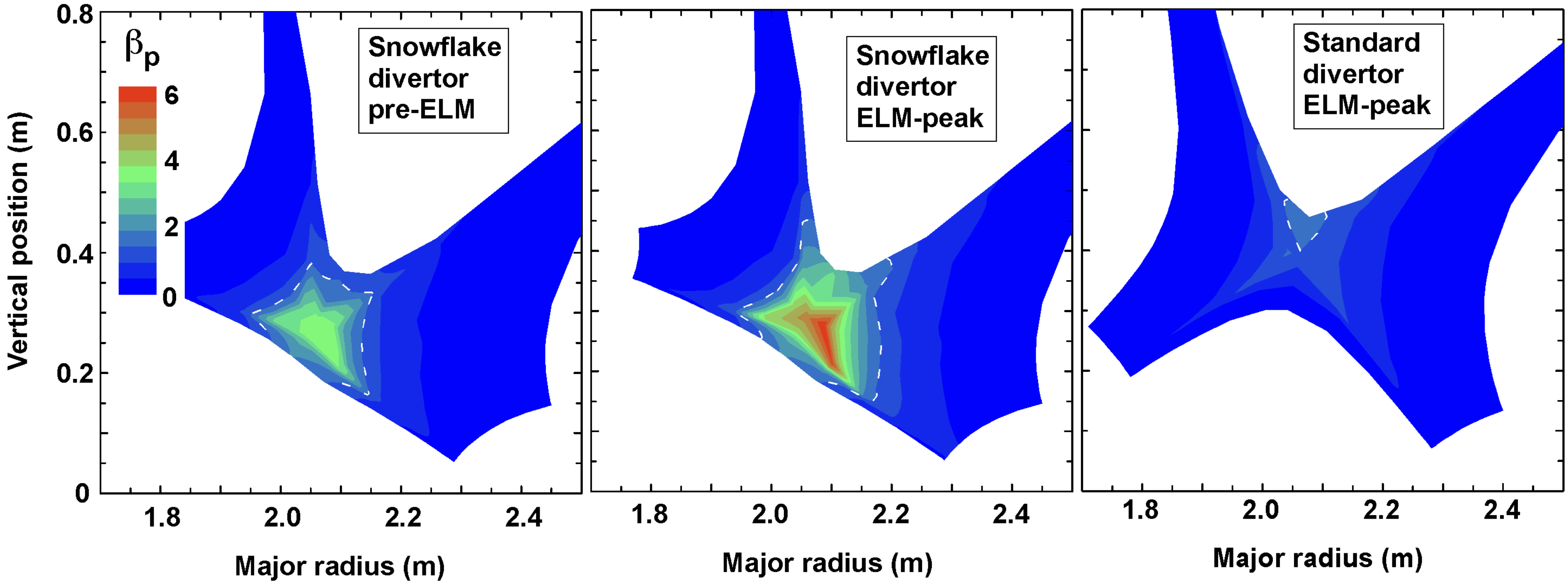
# Full divertor geometry used to compare a standard X-point divertor and snowflake-plus



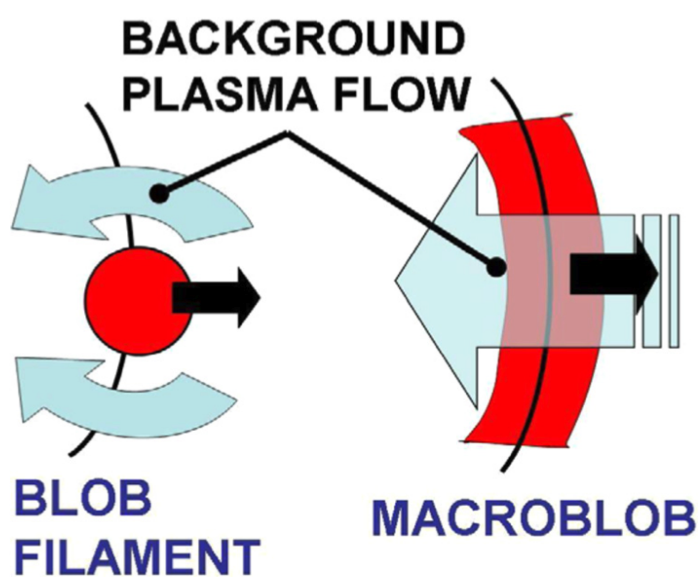
# Poloidal plasma beta substantially exceeds unity for snowflake, especially during ELMs

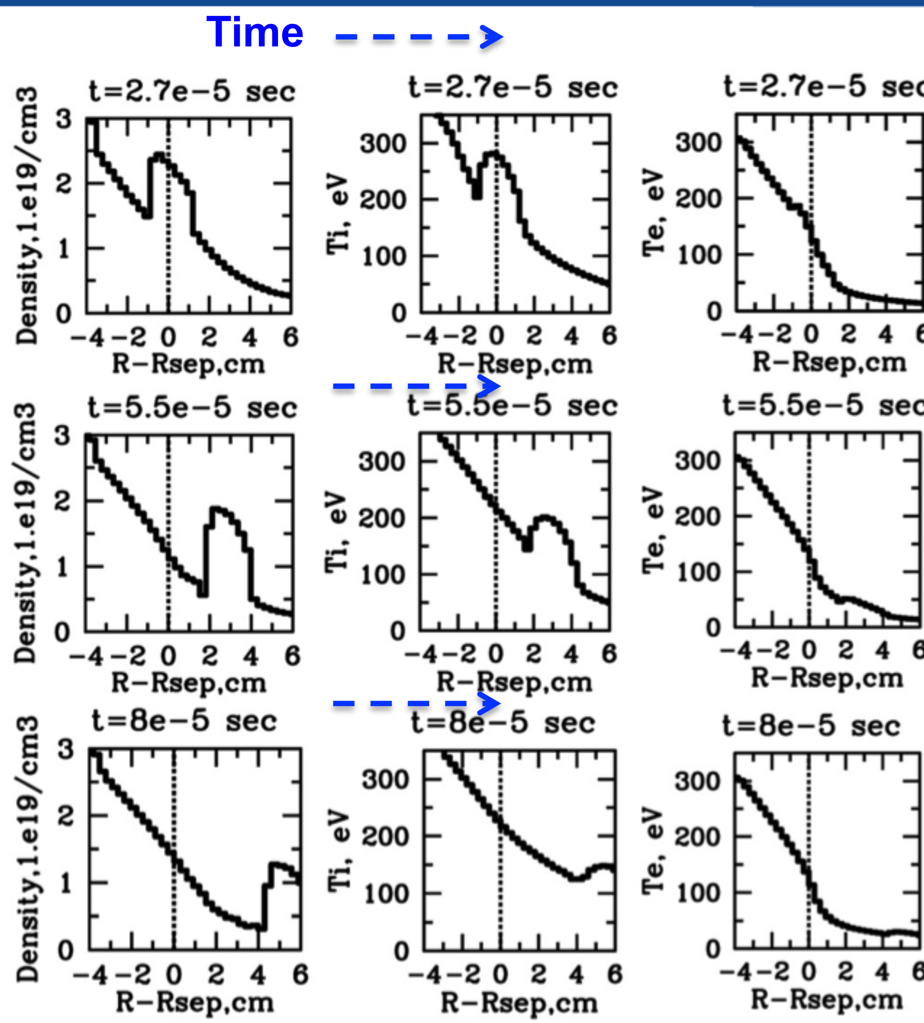
- **When poloidal beta > 1, pressure-driven flute modes can be unstable**
- **Estimated turbulent mixing greatly exceeds parallel ELM transit time**
- **Result should be broadening of ELM and 4 divertor-leg power sharing**

**White dash line is beta = 1 contour**



# 3. Plasma heat & particle fluxes observed to be carried by filamentary "blobs" added to UEDGE

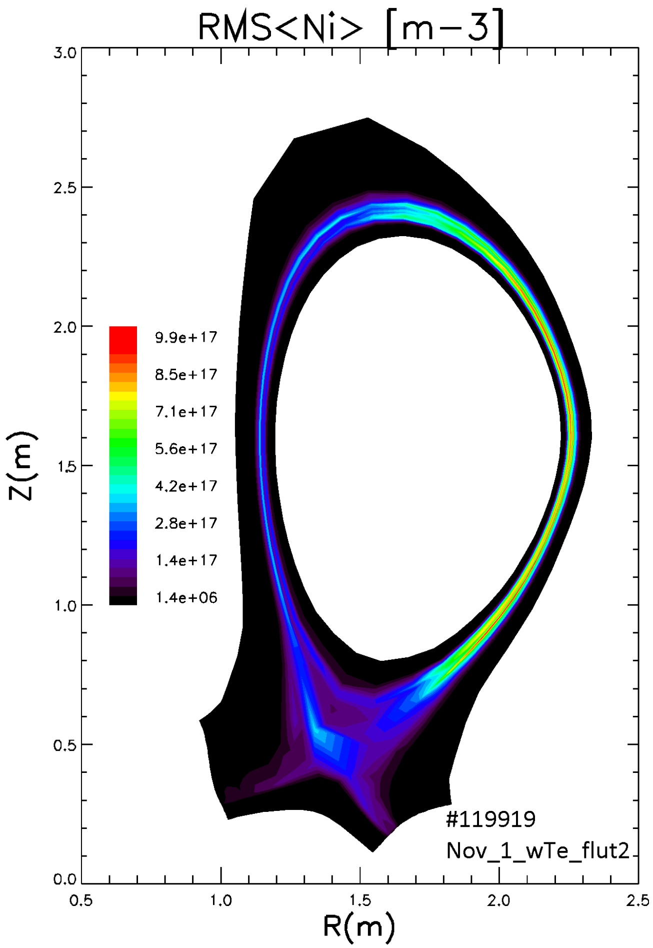


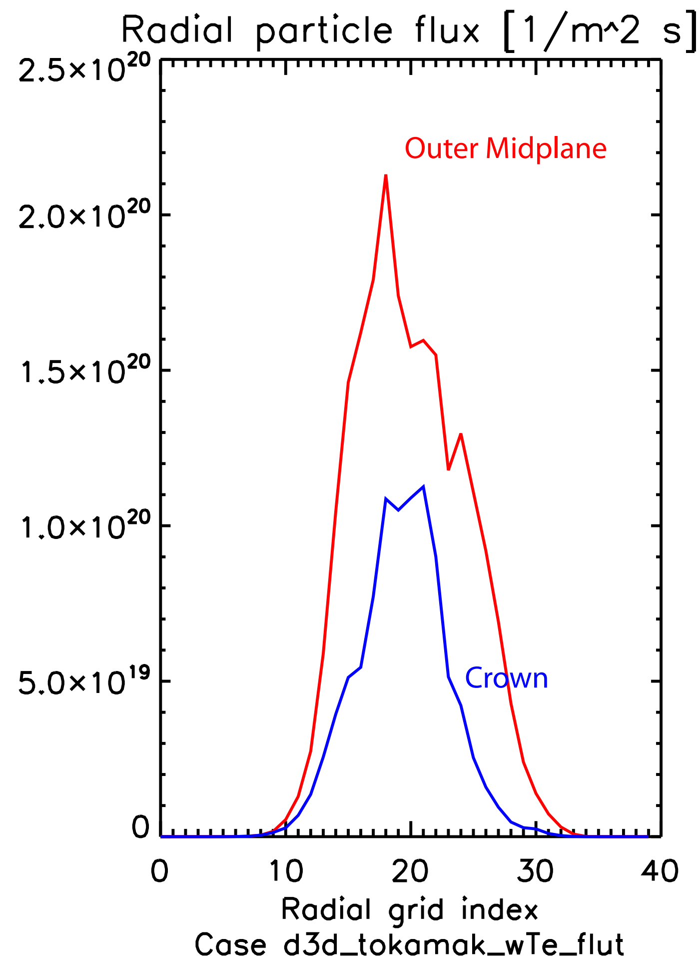




A. Pigarov, S. Krasheninnikov, T. Rognlien, Phys. Plasmas 2011; and submitted, 2012

# BOUT simulates 3D drift instabilities (filamentary “blobs”); energy flux includes convection/conduction components

### 3D BOUT density fluctuations




**B.I. Cohen, M. Umansky, APS-DPP, 2011**

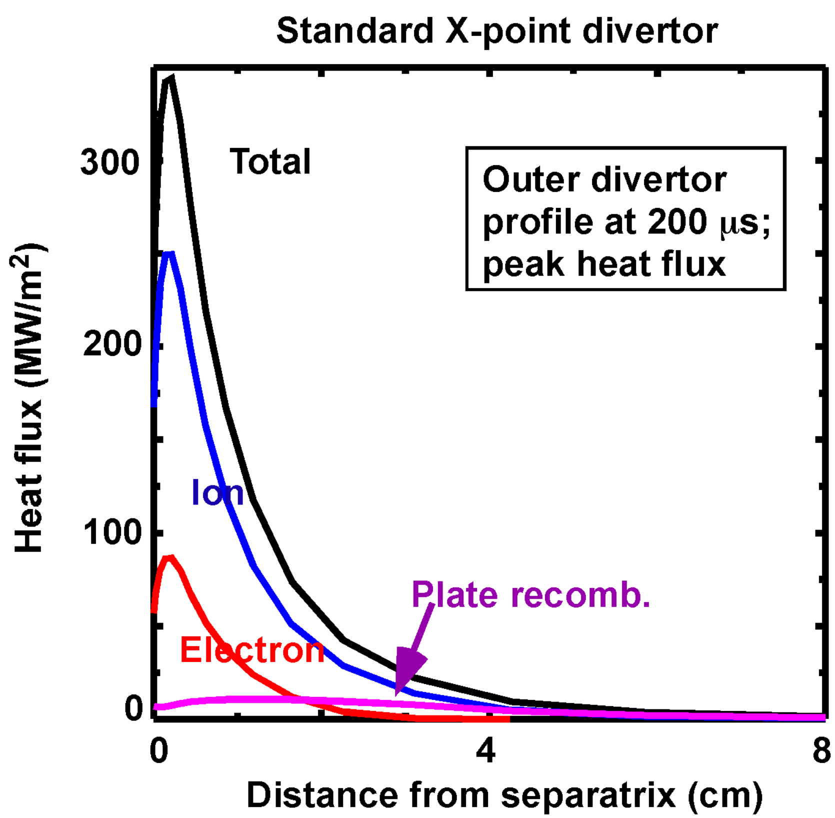
# Advances made in 3 plasma heat-flux modeling areas

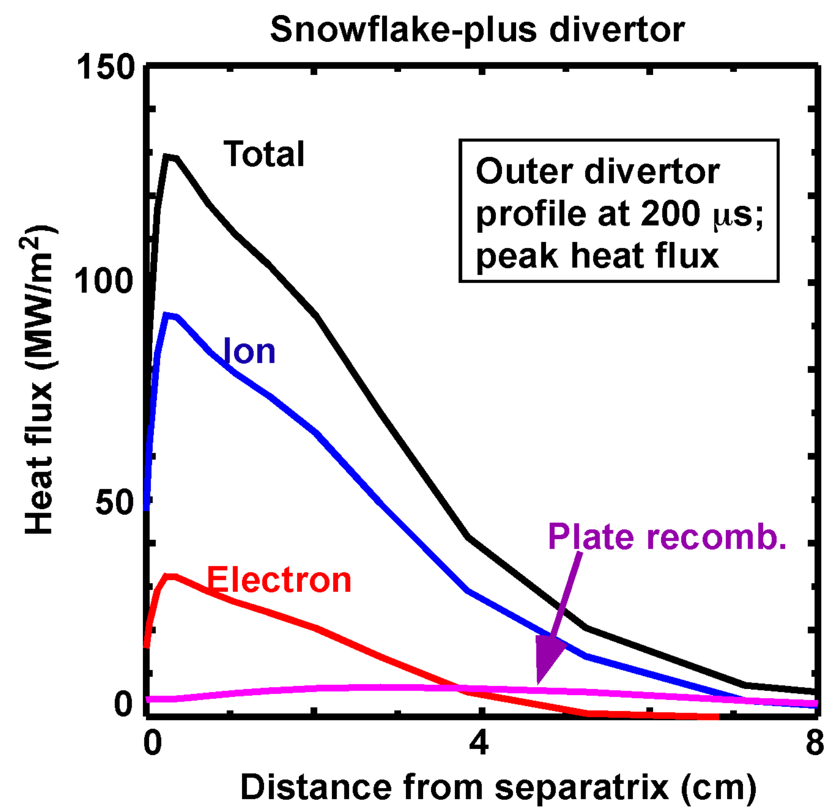
1. Lithium radiation from sputtered/evaporated at divertor plate could induce divertor plasma detachment

2. Snowflake divertors can significantly reduce ELM heat loads by null-point mixing and increased connection length

3. Advances made in blob model within UEDGE and beginning higher-fidelity 3D BOUT simulation of wall fluxes

# Even without null-point mixing, divertor heat profiles show lower peak heat flux for snowflake




**Combining null-point mixing and field-line length effect underway**



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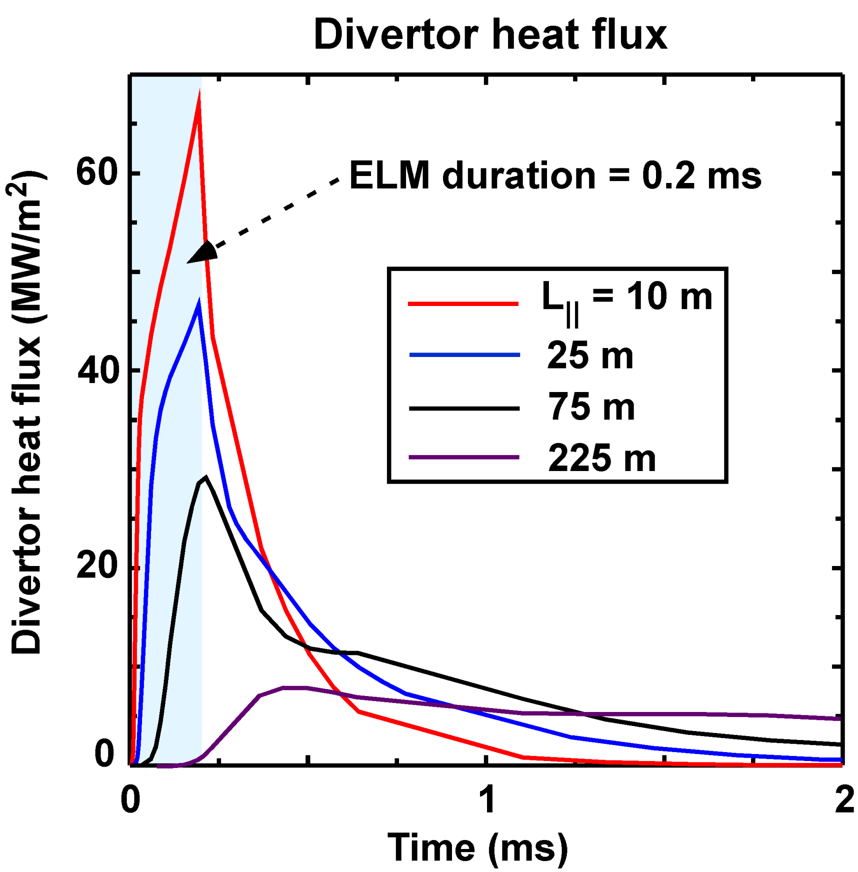
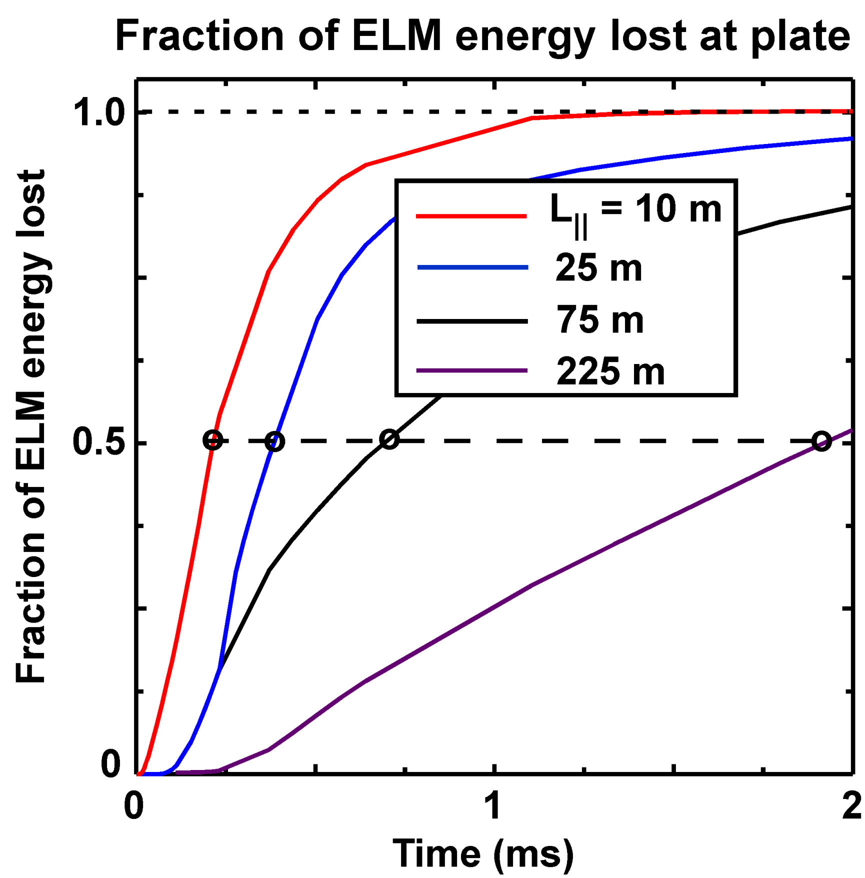
# 1D: Peak divertor heat flux is reduced as the column length increases – total energy is a constant




**Surface-temperature rise ~ $(T_{depos.})^{1/2}$ decreases by ~3**