Fluid Edge-Plasma Modeling Status*

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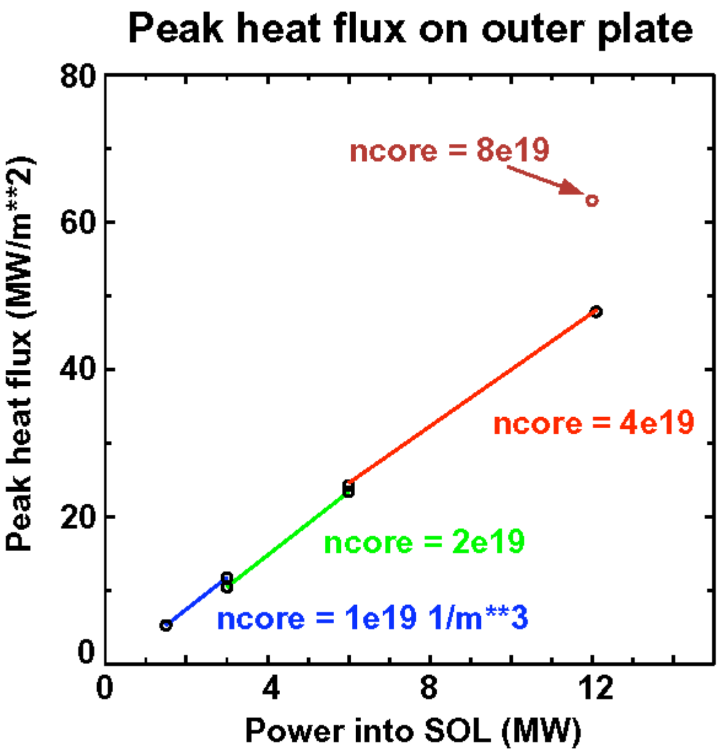
Outline

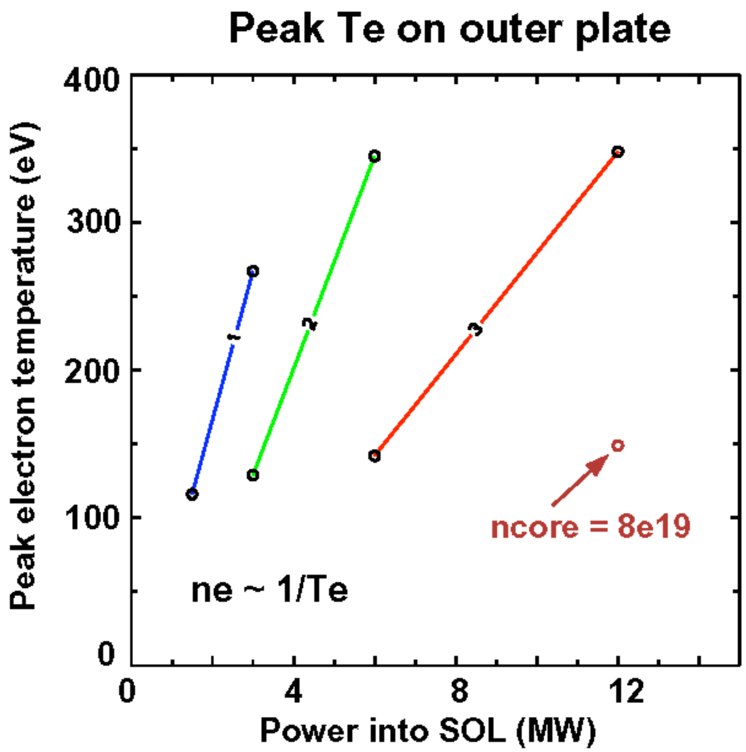
- **Edge-plasma response to NSTX lithium module**
- **Low-collisionality edge-plasma transport; $T_{i\perp} > T_{i||}$, magnetic trapping**
- **Temporal heat-flux pulses from ELMs**

Edge-plasma conditions have been calculated by UEDGE for various NSTX power levels

Various core-edge densities used as boundary conditions; n_sep ~ 0.6 ncore

Impurity radiation is neglected; module aligned to divertor plate





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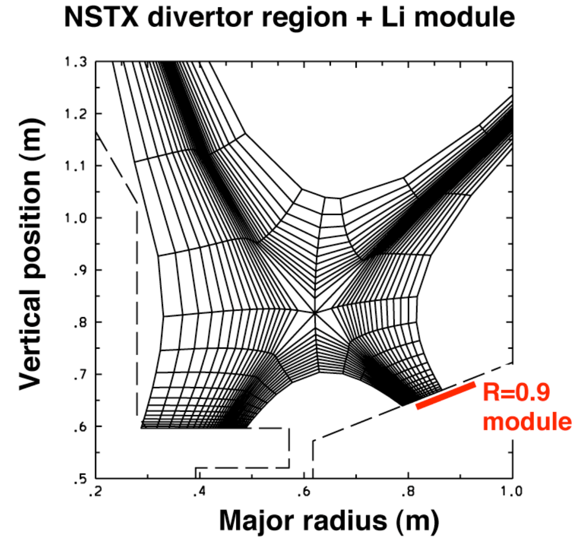
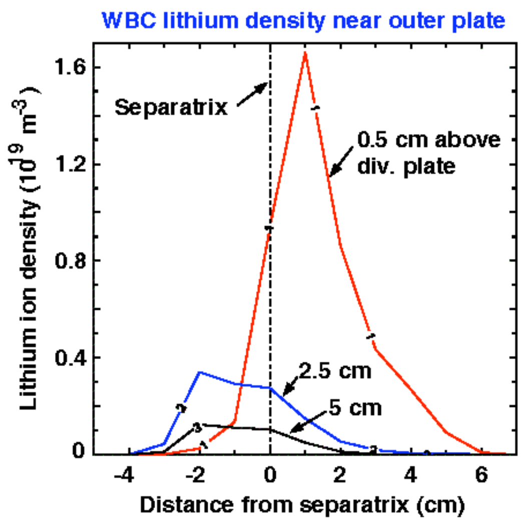
Lithium contamination of core from NSTX module modeled by coupling UEDGE & WBC

- Heat and particle flux to module computed by UEDGE
- Temperature rise of Li surface from Ulrickson's model
- Sputtering of Li from U. Ill. composite model
- WBC calculates lithium source near the divertor plate
- UEDGE uses this Li source to calculate lithium density throughout the edge region





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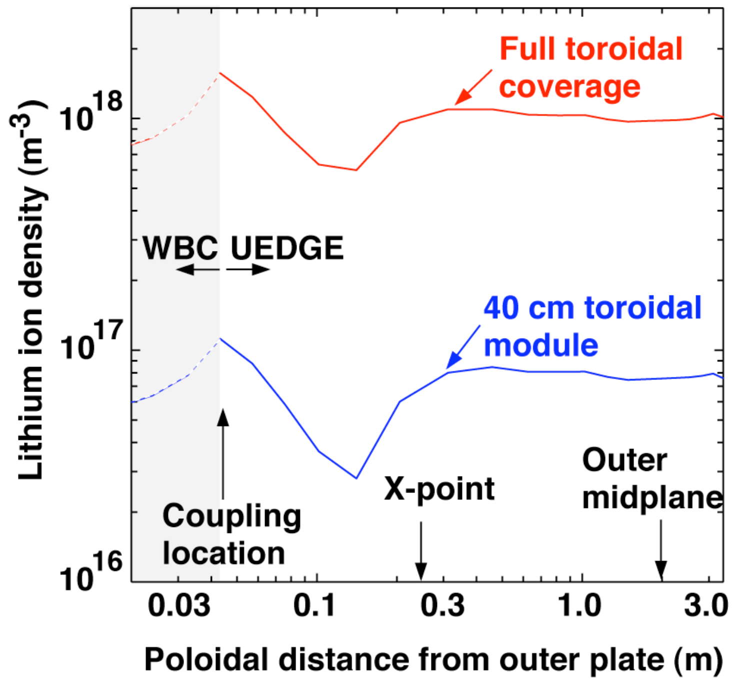
Core-edge lithium concentration from 40 cm module is ~0.2% for 6 MW case

- **UEDGE takes lithium ion source from WBC 5 cm above the plate**
- **Full SOL hydrogen/lithium plasma is then evolved to steady state with hydrogen core-edge density 4×10^{19}**
- **For the planned 40 cm (toroidally) module, only 0.2% Li at core edge**
- **For full toroidal coverage with 13 times more module gives 2.5% Li**
- **Even for full coverage, Li SOL radiation is only 6.4×10^{4} W, or 1% of core input power; thus, no need to iterate WBC/UEDGE here**

Lithium density vs. distance from plate along flux surface 0.3 cm in SOL



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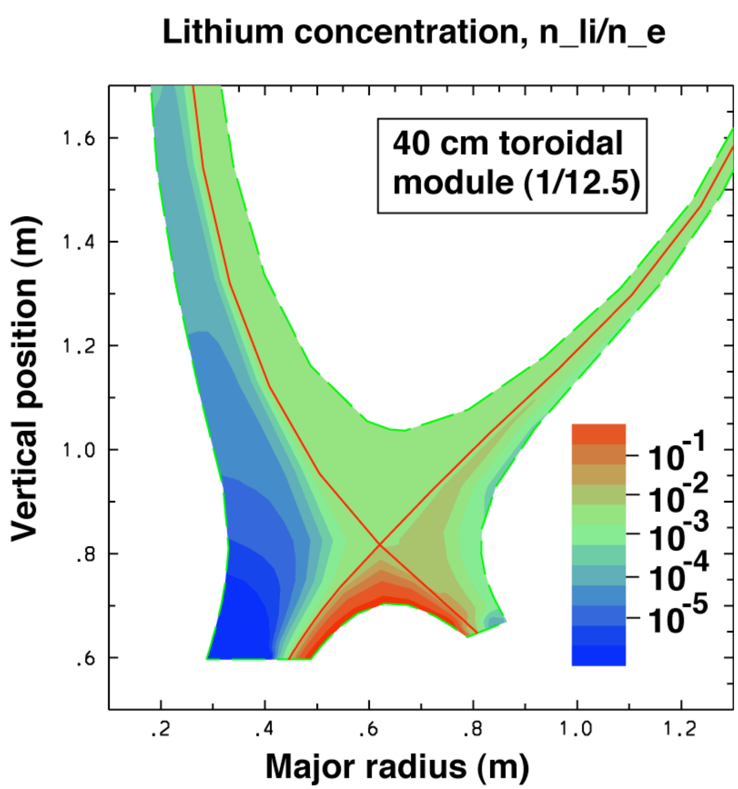
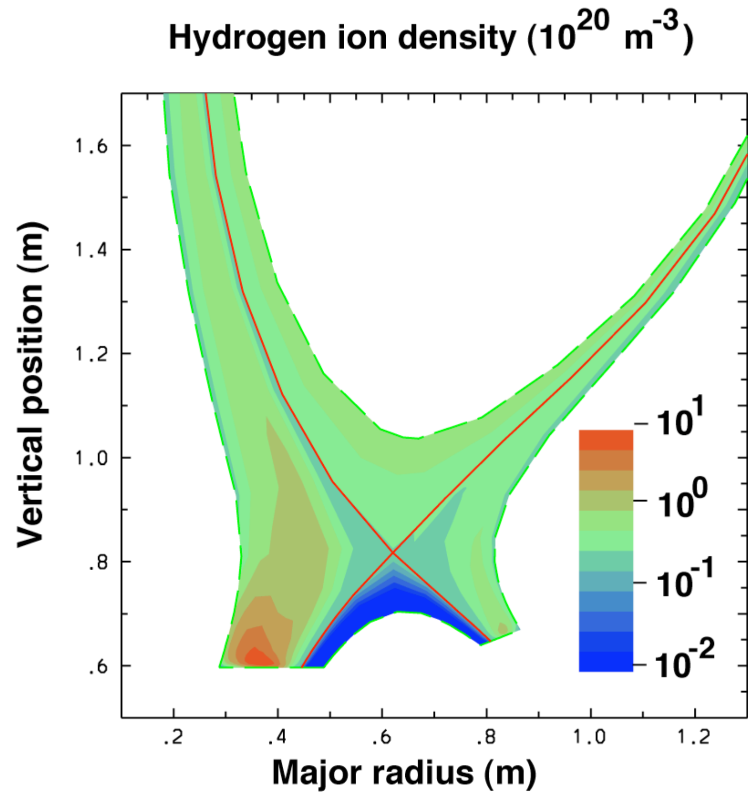
Lithium flows throughout the SOL, but core boundary concentration is only ~0.2%

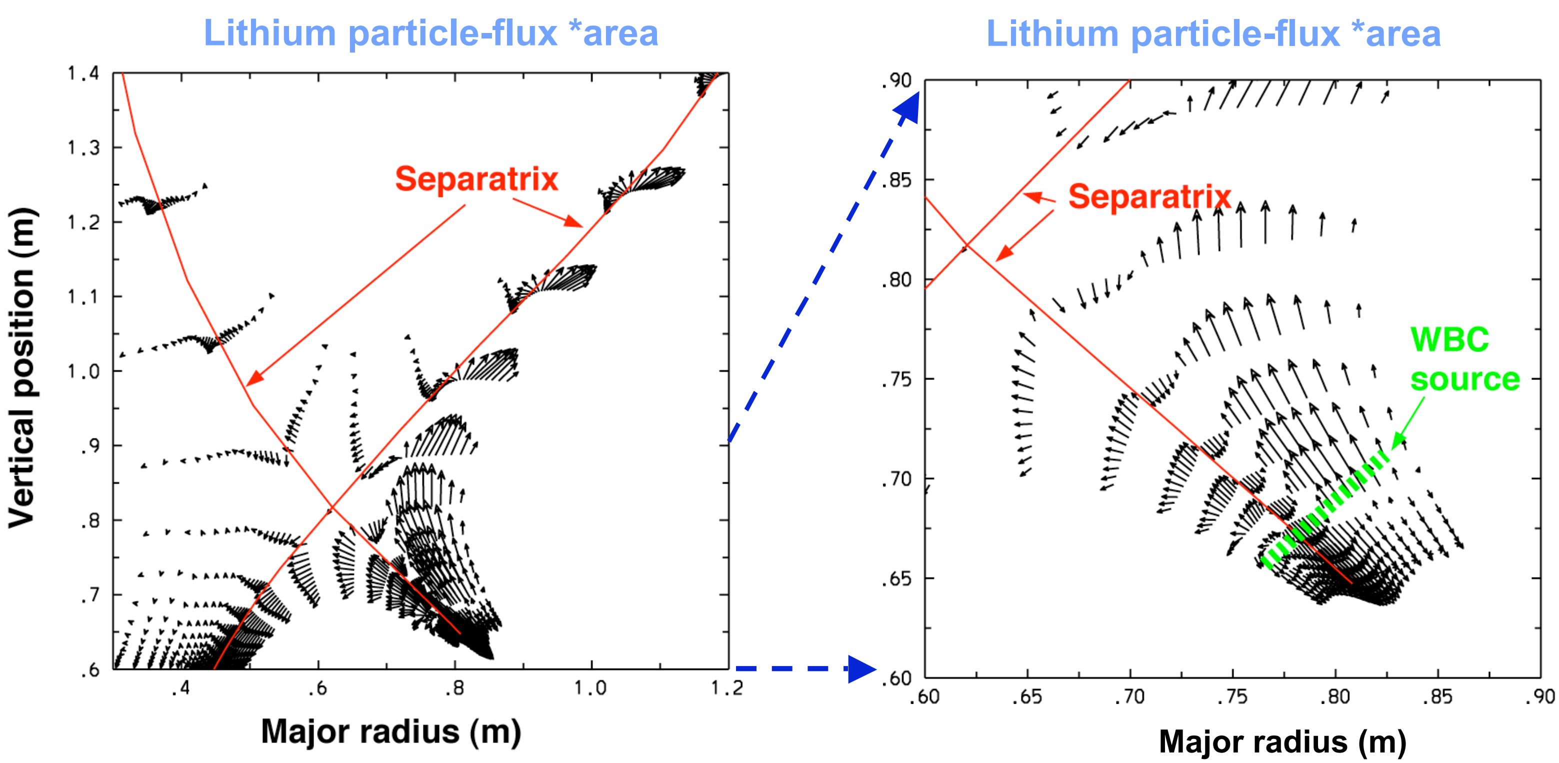
- **Lithium concentration peaks in outer SOL and private-flux region**





Large lithium flow away from divertor in the outer SOL region

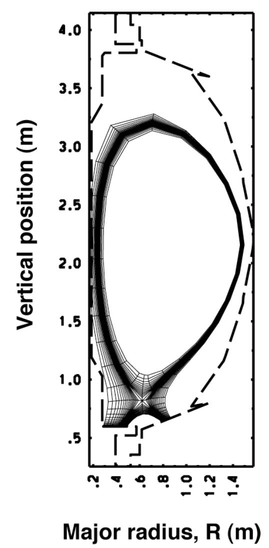
- **Lithium ions are lost to three main areas:**
  - **Outer divertor plate: 45%**
  - **Outer wall: 30%**
  - **Inner divertor: 25%**

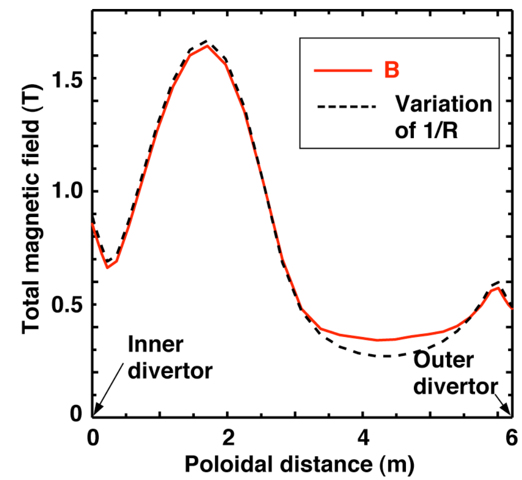


Spherical tori have large variations of B-field in the edge-plasma region that can effect flows

- Low recycling by lithium (or external divertor) leads to weaker collisionality via lower n_i and higher T_i
- Ions stay hotter and have slower relaxation times than electrons
- Ions acquire significantly different $T_\perp$, $T_{||}$ temperatures, giving $-(T_\perp - T_{||})\, dB/ds$ force on ions
- Impurity intrusion can be affected by the changes in the hydrogen edge plasma and their own T_i anisotropy

NSTX UEDGE mesh





We have completed the coding and initial debugging for separate $T_\perp$ and $T_{||}$ equations in UEDGE

Low density, high temperature for low recycling plasma limits single T_i assumption for all species

- **Previous SOL fluid transport modeling uses a summed ion energy equation based on high collisionality**
- **Low recycling leads to low collisionality**
- **Resulting lower impurity temperature can reduce influx to core**
- **Separate T_i equations have been implemented in UEDGE to assess this effect**

- ION PARALLEL MOMENTUM

$$\frac{\partial}{\partial t}(m_i n_i v_{i\|}) + \frac{\partial}{\partial x}\left(m_i n_i v_{i\|} v_{ix} - \eta_x \frac{\partial v_{i\|}}{\partial x}\right)$$
$$+ \frac{\partial}{\partial y}\left(m_i n_i v_{i\|} v_{iy} - \eta_{ya} \frac{\partial v_{i\|}}{\partial y}\right)$$
$$= \frac{B_x}{B}\left(-\frac{\partial p_p}{\partial x}\right) - m_i n_i n_n K_{cx}(v_{i\|} - v_{n\|})$$
$$- m_i n_e (n_i K_r v_{i\|} - n_n K_i v_{n\|})$$
$$+ n_i (T_{i\perp} - T_{i\|}) \frac{B_x}{B^2} \frac{dB}{dx}$$

with x, y the poloidal and radial directions, respectively.

- PERPENDICULAR TEMPERATURE EQN. REQUIRED

$$\frac{\partial}{\partial t}(n_i T_{i\perp}) + \ldots = -n_i \nu_T (T_{i\perp} - T_{i\|})$$

where the collision frequency is

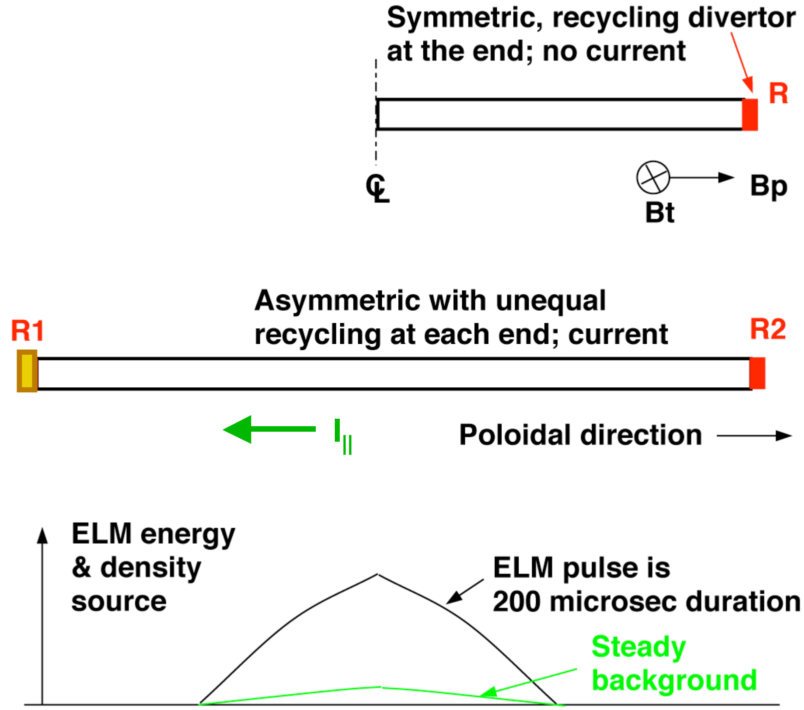
$$\nu_T = A_1 n_i \ln\Lambda \; Z^2 (m_p/m_i)^{1/2} \; T_i^{-3/2}$$

and $T_i = (2/3)(T_{i\perp} + T_{i\|}/2)$.

Time history and width of energy deposition on divertor surface helps determine damage

- Electron conduction time is fast
- Ion conduction and convection are much slower [$\sim(m_e/m_i)^{1/2}$]
- Experiments indicate substantial power comes out on the ion time-scale
- In/out divertor asymmetries and parallel currents play important roles in which plate receives most of the energy

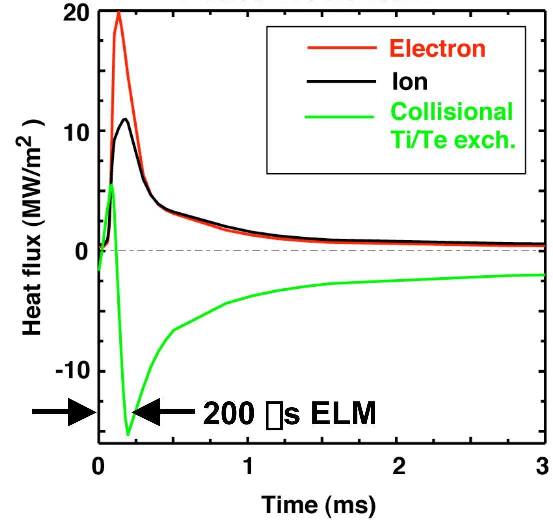
One-Dimensional SOL ELM Models



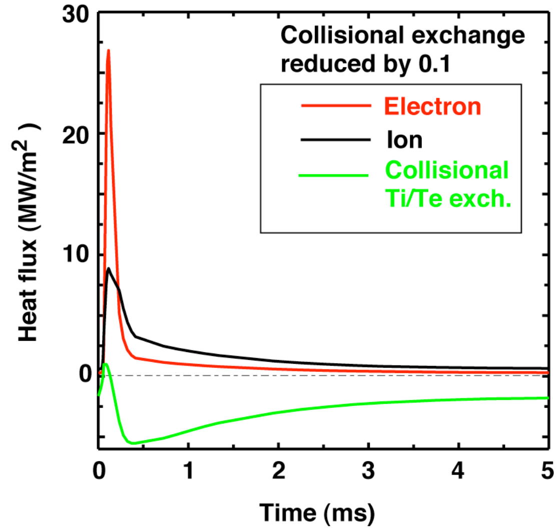
Significant ion ELM energy is transmitted to the electron channel via Coulomb collisions

- UEDGE model is used in 1D and 2D with kinetic corrections for heat transport & sheath loss
- ELM is simulated by energy and density injected at midplane for 200 μsec
- For the heat flux at the plate, a fast electron response is seen, but a second electron response from (T_e-T_i) collisional coupling is observed
- Plate power deposition time is several times the input duration

Plate heat flux



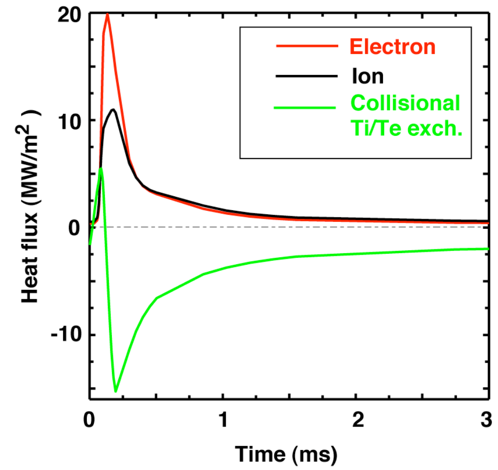
Base case



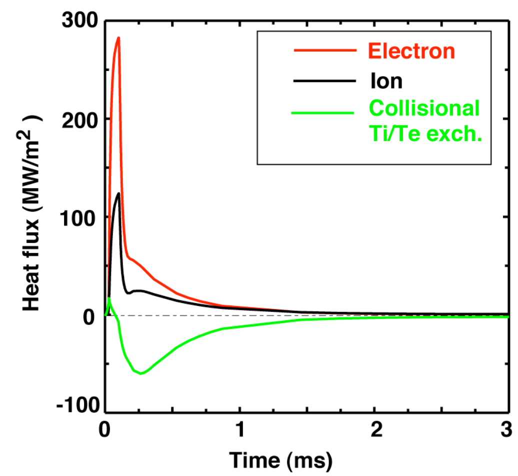
Collisional coupling remains large for high power ELM

- Increasing ELM energy more clearly separates the electron and ion time scales

- The second-stage slower electron responses is caused by $T_i \rightarrow T_e$ coupling



Base case



x6 ELM energy

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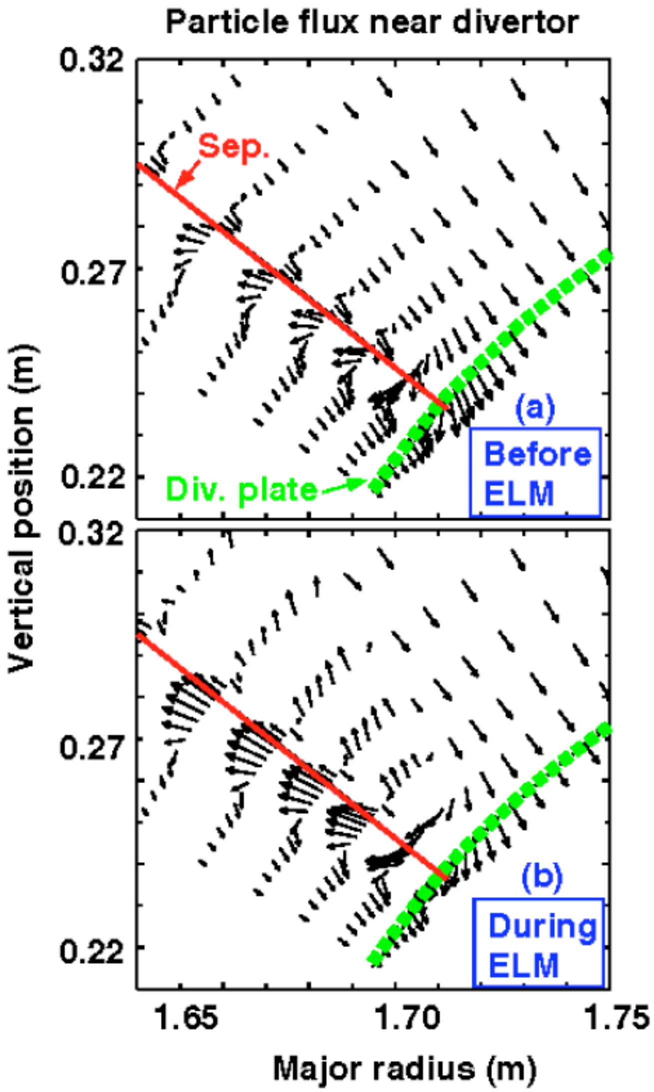
Time-dependent ELM modeling is being done by UEDGE

- UEDGE considers SOL currents and ExB drifts
- Characteristic two-time-scale seen: electron conduction and ion flow
- Parallel currents can dominate heat flow, causing outboard or inboard peaking, depending on current direction
- Can currents be manipulated to advantage?



ExB drift causes strong reverse-flow near separatrix

Summary

- **Lithium intrusion to the core is only ~0.2% for the 40 cm NSTX module**

- **Ion temperature anisotropy and magnetic trapping being included in fluid edge-plasma transport modeling - important for low recycling**

- **ELM heat fluxes are strongly influenced by electron/ion thermal coupling and parallel currents**