A mechanism for large divertor plasma energy loss via lithium radiation in tokamaks

T.D. Rognlien[1], E.T. Meier[1,2], M.E. Rensink[1], D.P. Stotler[3], and V.A. Soukhanovskii[1,2]

[1]Lawrence Livermore National Laboratory

[2]On assignment at PPPL with the NSTX-U team

[3]Princeton Plasma Physics Laboratory

54th Annual Meeting of the APS Division of Plasma Physics

Providence, RI

Oct. 29 – Nov. 2, 2012

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Security, LLC, Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-PRES-584993

Overview - paper PP8.00031

1. Motivation & previous results with “old” lithium atomic rates (~ 2000)
2. Compare (very) new rates (Stotler/Rensink, Oct. 2012) & “old”
3. Simulation results with new rates and with elec. density dependence
4. Conclusions and next steps

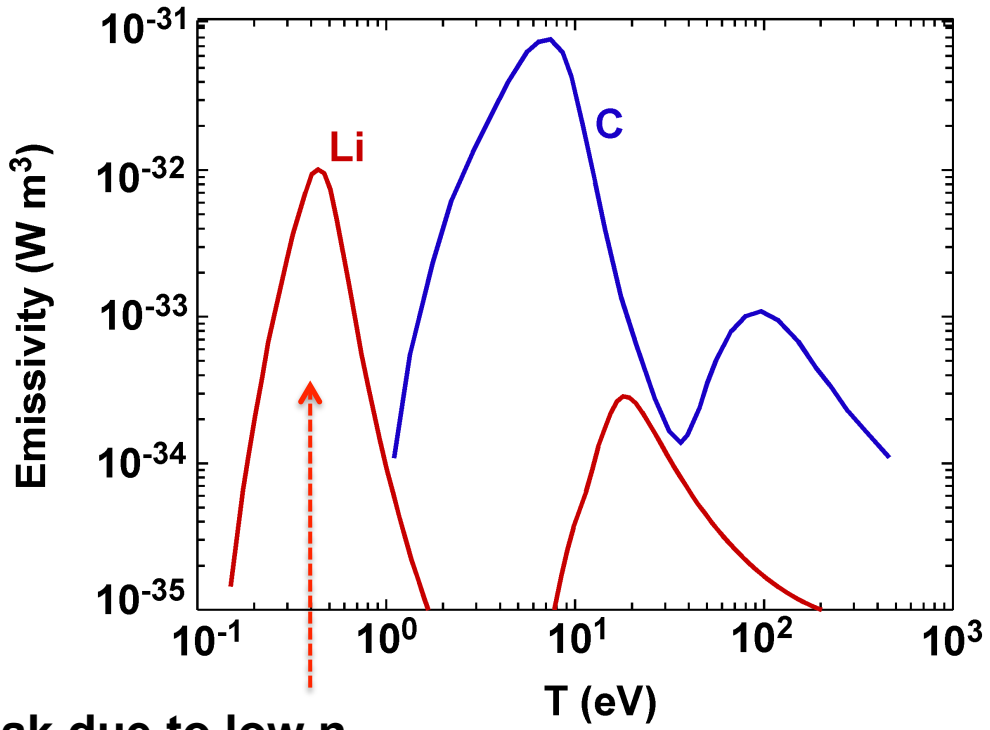
Li has been used successfully in NSTX & other tokamaks; does it just change surface properties or do more?

1.

Main question: Can Li radiation be important for power balance?

For ADPAK data with no transport, charge-exchange

Radiated power = emissivity * $n_e n_{i,z}$

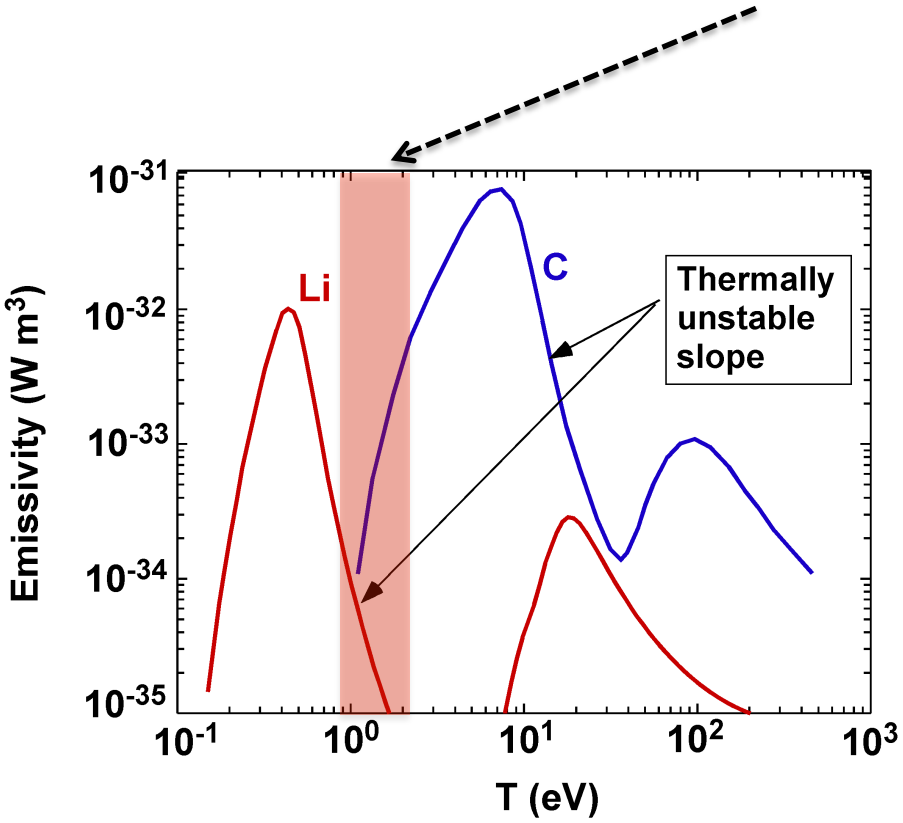


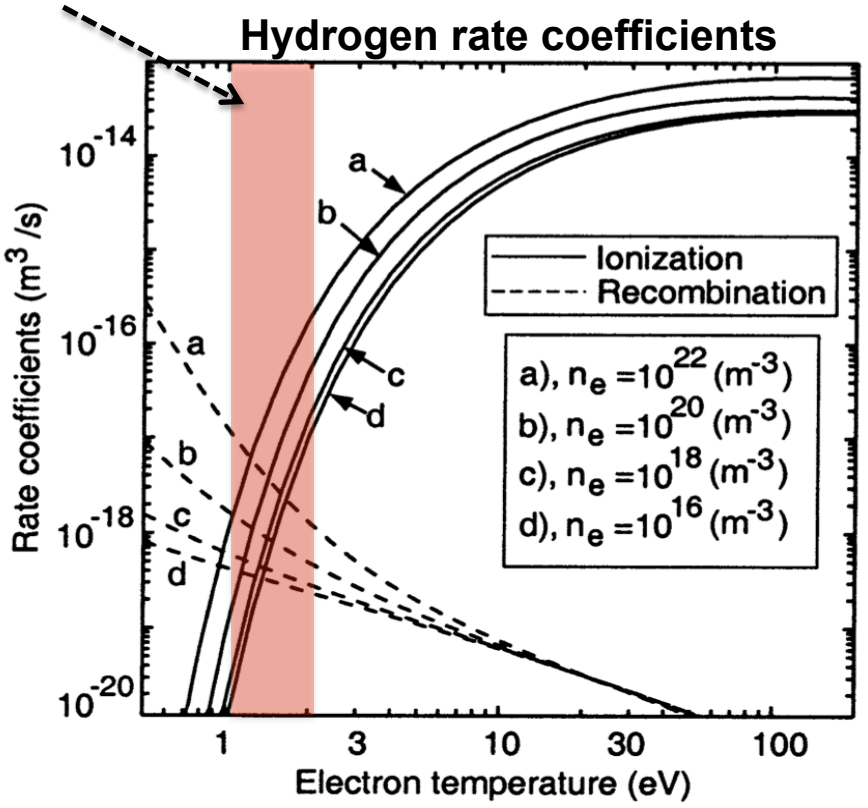
Peak due to low $n_{i,z}$

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

1.

Typical detached plasma T_e range



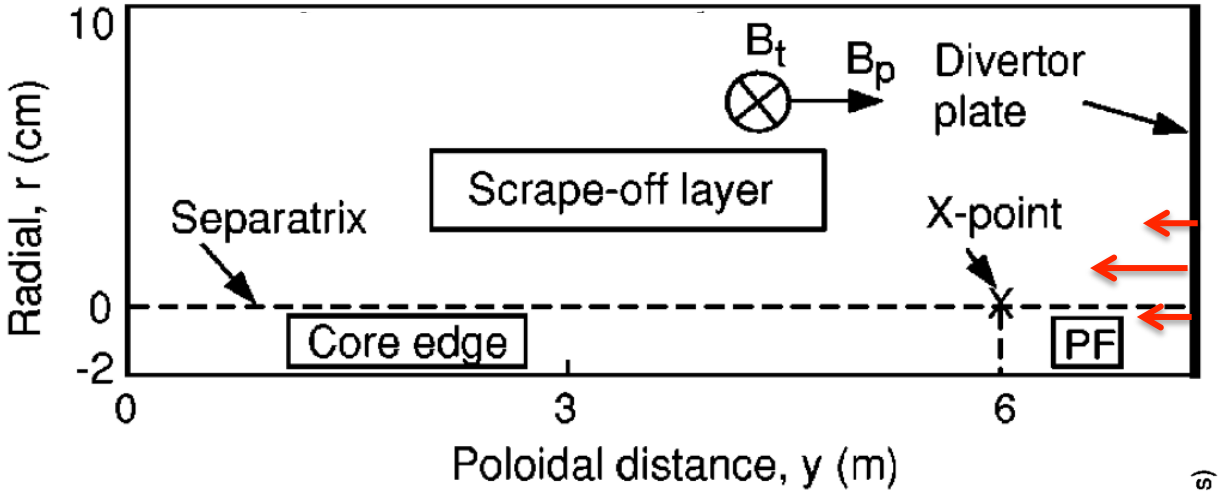


Radiated power: $P_{rad} \sim n_e \times n_{i,Li} \times Emiss$

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

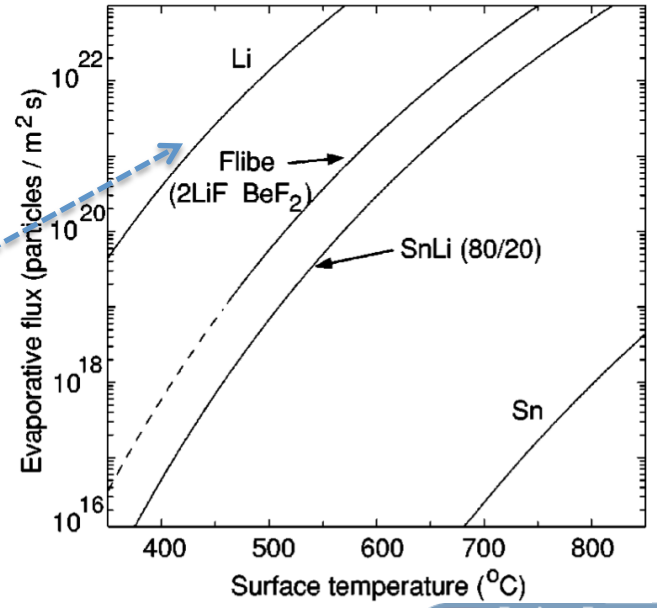
1.

Here only consider effect of Li on detachment; large flux expansion of snowflake can add synergistic effect



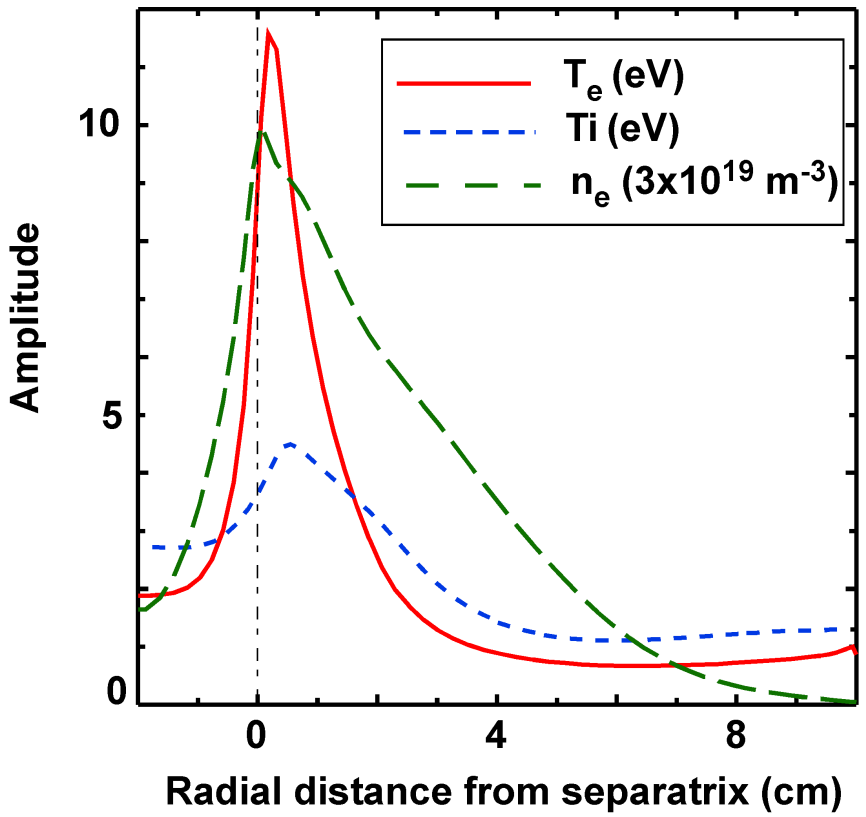
Simulations to follow use 2D UEDGE with non-coronal, multi-charge-state lithium and deuterium

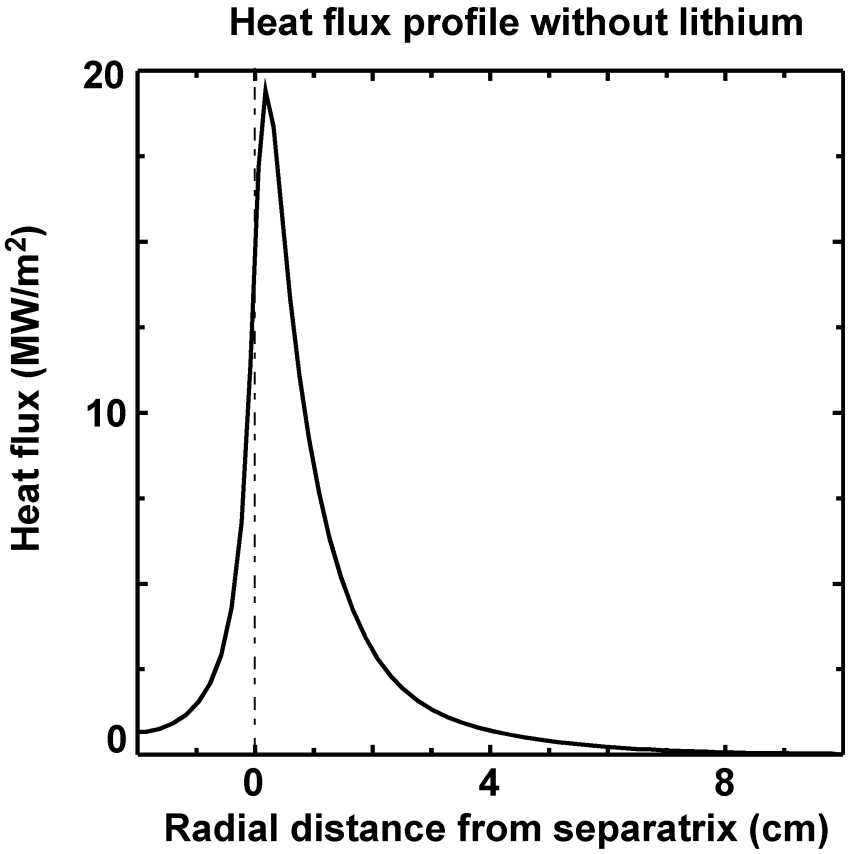
Li evaporative flux is strong function of surface temp.



Plasma profiles on the divertor plate without lithium injection are peaked near the separatrix strike point

1.



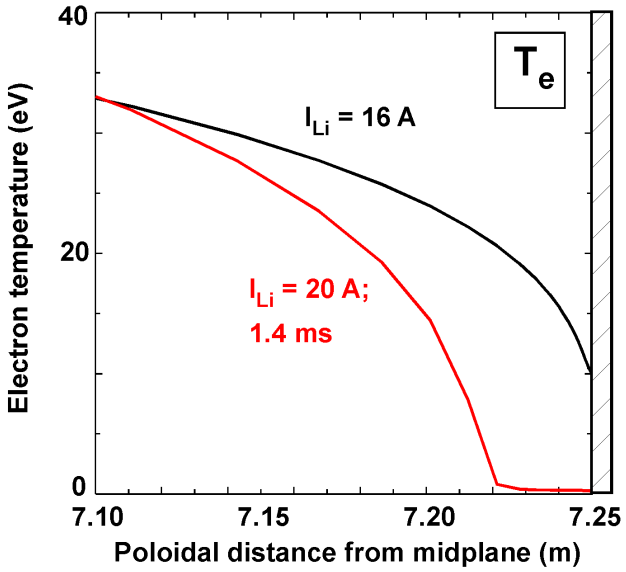


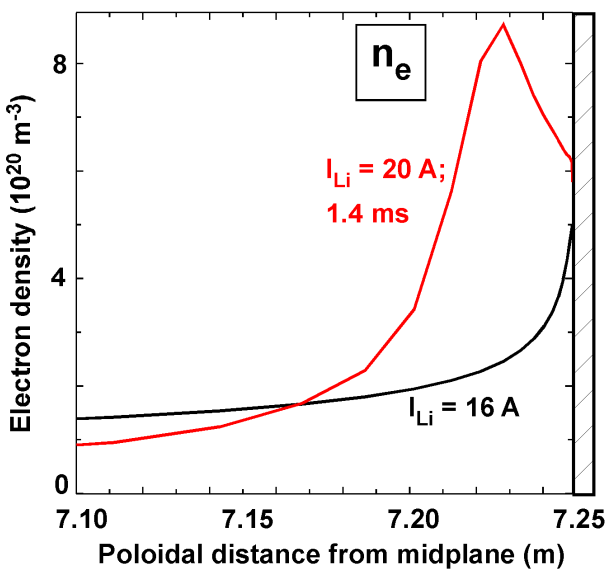
Increasing Li plate source from 16 A to 20 A yields detached divertor in ~1 ms; not steady-state

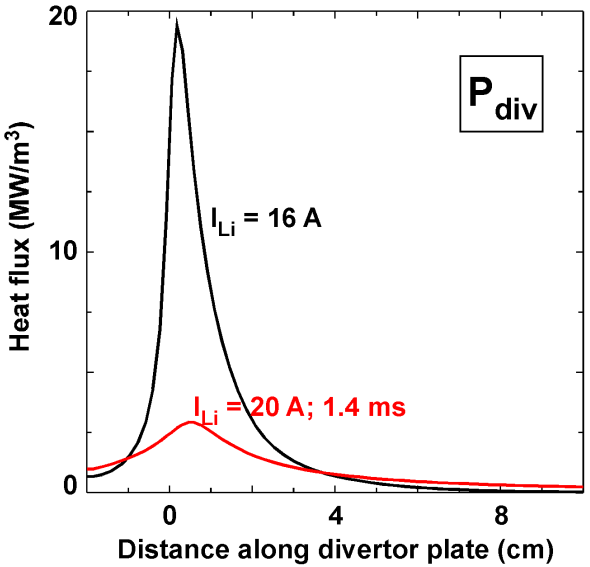
1.

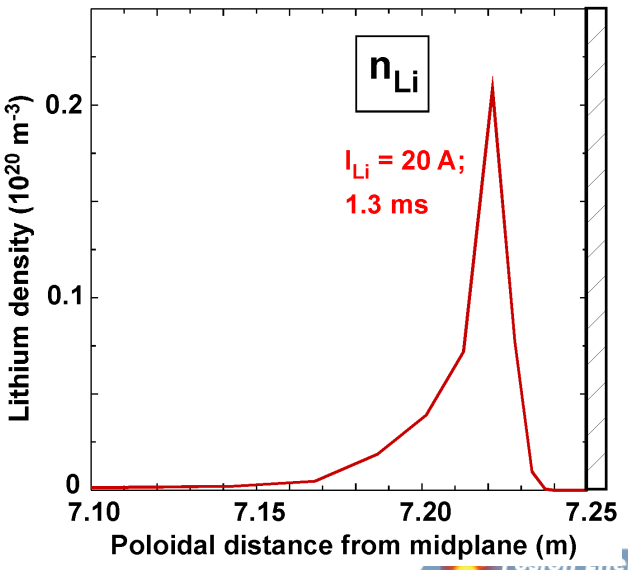
UEDGE simulation with ~2002 ADAS rates, no n_e dep.

Comparing 16 A & 20 A cases shows radiated Li power increases ~50 times - about matches input power









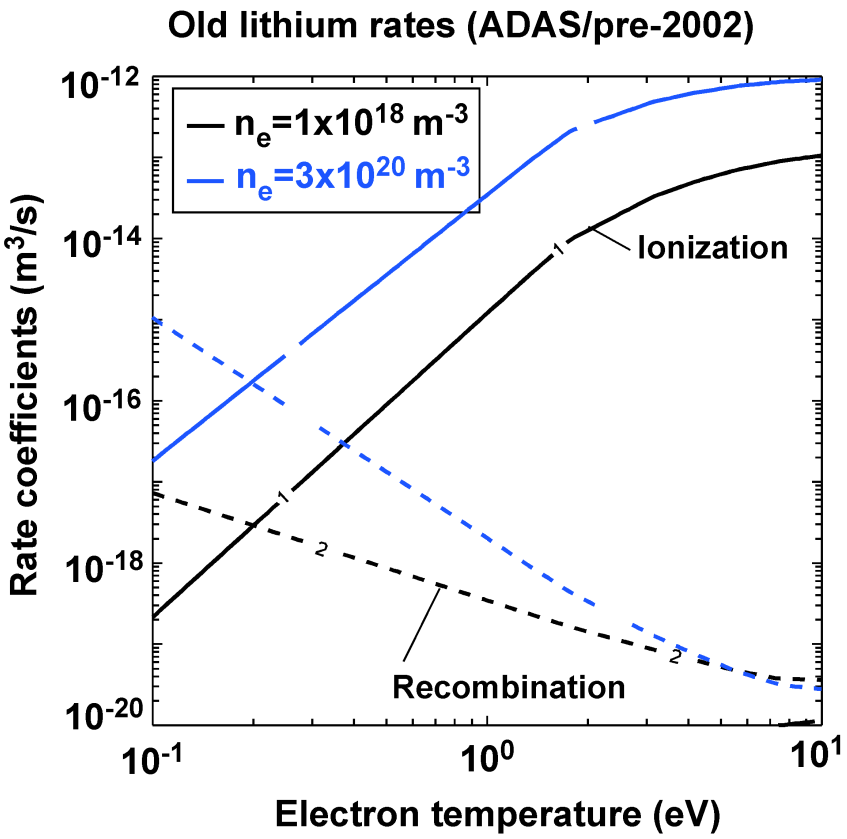
Because of "2001" coarse representation of low T_e data, new b2frate tables were constructed from ADAS (Stotler)

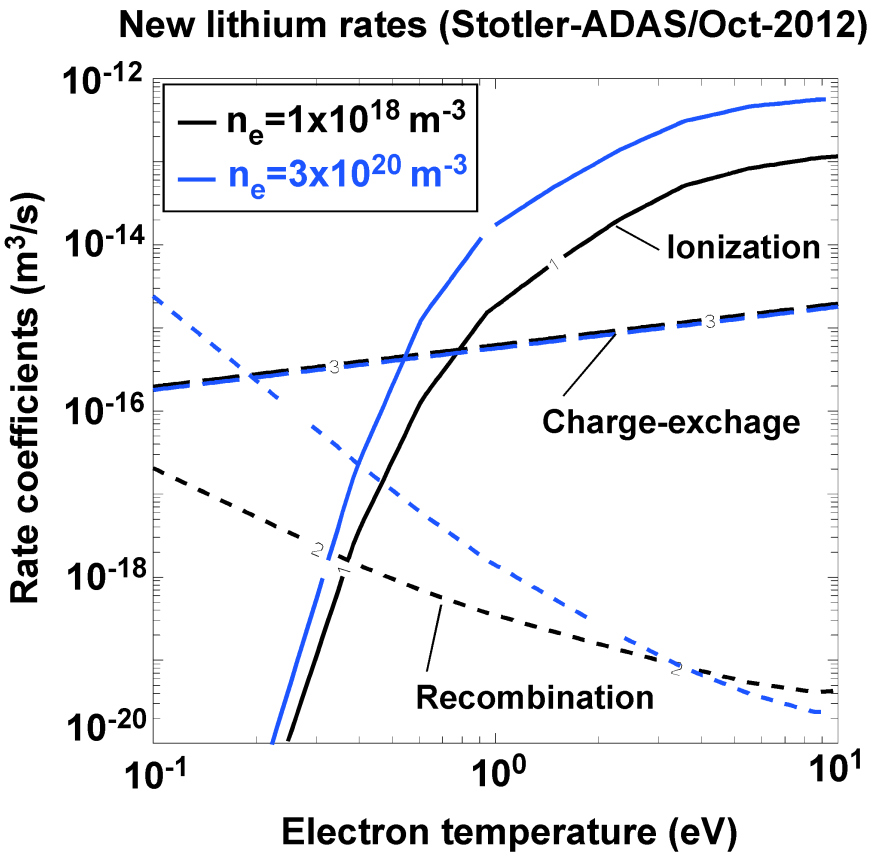
2.

- New (~2012) ADAS rate tables have been interpolated with finer resolution for T_e < 1 eV into B2FRATE file format used by UEDGE. The Li CR model: S.D. Loch et al., At. Data Nucl. Data Tables 92, 813 (2006)
- Also clarified line-radiation, bremsstrahlung, and binding energy components of electron energy lost
- Modified UEDGE to account for binding-energy contributions to electron energy loss for the new rate tables listing only radiation components
- Charge-exchange data included

Ionization and charge-exchange rates at low T_e show largest difference between "2001" and "2012" rates

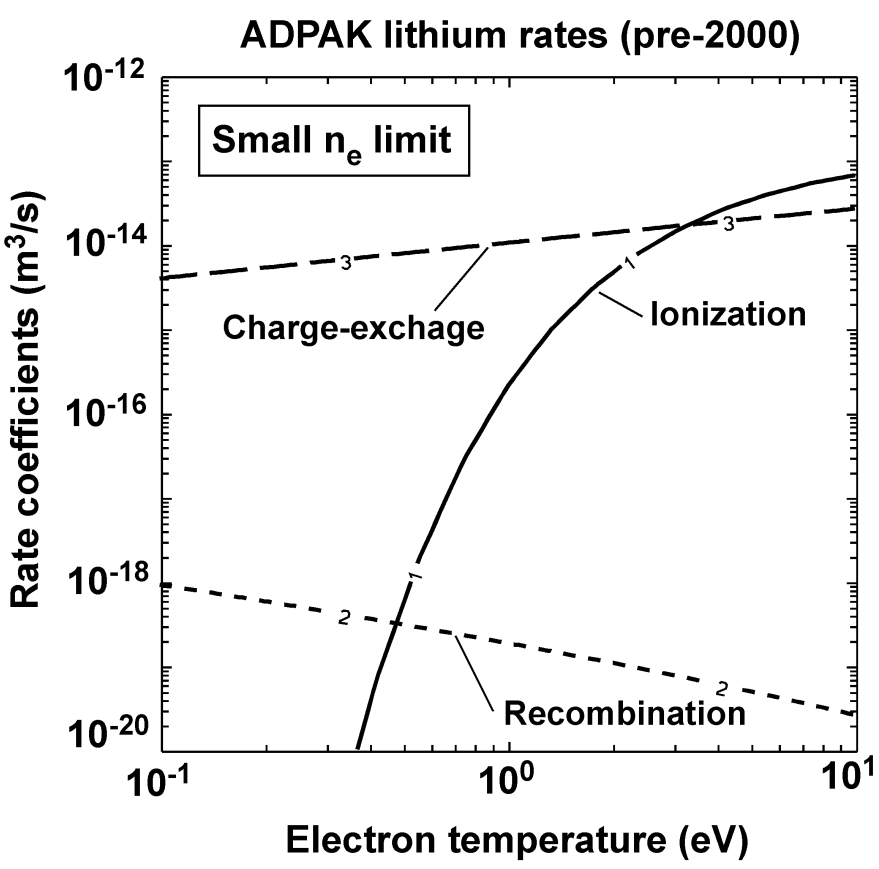
2.

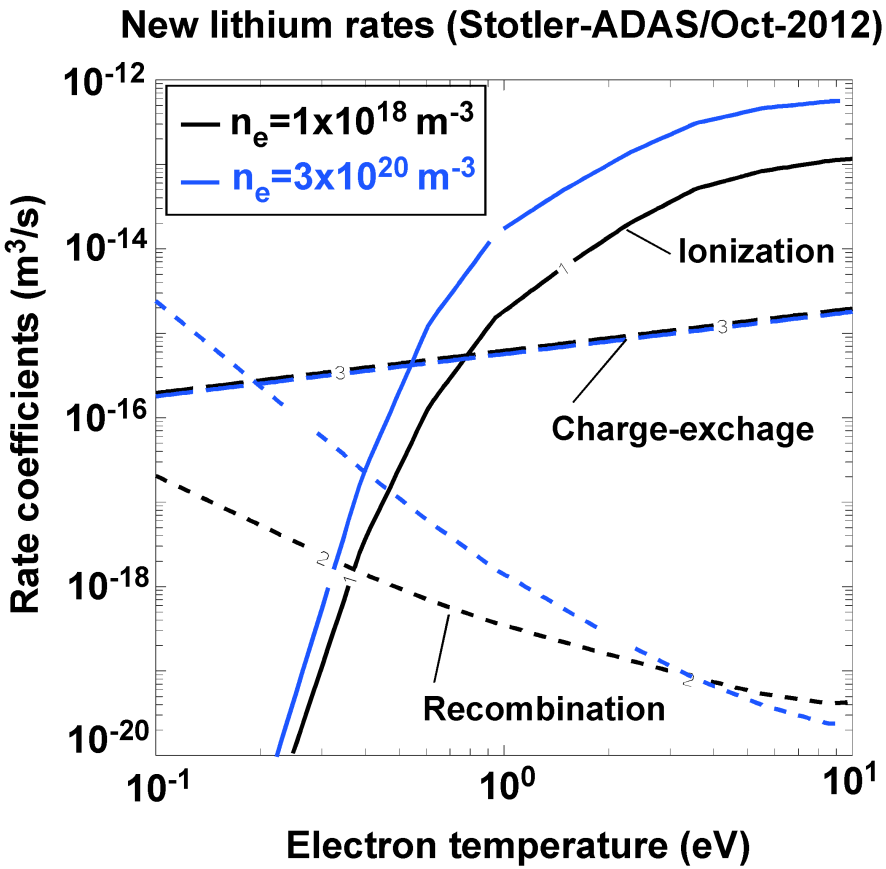




Previous ADPAK rates used by UEDGE in ~2001 also had larger charge-exchange & smaller ionization

2. **ADPAK rates used in Rognlien, Rensink Phys. Plasmas 2002 Li study**



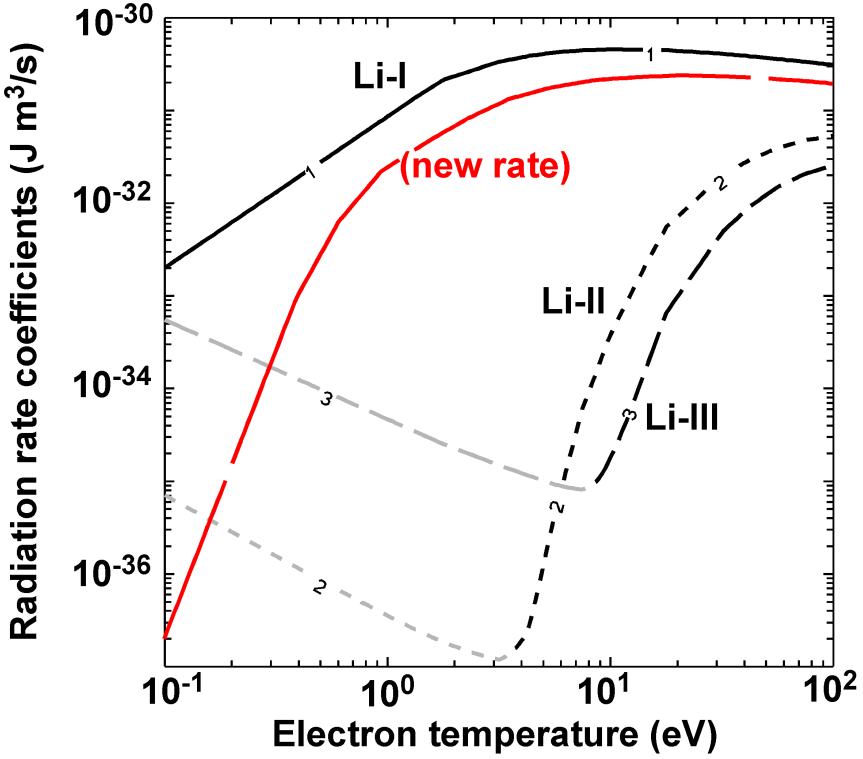


Line radiation + bremsstrahlung also show largest difference at very low T_e

2.

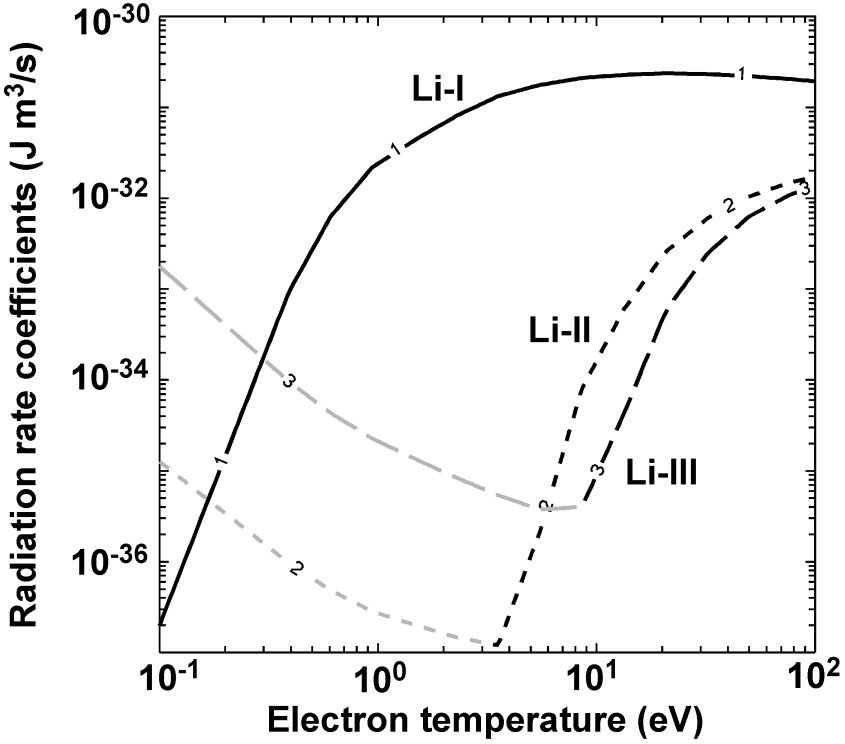
Radiation rate coeff. - old ADAS (<2002)

(Actual radiation depends on charge-state distribution, i.e., n_{Li0}, n_{Li+1}, n_{Li+2}, and n_{Li+3})



Radiation rate coeff. - New ADAS (Stotler, Oct.-2012)

(Actual radiation depends on charge-state distribution, i.e., n_{Li0}, n_{Li+1}, n_{Li+2}, and n_{Li+3})



Repeating simulation with new rates, but no n_e dep. shows qualitative behavior, but need much larger I_{Li}

3.

UEDGE simulation with ~2012 ADAS rates, no n_e dep.

- **Now transition from attached to detached plasma takes place between 200 and 400 A of Li input current from plate, where of rate tables (~2001) gave a transition between 16-20 A**

UEDGE simulation with ~2012 ADAS rates, with n_e dep.

- **Now transition from attached to detached plasma takes place between 2000 and 4000 A of Li input current from plate, where of rate tables (~2001) gave a transition between 16-20 A**

Caution: these results are very new and need further vetting/diagnosing

As rate tables are better verified, they will be applied to actual NSTX discharges; an example by E.T. Meier

4.

In this session, see:

<u>PP8.00028 (this session):</u> E.T. Meier et al.,

"UEDGE modeling of NSTX and NSTX-U snowflake divertor configurations"

Conclusions

1. Lithium radiation from sputtered/evaporated at divertor plate has the potential to induce divertor hydrogen plasma detachment

2. Detachment occurs abruptly with increased Li influx

3. Quantitative comparisons have hampered by previous lack of well-characterized Li rates for low T_e

4. Newest rates indicate that a substantial increase in Li neutral flux from the divertor is needed to detach the plasma than found earlier; results are surprisingly sensitive to modest rate changes – need further vetting

5. Will continue to verify new lithium rate tables to enable direct comparisons with NSTX data