NSTX Oak Ridge National Laboratory Supported by U.S. DEPARTMENT OF ENERGY Office of Science

Preliminary Results from the 2010 Joint Research Milestone (XP 1043)

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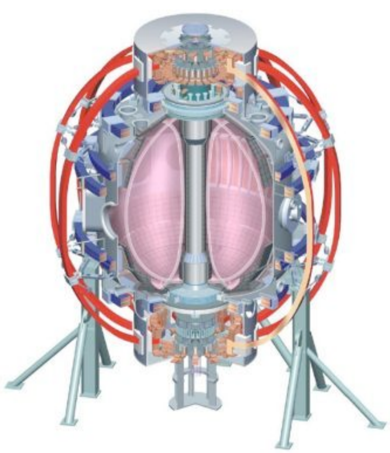
NSTX 2010 Results Review
Princeton Plasma Physics Laboratory
Nov 30 – Dec 2, 2010



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U Quebec

FY2010 JRT on SOL heat transport included analysis of data, development of two-color IR camera, and modeling

- Goal: An understanding of the **heat transport in the tokamak scrape-off layer (SOL) plasma**
- Data set from old XP's (434, 814, 816, 923) for non-lithiated discharges
  - Good Ip, PNBI and flux expansion scans (Mix of low and high δ)
  - Presented at PSI and IAEA (TK Gray) – see these talks for data
- Dual Band IR Camera technique developed (AG Mclean)
  - Presented at HTPD conference
- XP 1043: **LARGE** dataset obtained with Dual Band IR camera
  - Mostly high triangularity
  - Some preliminary analysis presented at APS-DPP (TK Gray)
- Modeling performed with SOLT (Myra) and XGC-0 with neoclassical transport (Park, Pankin, Chang)
- Final Report Completed and available online

Complete data set of SOL heat flux widths at 2 different lithium evaporation rates between discharges

<u>300 mg Dataset</u>

- Measure heat flux footprints at high δ
  - I_p scan 0.7 – 1.3 MA
    - PNBI = 4 MW and Bt = 0.45 T
  - NBI Scan 1 – 6 MW @ 1 MW increments (I_p = 0.8 and 1.2 MA)
  - B_t Scan 0.33 – 0.55 T
    - I_p = 0.8 MA, P_{NBI} = 4 MW
- δ_r^{sep} scan
  - High δ: δ_r^{sep} = 0, -2.5, -5, -7.5, -1 cm
  - Low δ: δ_r^{sep} = -0.7, -1.3 cm
- C-MOD/DIII-D Similarity shape
  - $0.72 \leq I_p \leq 0.8$ MA
- Camera resets complicating analysis

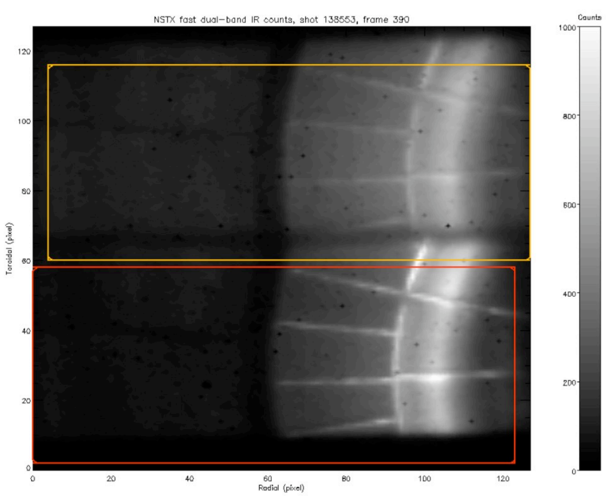
<u>150 mg Dataset</u>

- Measure heat flux footprints at high δ
  - I_p scan 0.7 – 1.3 MA
    - PNBI = 4 MW and Bt = 0.45 T
  - B_t Scan 0.35 – 0.55 T
    - I_p = 0.8 MA, P_{NBI} = 4 MW
  - Some comparison of 3 and 4 MW discharges
- δ_r^{sep} scan
  - High δ: δ_r^{sep} = 0 and -2 cm
- C-MOD/DIII-D Similarity shape
  - I_p = 0.75 MA, P_{NBI} = 2 and 3 MW
- Analysis is on going

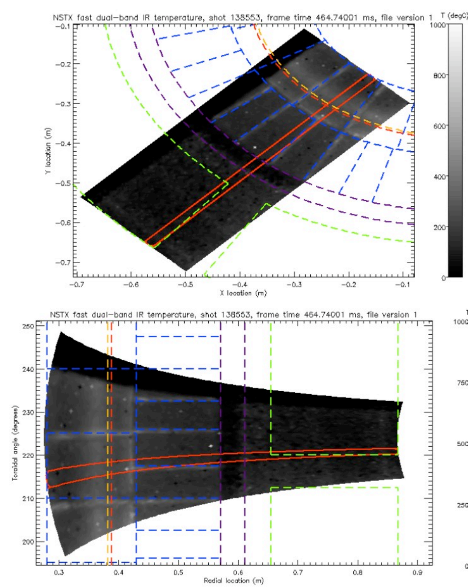
FIRNACE: Fast Infrared Research on NSTX by Automated Code Evaluation

- Integrates all aspects of dual-band IR analysis
  - Optical channel alignment (must be carried out manually once for each shot)
  - Application of temporal and spatial calibration
  - Temperature calibration of emission intensity ratios (blackbody *ex-situ* plus LLD *in-situ*)
  - Calculation of heat fluxes (accomplished with both 1-D Carslaw & Jeager, and 2-D THEODOR models, each for 1-D radial and 2-D area
    - Significant (2-3X) drop in q [MW/m2] using THEODOR
- ~150/1200 of 2010 campaign shots planned for analysis are complete
- XP1000/1002/1041 in October currently in progress

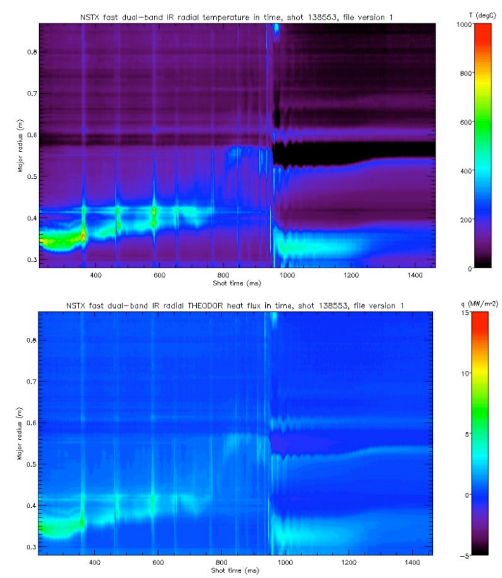
Raw dual-band data



Aligned, calibrated

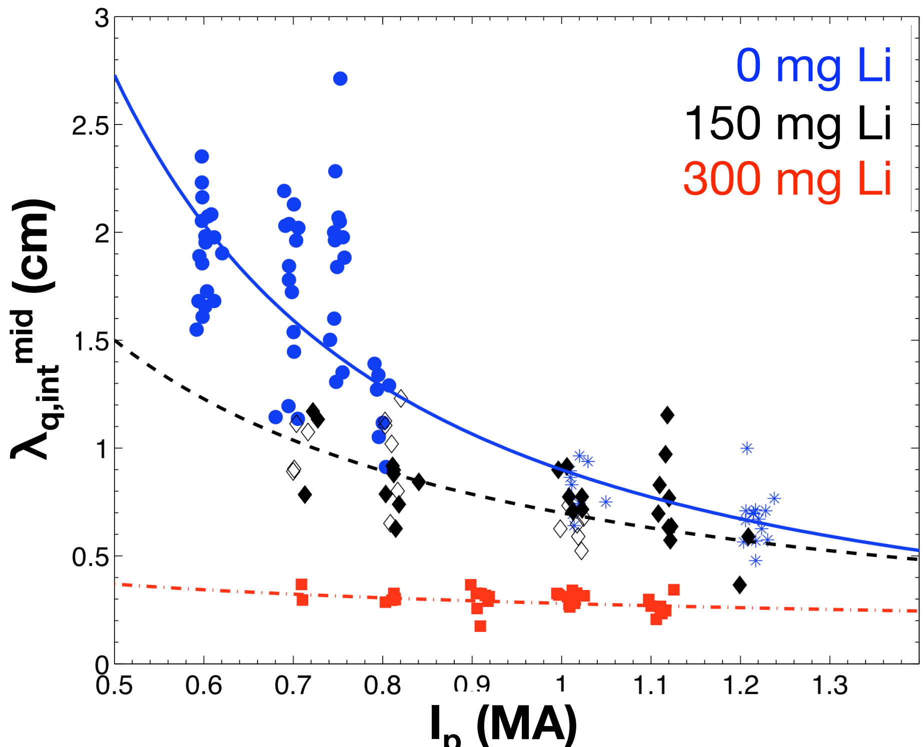


T(R,t), q(R,t)

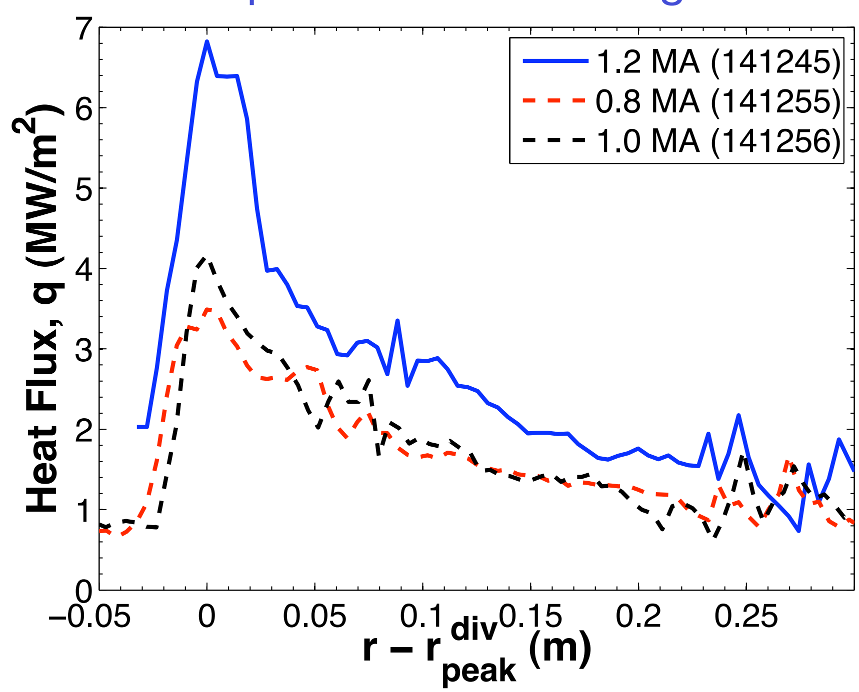


Inverse I_p dependence of SOL widths observed in discharges with lithium wall coatings

- Outer divertor peak heat flux increases with I_p, because both λ_q^{div} and λ_q^{mid} contract
  - Using integral definition of λ_q^{mid}
  - Data from 150 mg lithium
  - Consistent with no lithium results

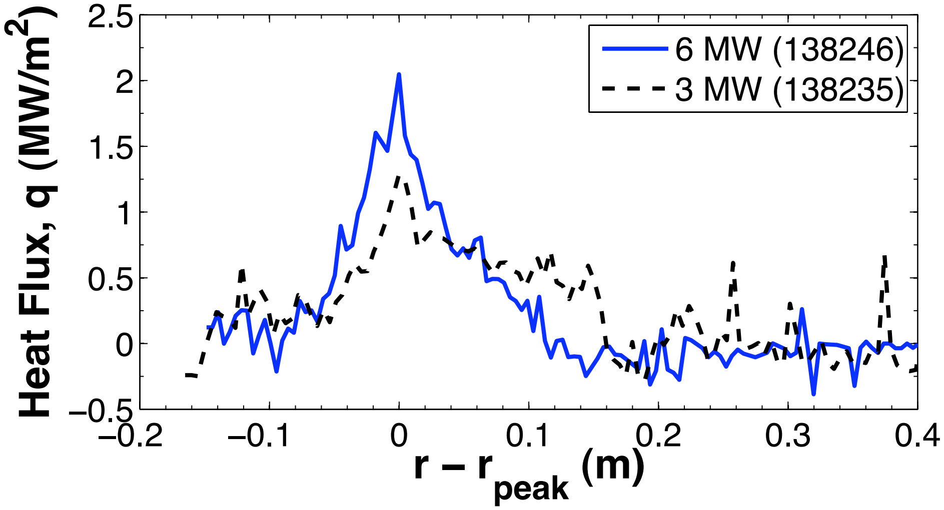


- λ_q^{mid} @ 300 mg Li shows a further contraction
  - Only single band data so far
- Preliminary analysis of $I_p \geq 1.2$ MA data suggests a flattening of the trend in λ_q^{mid}
  - Requires further investigation



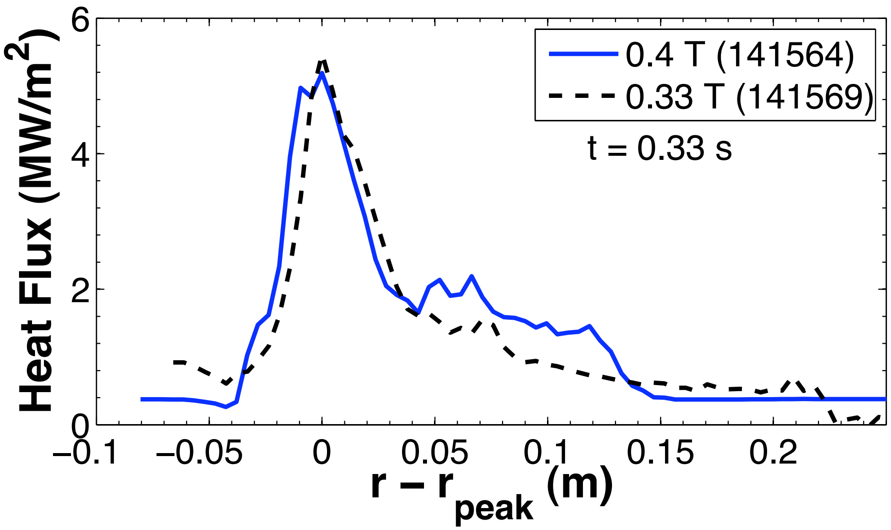
SOL width independent of P_{SOL} and B_t

- Outer divertor peak heat flux increases with NBI power



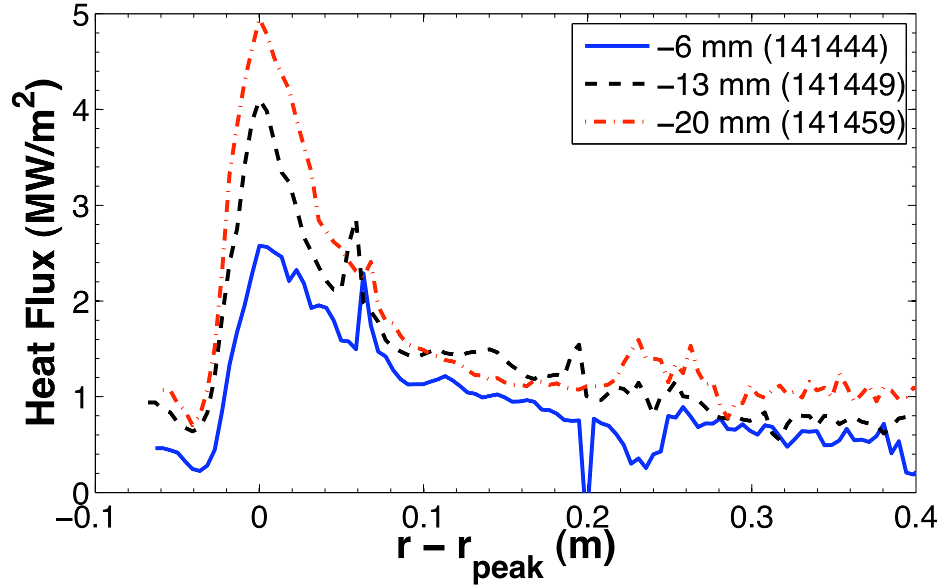
- λ_q^{div} and λ_q^{mid} stay constant
  - Consistent with no lithium results

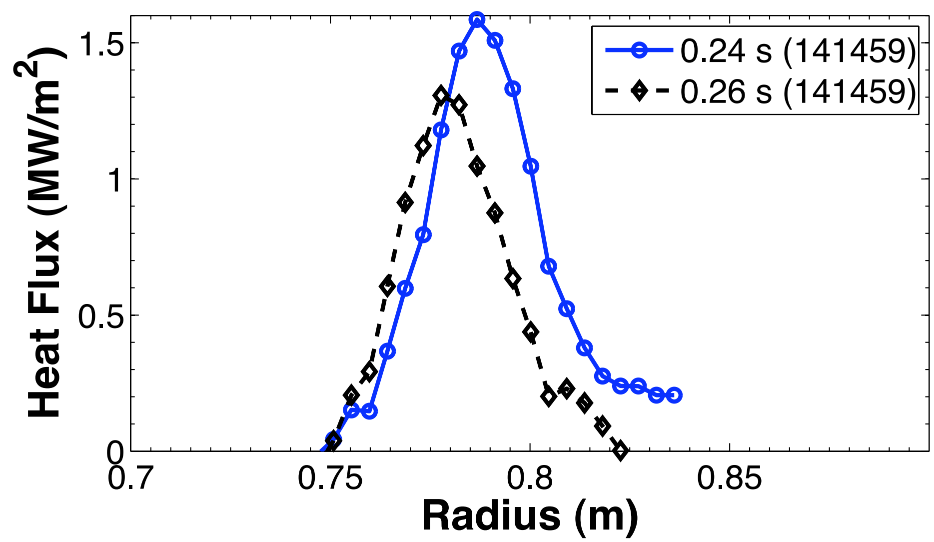
- Outer divertor peak heat flux, λ_q^{div} and λ_q^{mid} insensitive to B_t



SOL width contracts modestly with increasing $|\delta_r^{sep}|$

- Preliminary analysis shows that λ_q^{div} contracts modestly with increasing $|\delta_r^{sep}|$
  - Profiles are chosen to emphasize the trend
- In the C-MOD/DIII-D shape with low δ and low f_{exp}
  - Heat flux profile narrow and Gaussian
  - λ_q^{mid} (t=0.24s) = 0.79 cm
    λ_q^{mid} (t=0.26s) = 0.64 cm
  - Similar to high δ results
    - I_p = 0.75 MA, 0.7 ≤ λ_q^{mid} ≤ 1.2cm





Summary

- XP 1043 collected an extensive amount of data on heat flux widths over a wide variety of parameters
  - Including 2 different LiTER rates
- Preliminary analysis is in qualitative agreement with non-lithium discharges
- λ_q^{mid} scales as ~ I_p^{α}
  - 0 mg Li: $\alpha = -1.6$
  - 150 mg Li: $\alpha = -1.1$
  - 300 mg Li: $\alpha = -0.4$
- α decreases with increasing lithium deposition
  - λ_q^{mid} appears to be approaching a fundamental limit of 3 – 4 mm
  - More analysis is needed to understand this trend
- λ_q^{mid} has weak to no dependence on P_{heat} and B_t
- λ_q^{mid} modestly contracts with increasing $|\delta_r^{sep}|$

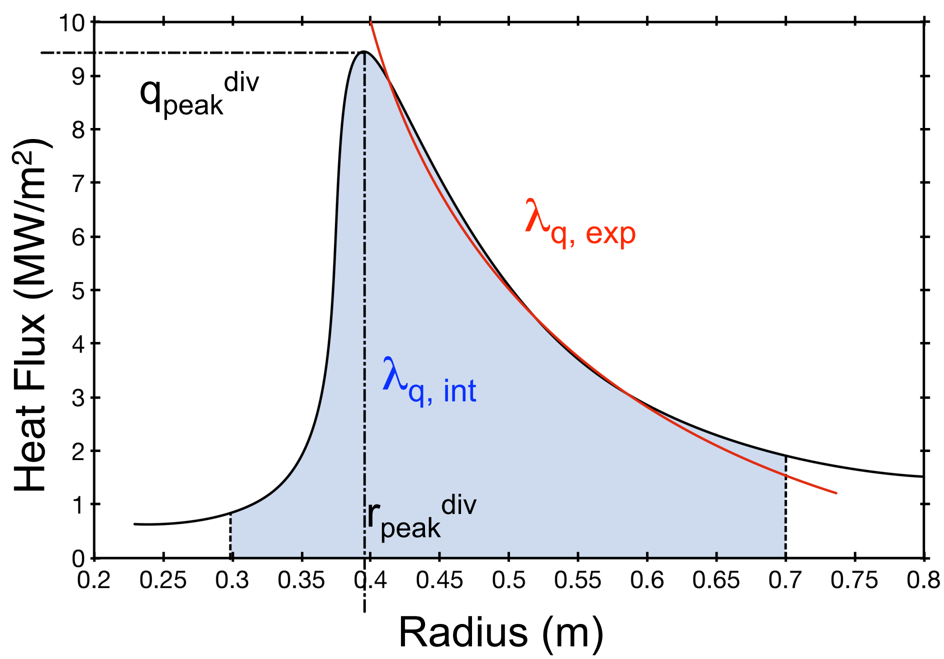
Back-up Slides

An integral heat flux width is used to determine the dependence of λ_q^{mid} on external parameters from NSTX data

- All data is time averaged over small ELMs
- IR thermography measures surface temperature of divertor tiles
- Perpendicular heat flux profile estimated from semi-infinite or finite difference models
- Define integral divertor heat flux scale length, λ_q^{div}✚

$$\lambda_q^{div} = P_{div}^{out} \Big/ \left(2\pi R_{peak}^{div} q_{div,peak}^{out}\right)$$

- λ_q^{div} related to characteristic midplane scale length through magnetic flux expansion, f_{exp}: $\lambda_q^{mid} = \lambda_q^{div} / f_{exp}$, where $f_{exp} \equiv \dfrac{R_{mid} B_\theta^{mid}}{R_{div} B_\theta^{div}}$



✚ A. Loarte, et al. JNM. 266—269 (1999) 587—592

Averaging frames of dual band camera data has minimal impact on interpretation of data

- Frame averaging has a minimal effect on peak heat flux
  - Magnitude of transients are reduced
- Averaging does lead to a slight broadening of the profile
  - Neglecting profiles during fast transients (ie ELMs)
  - 8 – 12% difference
  - Possibly due to movements in OSP location during averaging
    - No Type V ELMs in this discharge

Data taken at t_{frame} = 0.621 ms