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Radiative divertor in highly-shaped H-mode plasmas in NSTX

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V. A. Soukhanovskii

Lawrence Livermore National Laboratory, Livermore, CA

NSTX Team Review Meeting

13 March 2008

Princeton, NJ

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Experiments in NSTX demonstrated several ways of divertor peak heat flux reduction

- **Divertor heat flux mitigation solutions:**
  - ✓ Poloidal flux expansion at outer strike point (OSP)
    - Particularly well suited for STs, reduced q_{peak} by up to 50 % in NSTX
  - ✓ Strike point sweeping (Plasma stability and control issues?)
  - ✓ Radiative divertor
    - reduced q_{peak} by up to 60 % in NSTX with D_2 injection (next slides)
  - ✓ Radiative mantle
    - reduced q_{peak} by up to 50 % in NSTX (w/ neon) albeit confinement degradation
  - ✓ Divertor materials and geometry (plate tilt, closure, number of divertors…)
- **These solutions must be compatible with good core plasma performance (H-mode confinement, MHD, ELM regime, density)**
- **Solutions must scale to very high q_{peak} (15 - 40 MW/m^2) for future devices (NHTX, ST-CTF)**
  - Combinations of solutions may work

Radiative divertor removes power and momentum from plasma before it reaches divertor plate

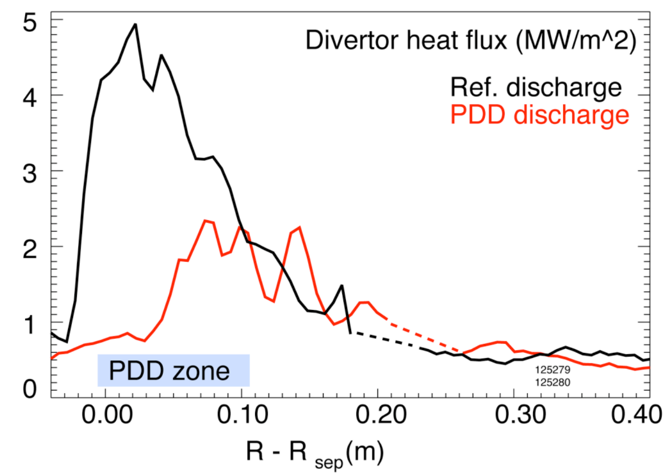
Parallel momentum and power balance

$$\frac{d}{ds}(m_i n v^2 + p_i + p_e) = -m_i(v_i - v_n)S_{i-n} + m_i v S_R$$

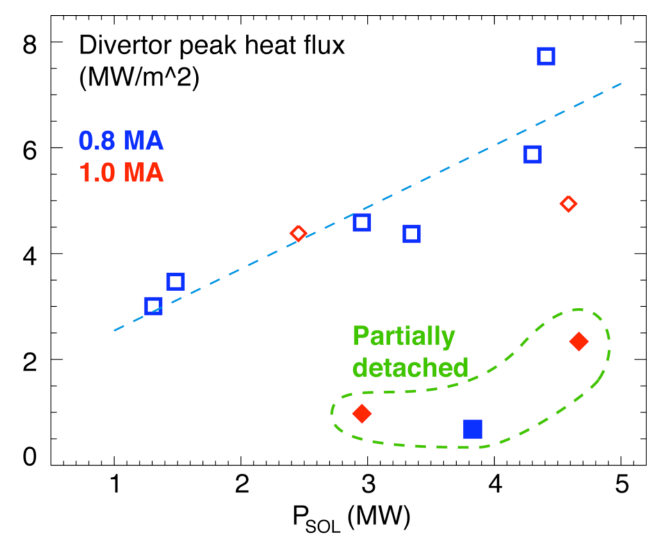
$$\frac{d}{ds}((-\kappa T_e^{5/2}\frac{dT_e}{ds}) + n v_{||}(\frac{5}{2}(T_i + T_e) + \frac{1}{2}m_i v_{||}^2 + I_0)) = S_E$$

Summary of FY 2007 radiative divertor results

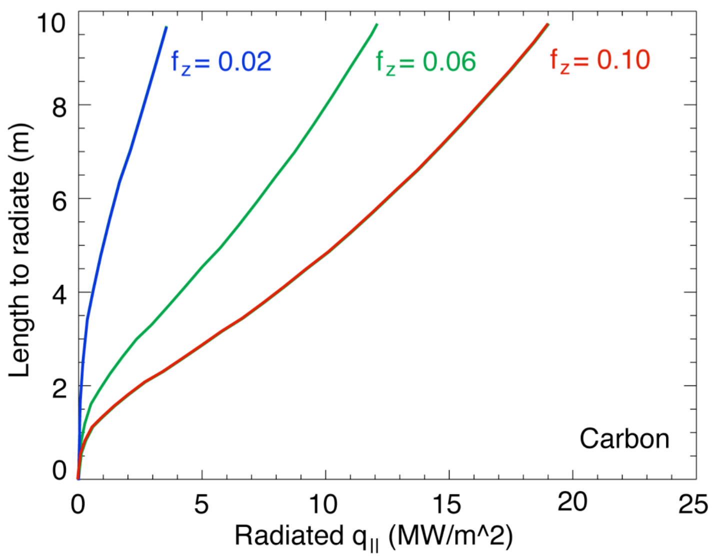
- Significant divertor **peak heat flux reduction** has been demonstrated in highly shaped high-performance H-mode plasmas in NSTX using **divertor magnetic flux expansion and radiative divertor** simultaneously with **high core plasma performance**
  - Good synergy of high performance small ELM H-mode regime with PDD



- Learnt detachment characteristics and limitations
  - Detachment achieved only with additional D_2 injection, or with additional low Z intrinsic impurities
  - PDD regime onset is abrupt. High radiated power, neutral pressure, volume recombination rate are measured
  - PDD properties appear to be similar to those observed in tokamaks



Impurity radiation role is to be clarified in radiative divertor experiments in FY 2008



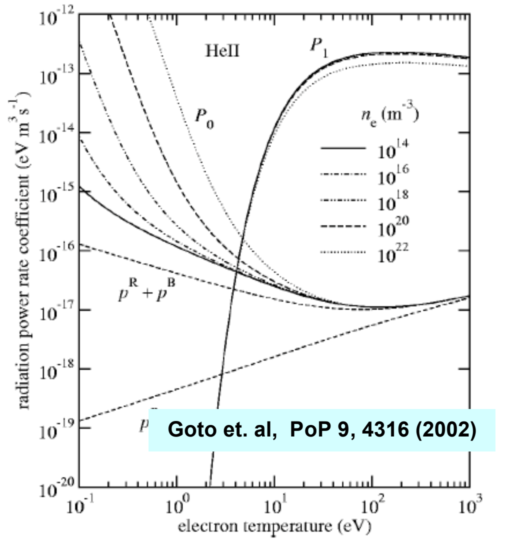
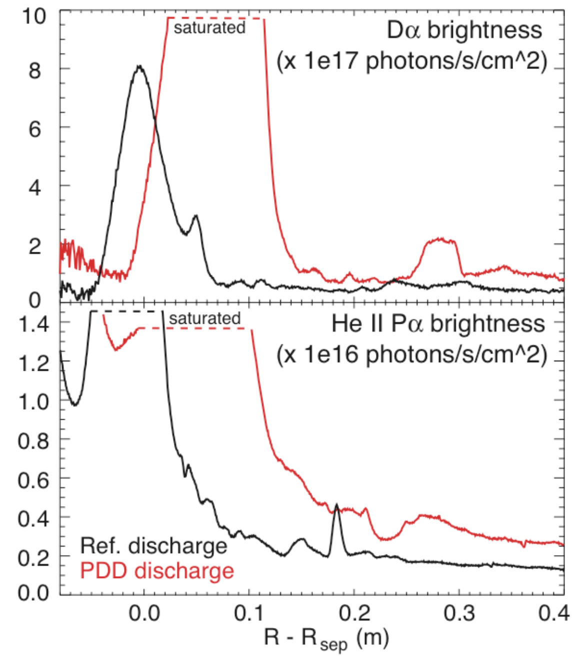


FIG. 14. T_e dependences of P_0 and P_1 for several n_e values for ionized helium.



- It is marginally possible to radiate the necessary fraction of $q_{||}$ with intrinsic carbon in NSTX
- Helium can play an important role in divertor power balance
  - Energy expensive (first I.P. 24.6 eV)
  - Radiates at 1-10 eV
- In FY 2007 experiment
  - Radiated power was due to deuterium, lithium, helium, and carbon
  - He and C were main contributors

FY 2008 radiative divertor experiment is likely to complete radiative divertor studies in NSTX

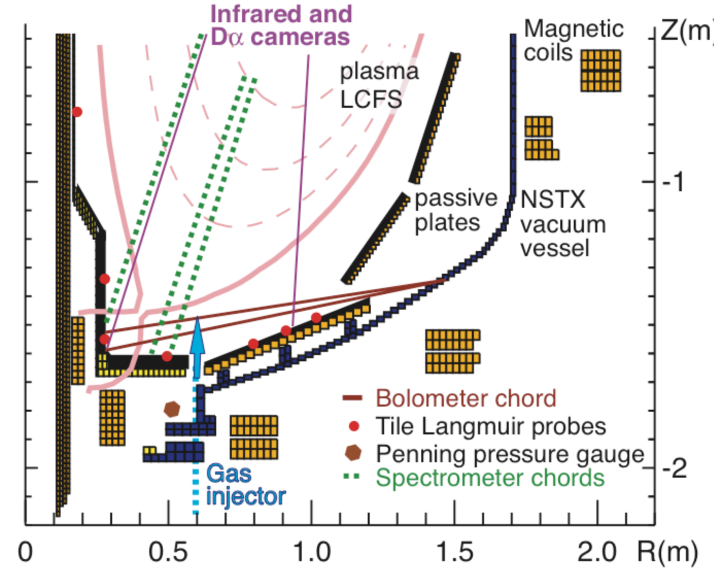
- Lithium coating experiments (FY 2008 - 2009) and liquid lithium divertor (FY 2009) will shift emphasis of divertor research to lithium work

- Lithium experiments make radiative divertor work impractical
  - Uncertainties in divertor q_{peak} and P_{rad} measurements
  - Different divertor transport regimes

- Proposed XP fits into the NSTX radiative divertor program in a logical way:
  - Divertor heat flux mitigation in low κ, δ configuration (2005-2006)
  - Divertor heat flux mitigation in highly-shaped configuration with D_2 injection (but also with intrinsic He) (2007)
  - Divertor heat flux mitigation in highly-shaped configuration with D_2 and impurity injections (without intrinsic He) (2008)

Multiple diagnostic measurements will be needed to elucidate on radiative divertor physics in NSTX

- Machine capabilities:
  - Low Z_{eff}, low H/D
  - Reliable H-mode access
  - B_t up to 5.5 kG
  - New divertor gas injector (Bay E)
  - rtEFIT-controlled highly-shaped configuration for FY 2008



- Needed diagnostics:
  - IR cameras (upper/lower divertor heat flux)
  - Bolometers (core plasma and new divertor bolometers)
  - Dα, Dγ, C III divertor cameras
  - Neutral pressure gauges (incl. 3 lower div. Penning gauges)
  - Divertor Langmuir probes
  - MPTS, CHERS, ERD (n_e, T_e, n_c)
  - Spectroscopy (D I Balmer series, impurities)
  - Gas puff imaging

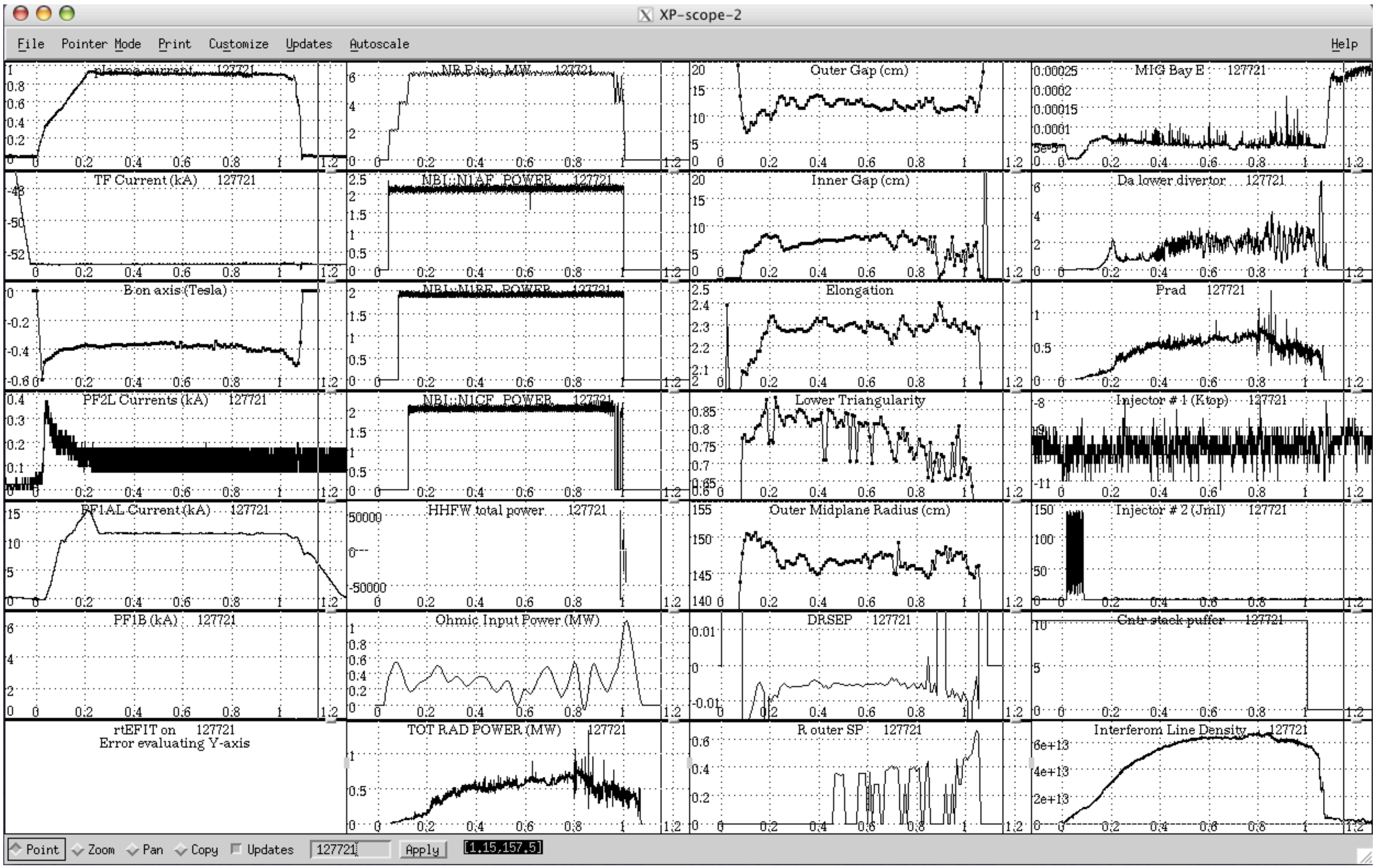
Radiative divertor XP: three parts involving different magnetic configurations and gas injections

- Obtain highly–shaped (κ = 2.2-2.3, δ = 0.65-0.75) LSN reference shot and reproduce PDD conditions at three I_p, P_{NBI} values (up to 10 shots)
  - Wall conditions should permit reproducible H-mode access with 2 NBI sources.
  - Use 3 NBI sources at full energy (80-90 kV)
  - HFS plenum pressure is 1100-1300 Torr
  - Example shots: 127721 (0.9 MA, 6 MW NBI), 125277 (1.0 MA, 4 MW NBI), 125280 (1.0 MA, 6 MW NBI)
  - Configuration will be adjusted to obtain drsep ~ -10 -12 mm,
  - rtEFIT control will be used
  - Operate GPI and divertor fast camera in PDD shots to elucidate on Lodestar blob theory and turbulence measurements
  - Use new Bay E lower divertor gas injector with D_2 at 70 - 160 Torr l /s . Perform a gas injection rate and/or time scan (5 shots). Use new Bay E lower divertor gas injector. As a backup option, may use Branch 5 injector and the PZV4/4a valve to inject gas in the outer SOL close to outer strike point.

- Obtain highly–shaped (κ = 2.2-2.3, δ = 0.65-0.75) DN reference shot and obtain PDD conditions at three I_p, P_{NBI} values using various gas injection rates (up to 10 shots)

- Obtain highly–shaped (κ = 2.2-2.3, δ = 0.65-0.75) LSN reference shot and obtain PDD conditions using He or CD_4 injection (up to 10 shots)

Waveforms


XP-scope-2
File
Pointer Mode
Print
Customize
Updates
Autoscale
Help
Plasma current 127721
NB P inj MW 127721
Outer Gap (cm)
MIG Bay E 127721
TF Current (kA) 127721
NBI::N1AF_POWER 127721
Inner Gap (cm)
Da lower divertor 127721
B on axis (Tesla)
NBI::N1BE_POWER 127721
Elongation
Prad 127721
PF2L Currents (kA) 127721
NBI::N1CF_POWER 127721
Lower Triangularity
Injector # 1 (Ktop) 127721
PF1AL Current (kA) 127721
HHFW total power 127721
Outer Midplane Radius (cm)
Injector # 2 (Jml) 127721
PF1B (kA) 127721
Ohmic Input Power (MW)
DRSEP 127721
Cntr stack puffer 127721
rtEFIT on 127721
Error evaluating Y-axis
TOT RAD POWER (MW) 127721
R outer SP 127721
Interferom Line Density 127721
Point
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Updates
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