NSTX

Supported by

U.S. DEPARTMENT OF ENERGY | Office of Science

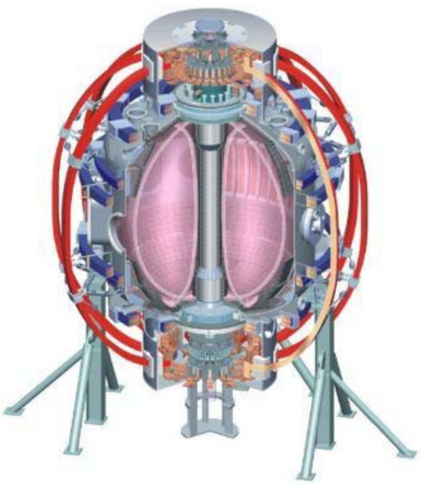
Core impurity reduction using divertor D_2 injection in lithium-conditioned H-mode discharges in NSTX

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin

Filippo Scotti (PPPL)

V.A. Soukhanovskii (LLNL) , R.E. Bell , S. Gerhardt, M. Jaworski , R. Kaita, J. Kallman, H.W. Kugel, B.P. Leblanc, R. Maqueda, S.F. Paul, M. Podesta' , A.L. Roquemore (PPPL), A. McLean, D.J. Battaglia (ORNL), R. Raman (U. Washington) and the NSTX Research Team

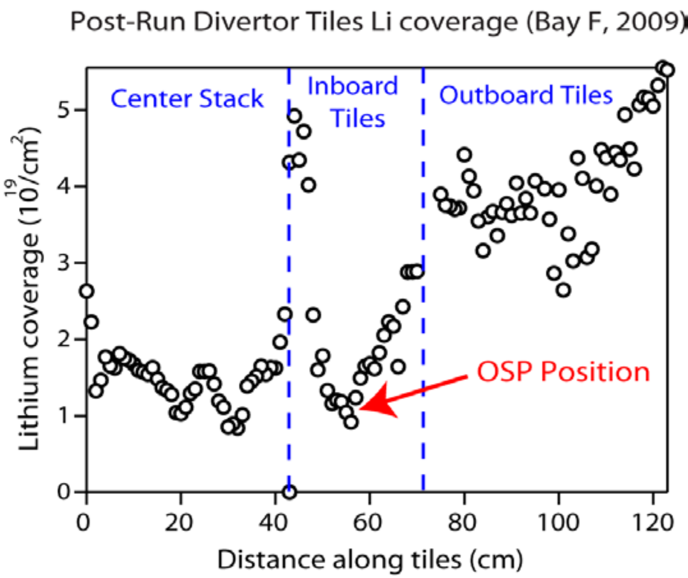
52nd American Physical Society Meeting
Division of Plasma Physics
Chicago, Illinois
November 8-12, 2010

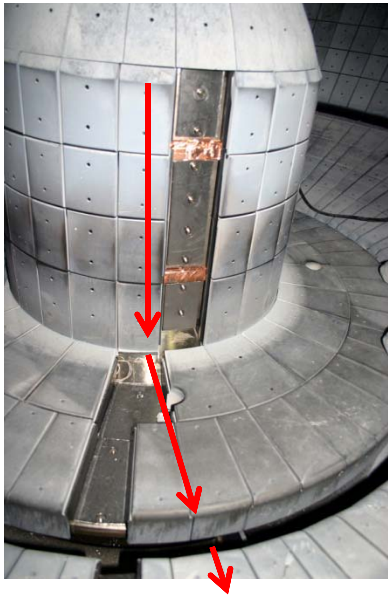


Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

Li conditioned ELM free discharges result in core impurity accumulation in NSTX plasmas

- Lithium wall conditioning between discharges in NSTX:
  - Lithium evaporators (LITER) deposit up to 40mg/min on the lower divertor
  - Lithium layers in the outer strike point (OSP) region degrade during discharges
  - Carbon sputtering possible despite Li conditioning
- Lithium conditioned discharges show impurity accumulation:
  - ELM suppression due to edge stabilization of ballooning/peeling modes
  - Z_{eff} up to 4 due to core carbon accumulation
  - Lithium screened from core (less than 1% of carbon concentration)
  - Core radiated power due to metals (up to 2MW)
- Research effort to:
  - Understand NSTX impurity sources distribution
  - Reduce core impurity accumulation

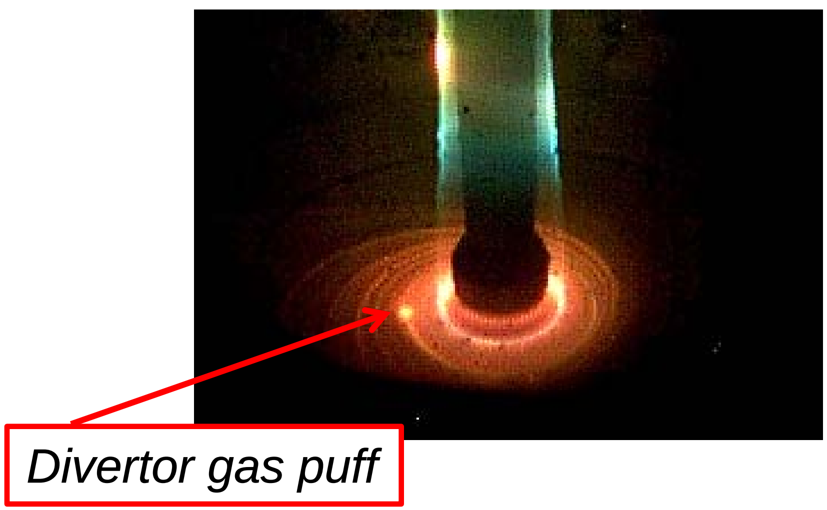


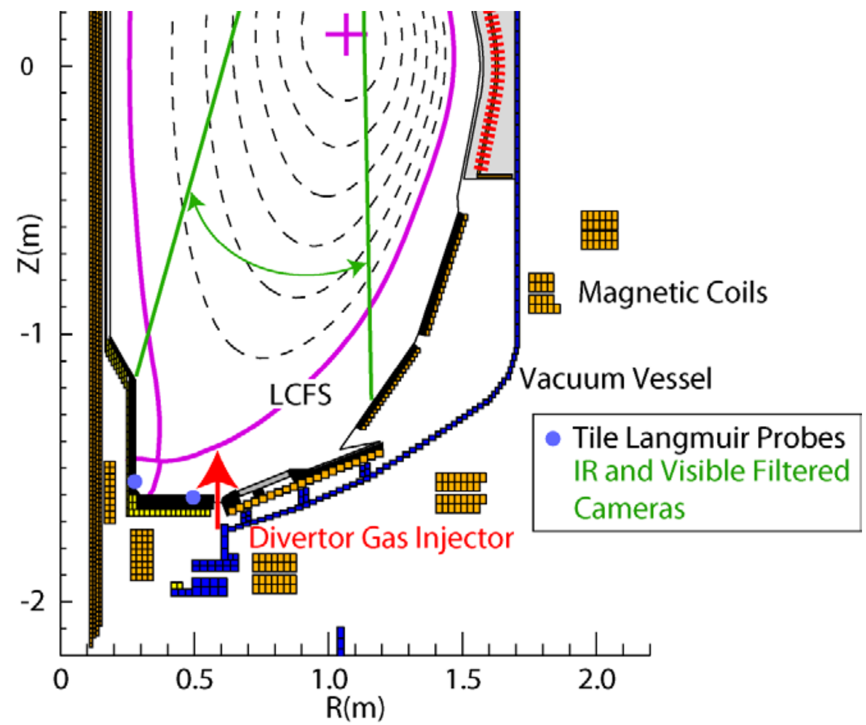


W. R. Wampler (SNL)

Divertor D_2 injection to reduce edge impurity sources in Li-conditioned H-mode discharges

- Dedicated experiment with D_2 divertor gas puff:
  - 10-25 Torr-l injected in the high flux expansion outer SOL
  - small amounts not to affect pedestal stability and core confinement
  - below threshold for OSP partially detached divertor





H-mode confinement and performance retained at moderate D_2 flow rates while Z_{eff} is reduced

ELM free H-mode discharges

I_p = 800 kA

P_{NBI} = 4 MW

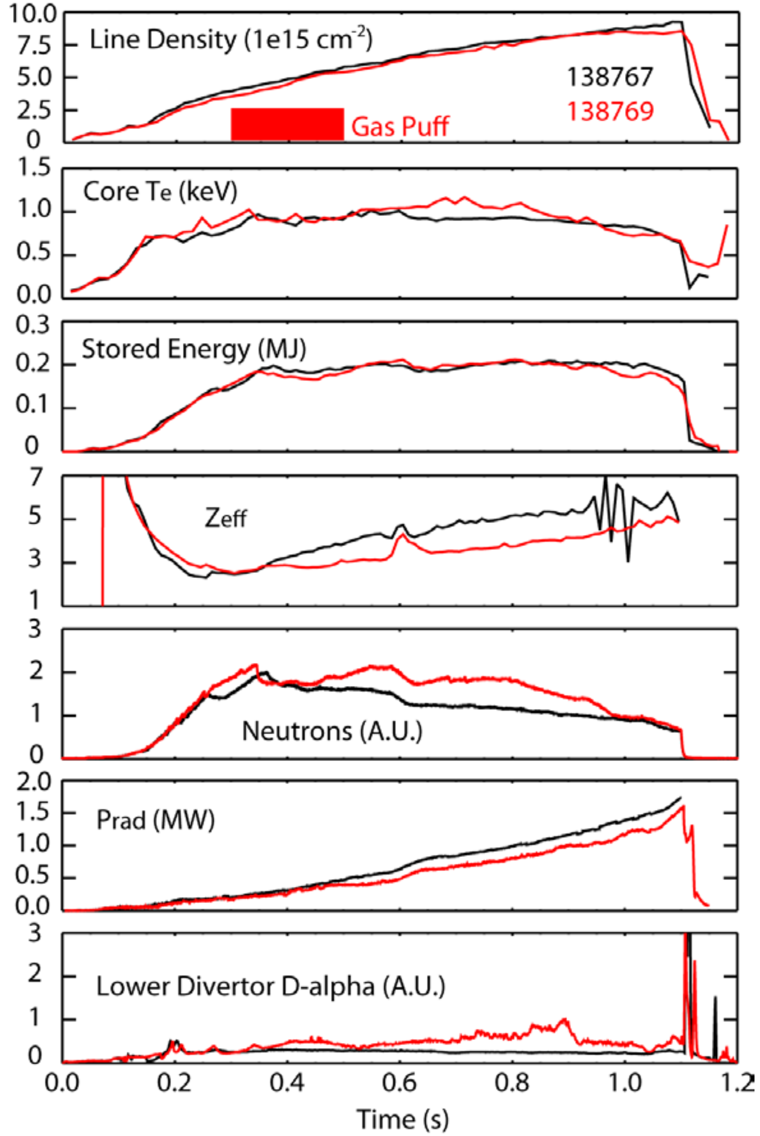
High elongation/triangularity: δ=2.3 - κ=0.8

dr_{sep}= -5 mm

175 mg Li between discharges

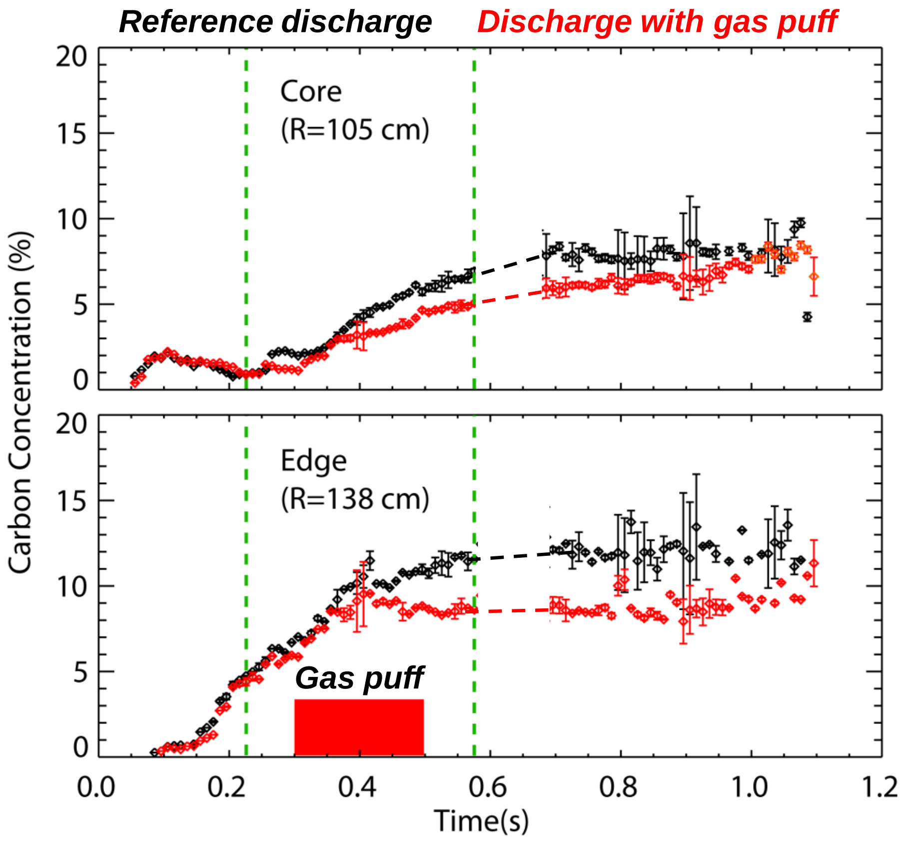
- D_2 divertor puff at 300-500 ms
- Core plasma parameters unaffected
- No change in confinement properties
- Z_{eff} reduced up to 30%
- Neutrons increased up to 30%
- Smaller core P_{rad} reduction (up to 20%)
- Higher gas injection rates lead to stronger impurity reduction until OSP partial detachment is achieved

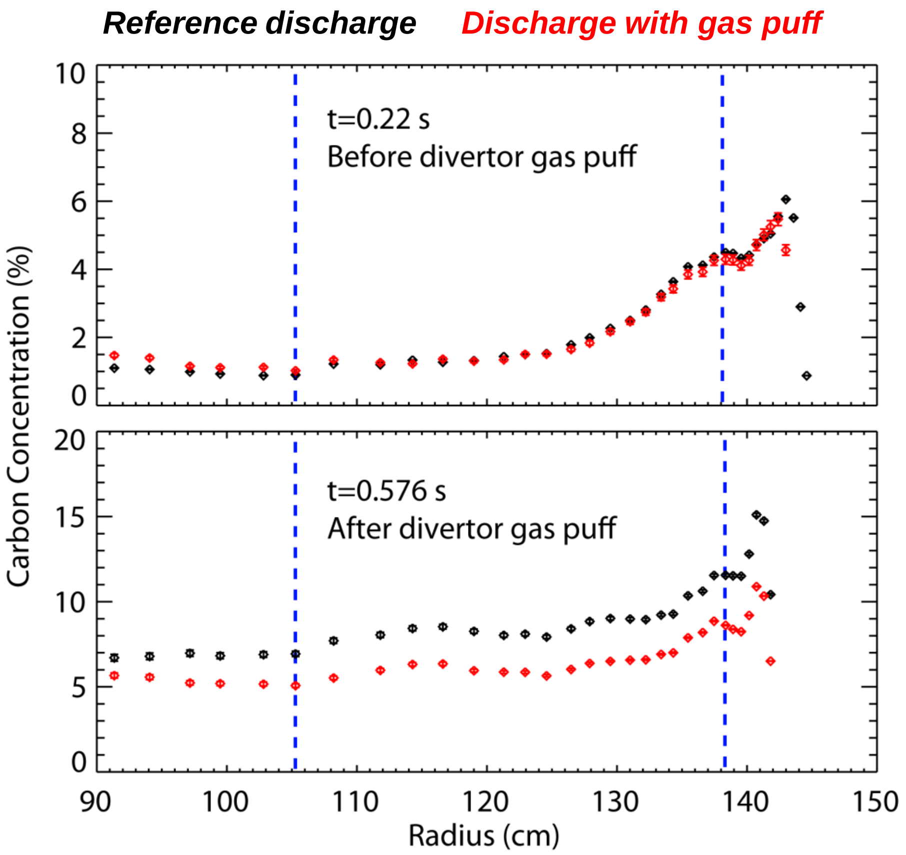
Reference discharge ***Discharge with gas puff***



Carbon concentration reduced up to 30% in both core and edge plasma

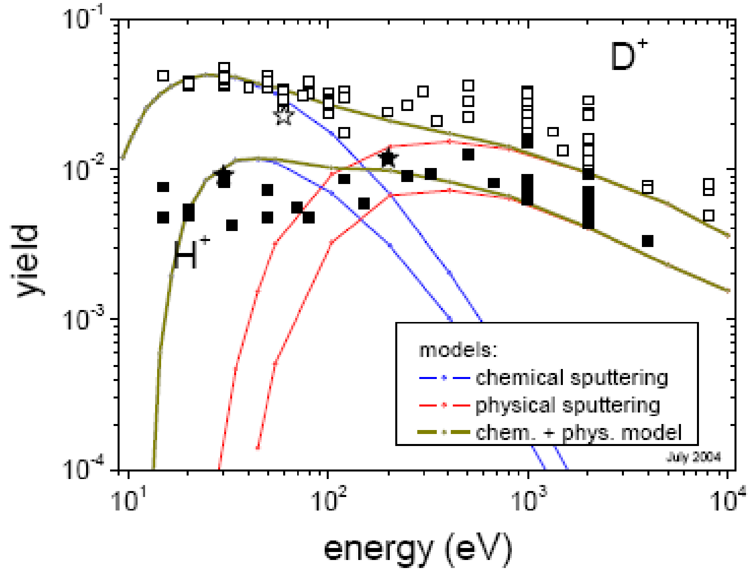
- Core carbon densities from CHERS (C VI, n=8-7, 529.1 nm)
- Carbon concentration reduced up to 30%, both in core and edge
- Carbon concentration radial profile shape unchanged
- Total carbon inventories reduced up to 30% (~1.5e19 ions)

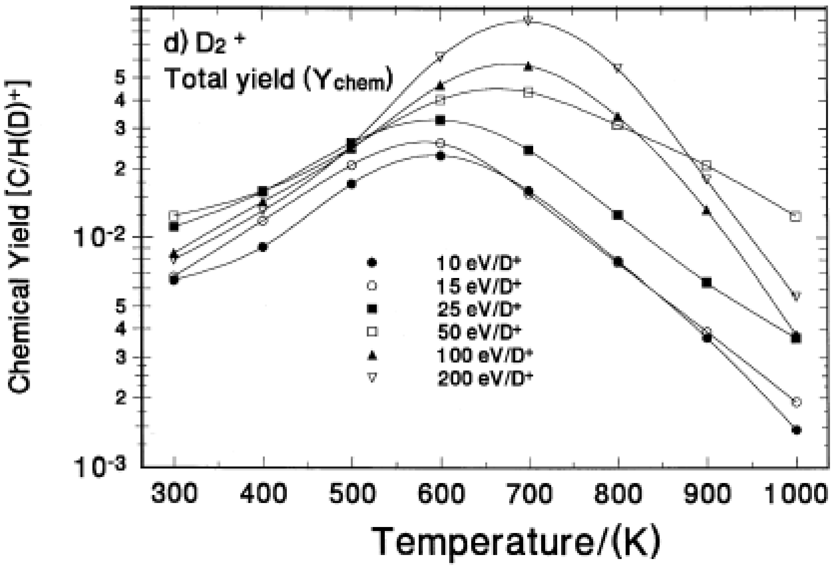




Possible explanations include changes in impurity sources, SOL and core transport

- Sources
  - Divertor target, main chamber wall
  - Divertor physical and chemical sputtering
- Parallel SOL transport
  - Parallel forces acting on impurity ion [Stangeby, 2000]
  - Force balance affects divertor entrainment of impurities
- Radial core transport (neoclassical)
  - Diffusive and convective transport



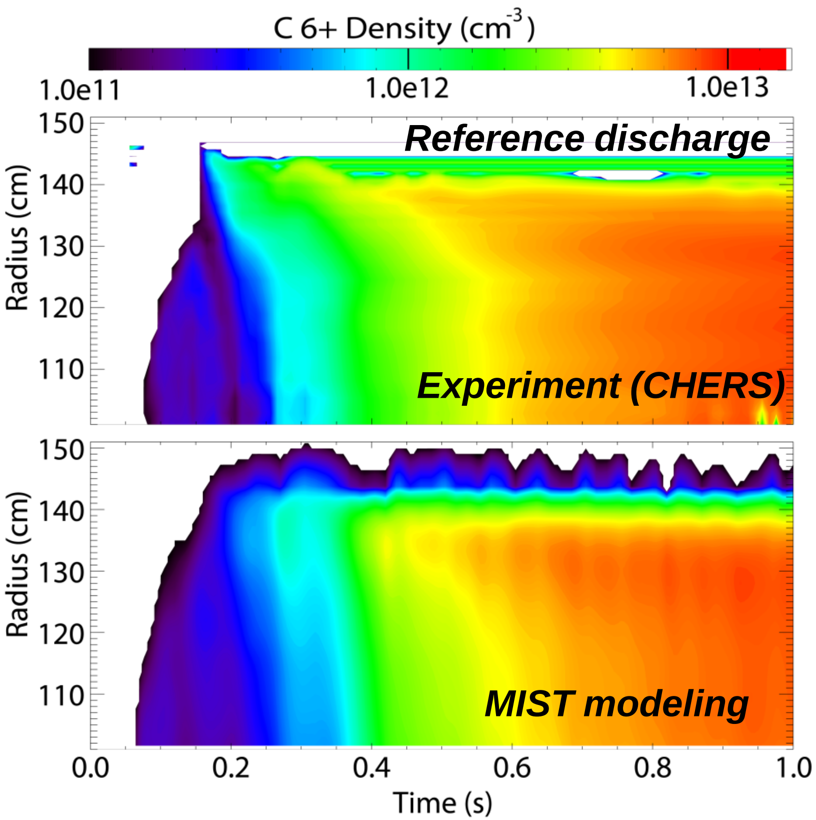


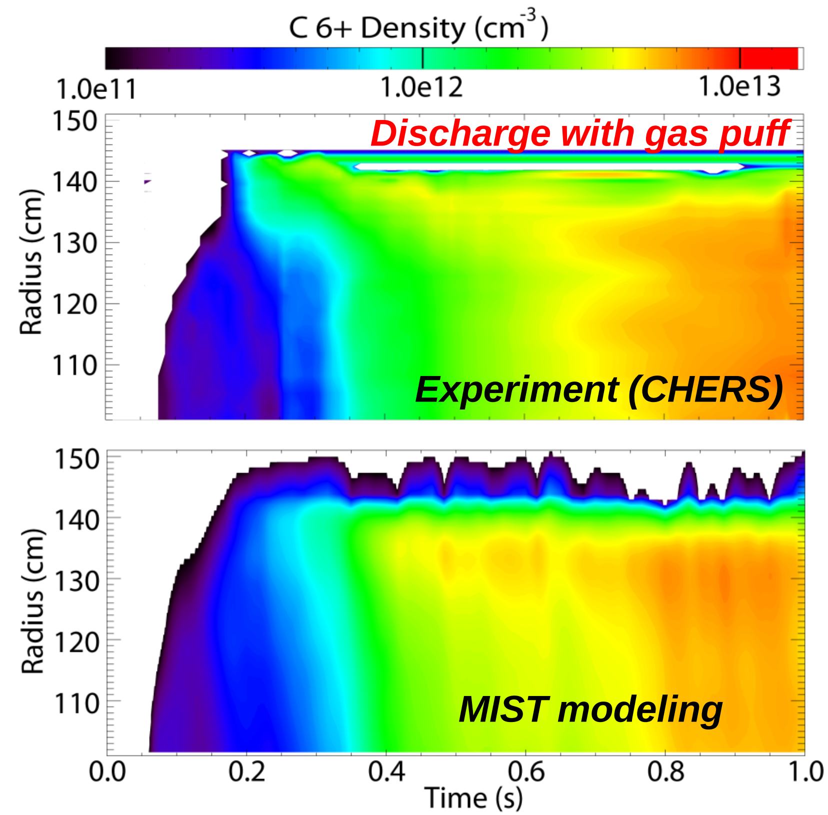
M. Balden, J. Roth, J. Nucl. Mater. 280, 39-44 (2000)
C. Hopfand W. Jacob, J. Nucl. Mater. , 342, 141–147 (2005)

B.V. Mech et al. J. Nucl. Mater. 255, 153–164 (1998).

1-D radial transport modeling shows that reduced impurity source is needed to explain core carbon concentrations

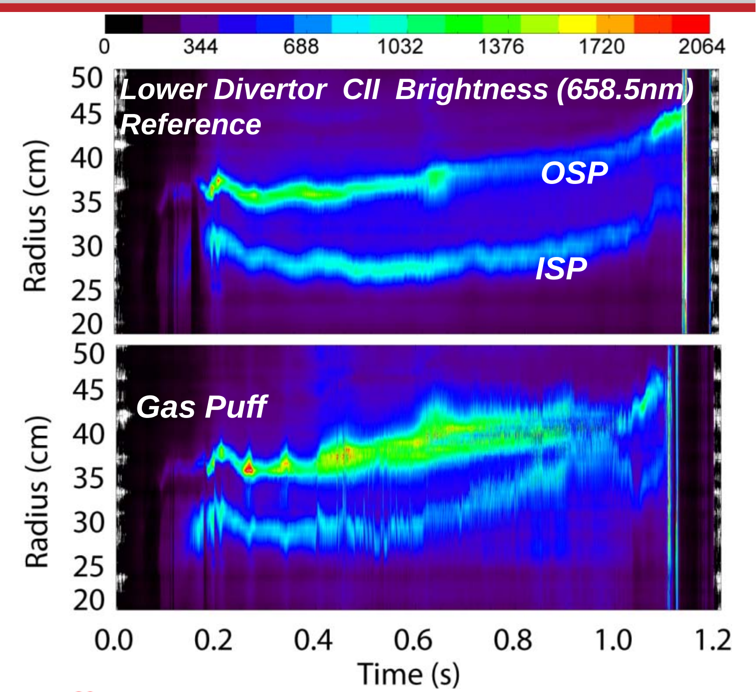
- MIST code simulations for reference discharge without gas puff:
  - neoclassical level diffusion (D = 1 m^2/s)
  - strong inward pinch velocity
  - T_e and n_e profiles from experiment
- Core carbon concentration of gas puff discharge reproduced reducing LCFS impurity source by ~20-25%

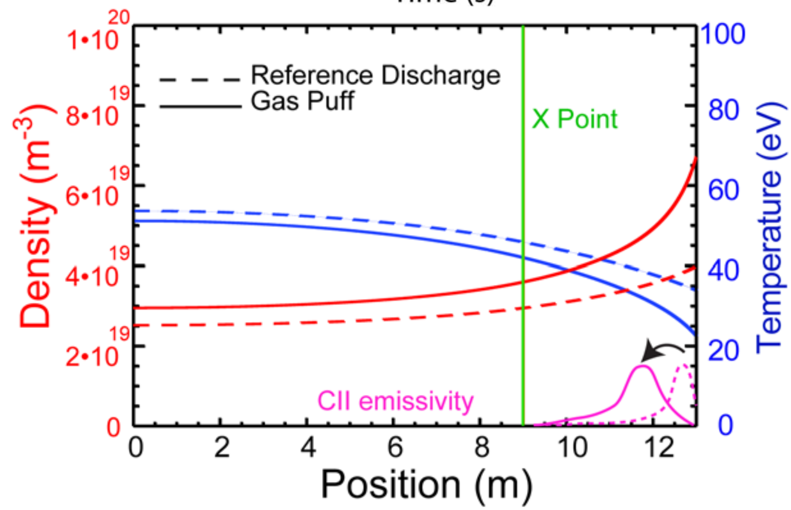




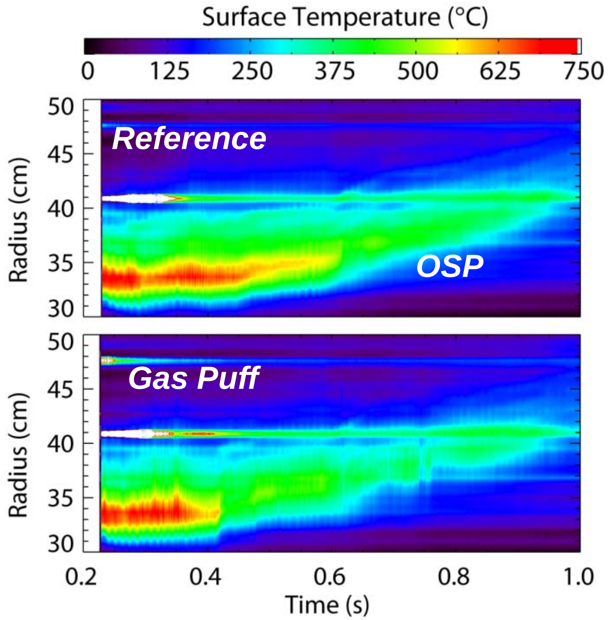
Reduced divertor T_e with divertor gas puff suggests reduced physical sputtering yield

- C II emission:
  - Spatial extent increases
  - Radiation front moves upstream
- T_e and n_e profiles with gas puff simulated with a 5 point SOL transport model via local flux amplification in the ionization region [R. Goswami, *Phys. Plasmas*, **8**,3 (2001)]
- Gas puff is effective in increasing n_e and decreasing T_e
- Consistent with observed CII broadening
- Suggests reduction in physical sputtering yield in the OSP region
- Lack of direct n_e and T_e measurements precludes use of S/XB method on gas puffing discharges to infer carbon influxes



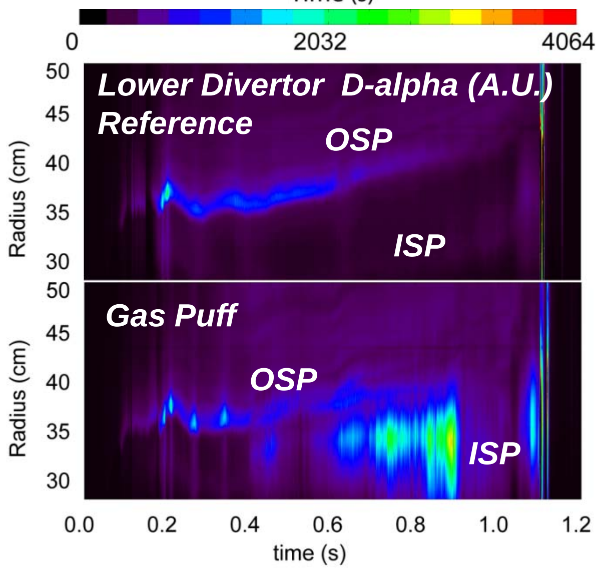


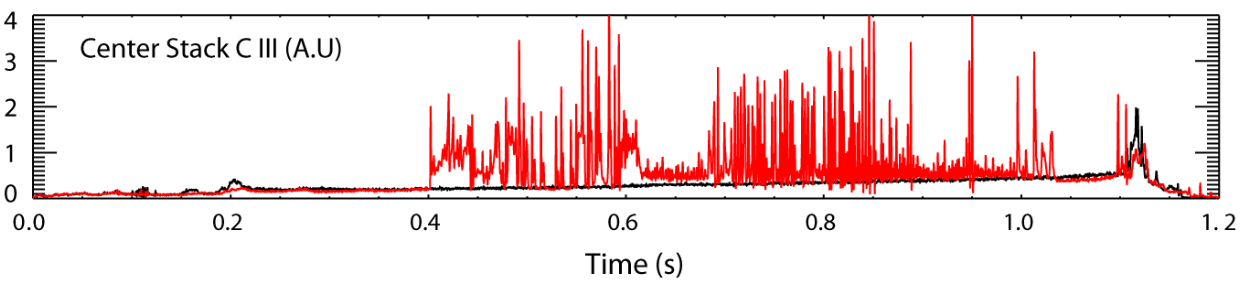
Reduction in divertor surface temperature does not imply reduction in chemical sputtering yield



- In discharges with gas puff reduction in surface temperature up to 150°C are observed w/o OSP detachment
- T decrease not enough to support conclusions about chemical sputtering yield

- With gas puff inner strike point detaches
  - Reduced physical sputtering
- Role of MARFE in impurity source?
  - Strong MARFE activity after divertor gas puff
  - Increase in n_e above MARFE threshold





Summary

- Lithium conditioned H-mode ELM free discharges in NSTX result in core impurity accumulation (carbon and metals)
- Divertor D_2 puffing resulted in:
  - Z_{eff} reduced by as much as 30%
  - Core carbon concentrations and inventories reduced up to 30%
  - Core radiated power reduced up to 20%
- MIST impurity transport modeling suggest reduction of LCFS impurity source
- Changes in divertor conditions suggest reduction in physical sputtering yield at OSP and ISP
- Divertor surface temperature reduction not enough to support reduction in chemical sputtering yield
- Further data and analysis needed to confirm the role of SOL transport and increased impurity entrainment in divertor

NSTX Reference Data

NSTX eng. and plasma parameters

R = 0.85 m, a = 0.67 m, A > 1.27

P_{NBI} < 7 MW, B_t < 0.6 T

NSTX fueling * 1 Torr l/s = 7e19 s^{-1}

- Gas injection: low field side (LFS, top + side)
  high field side (HFS, midplane + shoulder)
  D_2, He, injected at S = 20 - 80 Torr l /s.
- Neutral beam injection system:
  three beams, 80 - 100 keV, 0.8-7 MW,
  fueling rate: S < 4 Torr l / s
- Supersonic gas injection: S = 30 - 65 Torr l / s

NSTX wall conditioning

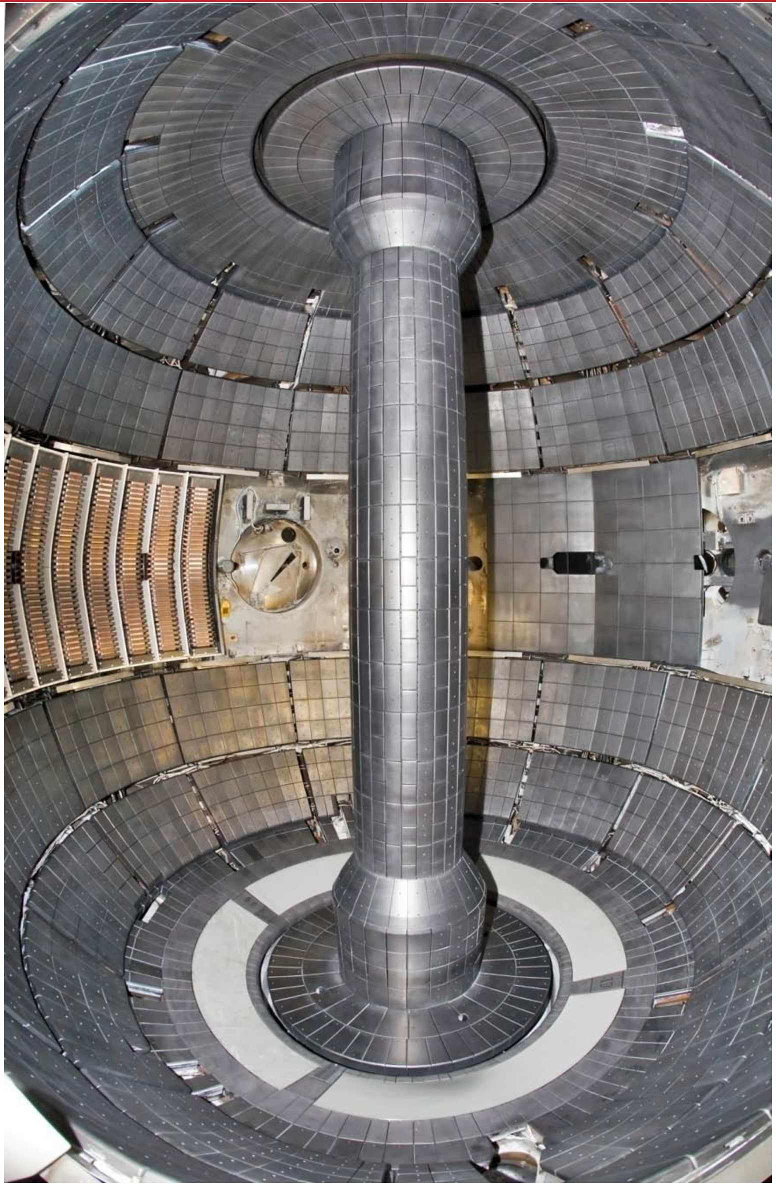
- Li coatings deposited by Li evaporator

NSTX pumping

- Turbomolecular pump (3400 l / s)
- NBI cryopump (50000 l / s, in NBI plasmas only)
- Conditioned walls, Li coatings

Plasma Facing Components

- ATJ graphite tiles on divertor and passive plates
- ATJ and CFC tiles on center stack
- Thickness 1” and 2”



Five point model of the SOL plasma

- Region 1: volumetric SOL heat $Q_\perp$ and particle sources $S_\perp$, from midplane (x=0) to X-point ($x=x_x$).

$$\frac{d}{dx}(nv) = S_\perp, \qquad \frac{dp}{dx} = 0, \qquad \frac{d}{dx}\left(\kappa_0 T^{\frac{5}{2}} \frac{dT}{dx}\right) = -Q_\perp$$

- Region 2: Conduction region, until start of energy loss zone ($x=x_L$,$T(x_L)$=10eV).

$$\frac{d}{dx}(nv) = 0, \qquad \frac{dp}{dx} = 0, \qquad \frac{d}{dx}\left(\kappa_0 T^{\frac{5}{2}} \frac{dT}{dx}\right) = 0$$

- Region 3: Radiation front region (max. C radiation eff.) until start of the neutral zone ($x=x_C$,$T(x_C)$=4eV).

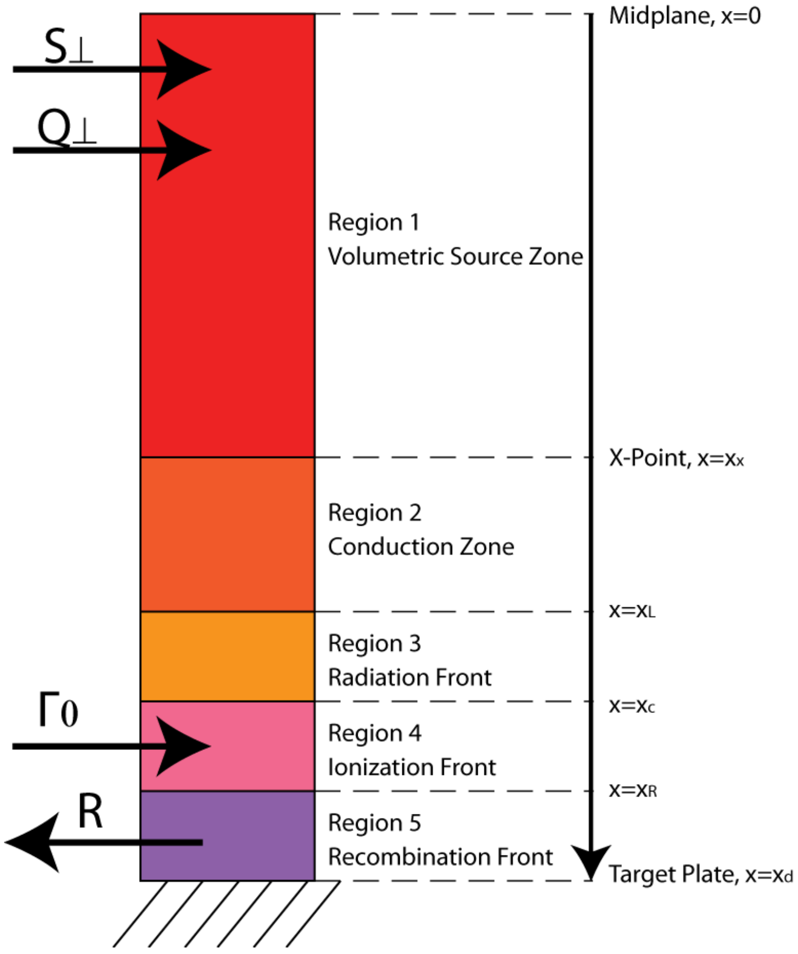
$$\frac{d}{dx}(nv) = 0, \qquad \frac{dp}{dx} = 0, \qquad \frac{d}{dx}\left(\kappa_0 T^{\frac{5}{2}} \frac{dT}{dx}\right) = L$$

- Region 4: Ionization front region (most neutrals are ionized) until onset of recombination region ($x=x_R$,$T(x_R)$=1.6eV).

$$\frac{d}{dx}(nv) = \Gamma_0 \delta(x - x_C), \qquad \frac{dp}{dx} = -m_i v_x n v, \qquad \frac{d}{dx}\left(\kappa_0 T^{\frac{5}{2}} \frac{dT}{dx}\right) = 0$$

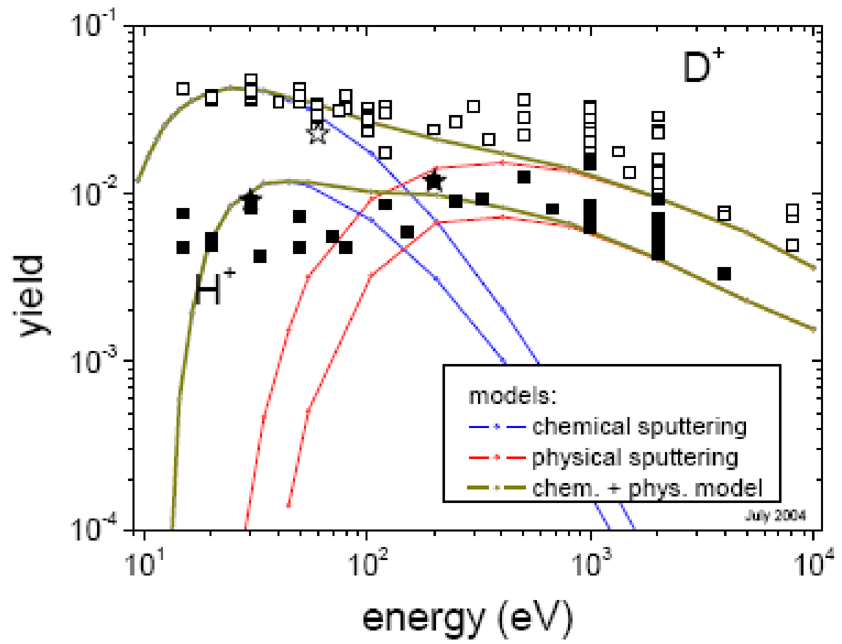
- Region 5: Recombination front region (recombination exceeds ionization), until divertor plate.

$$\frac{d}{dx}(nv) = -R, \qquad \frac{dp}{dx} = -m_i v_x n v, \qquad \frac{d}{dx}\left(\kappa_0 T^{\frac{5}{2}} \frac{dT}{dx}\right) = 0$$



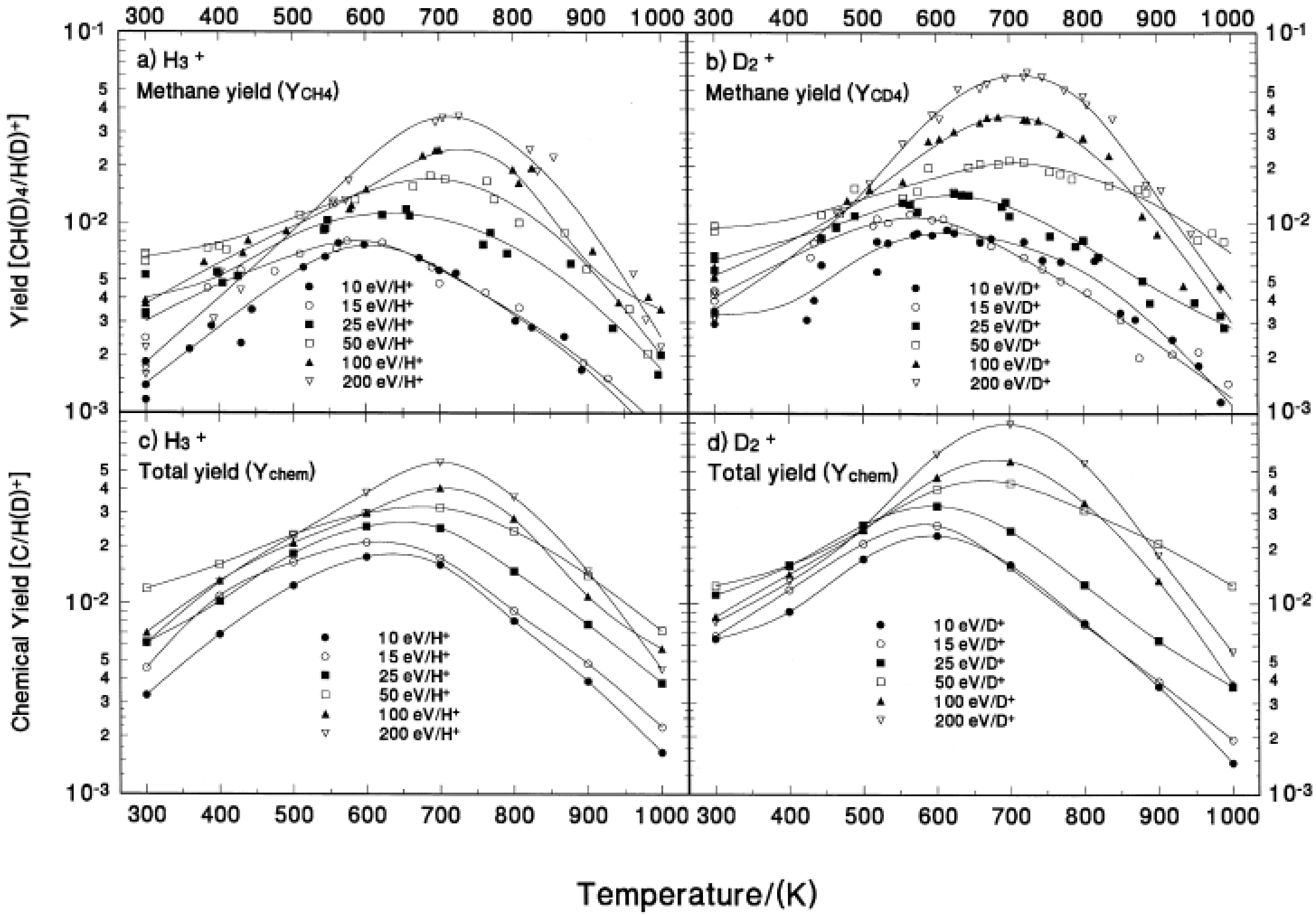
R. Goswami, Phys. Plasmas, 8,3 (2001)

Graphite Physical Sputtering Yield



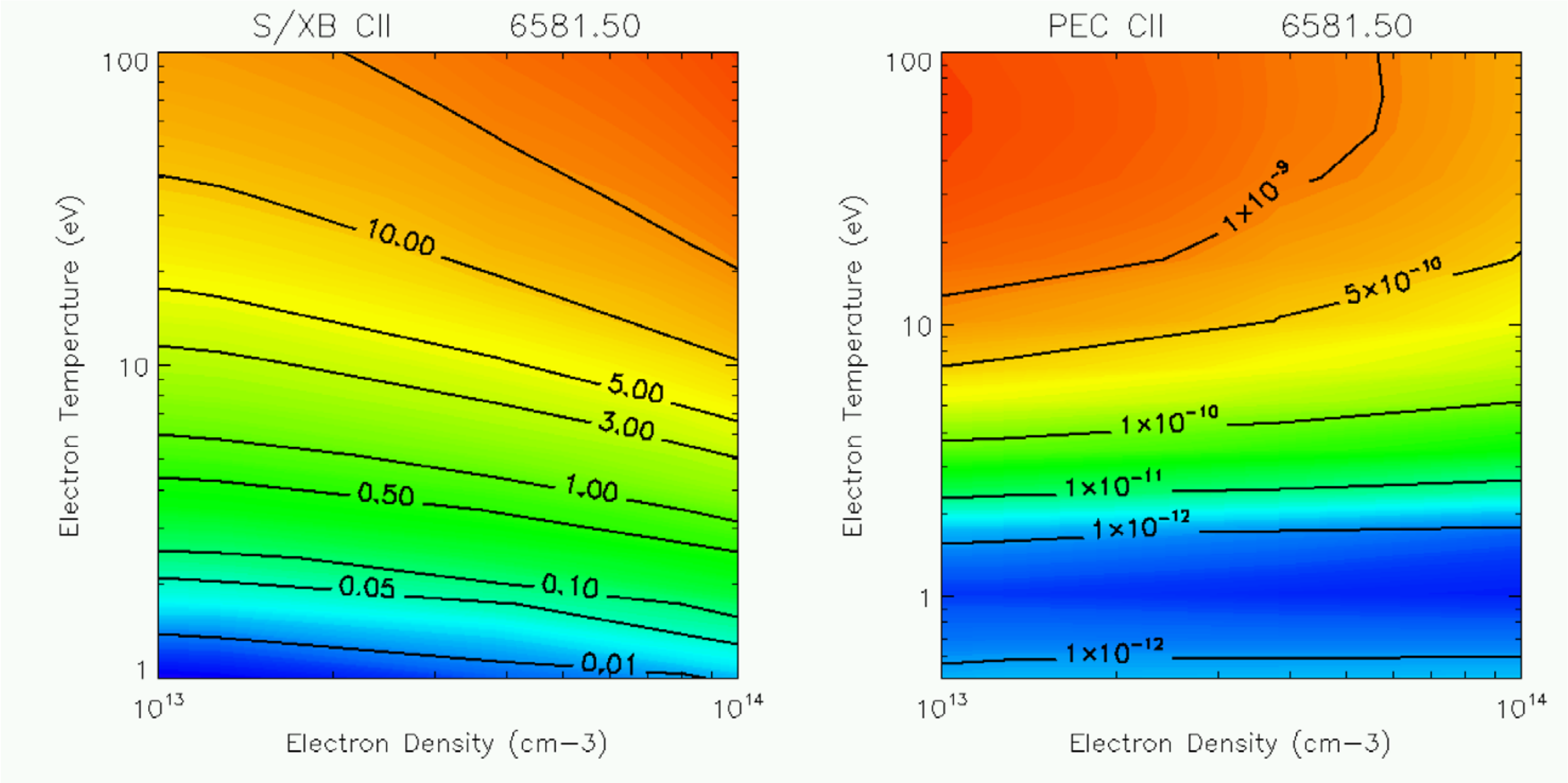
Data: M. Balden, J. Roth, J. Nucl. Mater. 280, 39-44 (2000)
Model: C. Hopfand W. Jacob, J. Nucl. Mater. , 342, 141–147 (2005).

Graphite Chemical Sputtering Yields



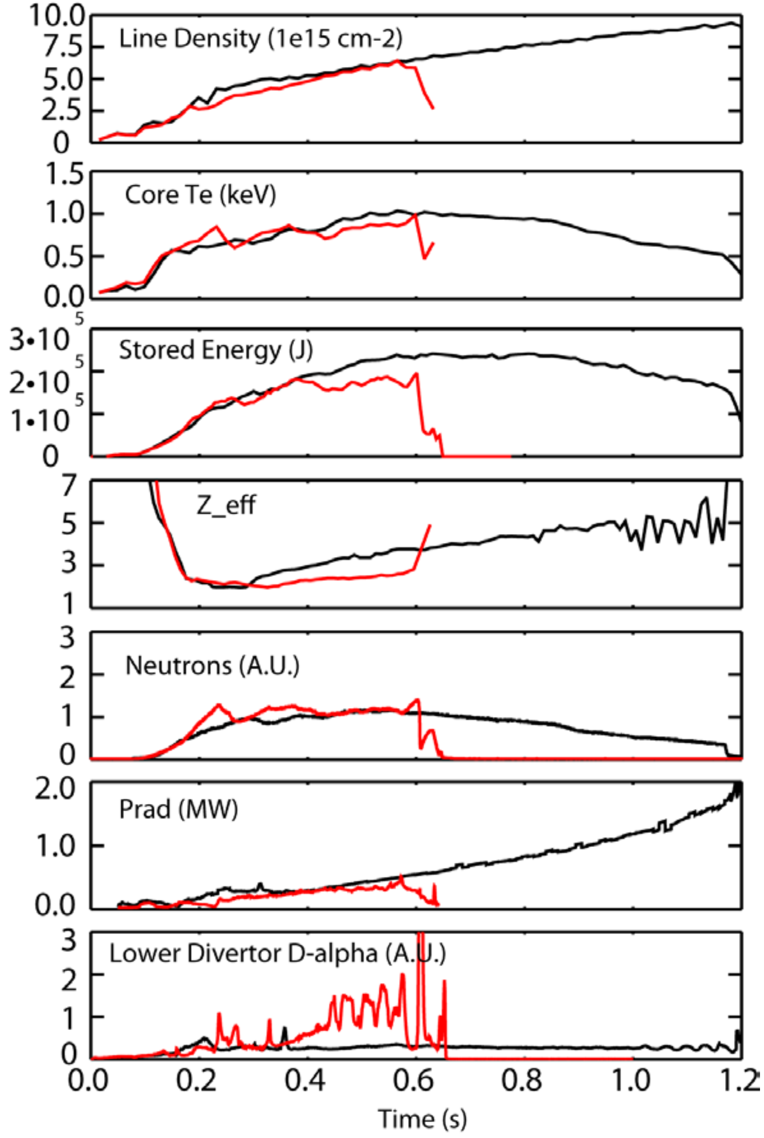
B.V. Mech et al. J. Nucl. Mater. 255, 153–164 (1998).

PEC and SXB coefficients for CII



Open ADAS

PDD Discharge



Possible explanations from changes in impurity sources, SOL and core transport

- Sources
  - Divertor target, main wall
  - Physical and chemical sputtering

- Parallel SOL transport
  - Parallel transport, balance between downward directed friction force and upward directed ion thermal gradient force

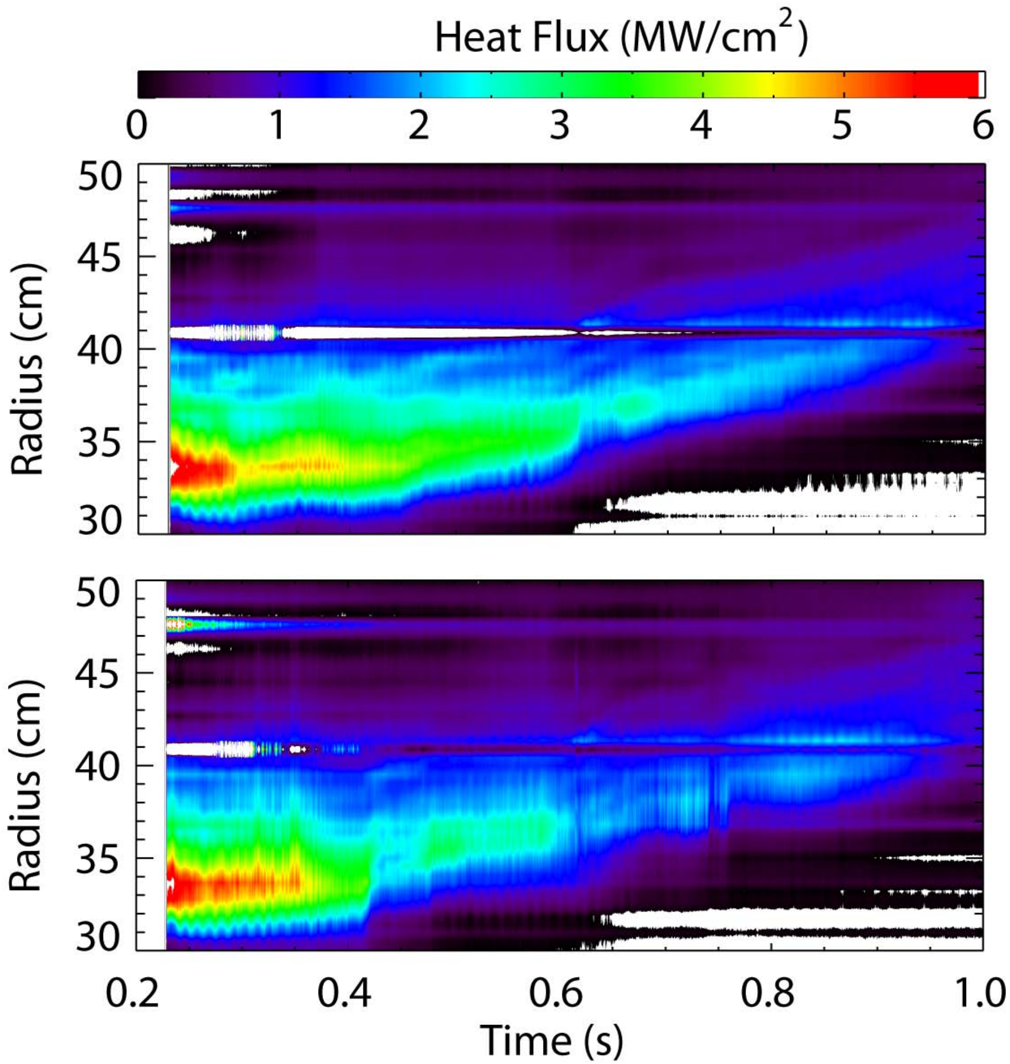
$$F_z = -\frac{1}{n_z}\frac{dp_z}{ds} + m_z\frac{(v_i - v_z)}{\tau_s} + ZeE + \alpha_e\frac{d(kT_e)}{ds} + \beta_i\frac{d(kT_i)}{ds}$$

Impurity pressure gradient force — ***Friction force*** — ***Electrostatic force*** — ***Electron T gradient force*** — ***Ion T gradient force***

  - Divertor retention (depends on local plasma parameters and SOL flows)

- Radial core transport (neoclassical)
  - Diffusive and convective transport

Heat flux at outer strike point reduced during gas puff



Reference discharge

Gas Puff discharge