Supersonic gas jet fueling experiments on NSTX

V. A. Soukhanovskii

Lawrence Livermore National Laboratory

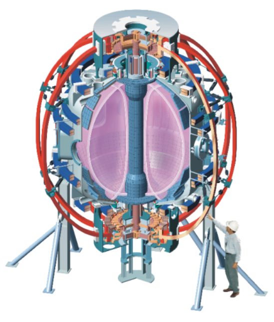
H. W. Kugel, R. Kaita, A. L. Roquemore

Princeton Plasma Physics Laboratory

Boundary Physics ET Meeting

9 February 2005

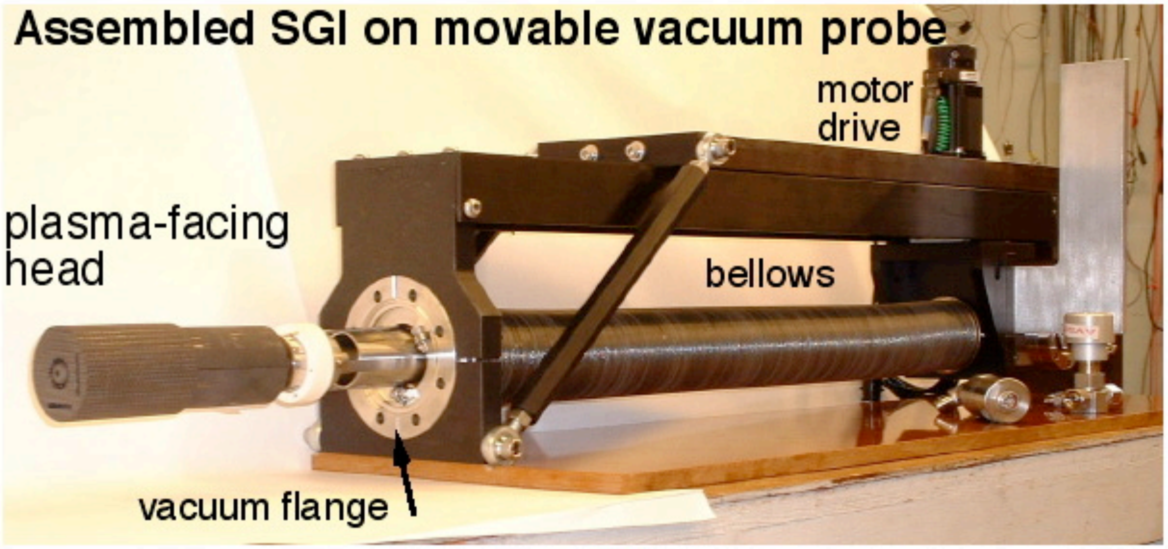
Princeton, NJ

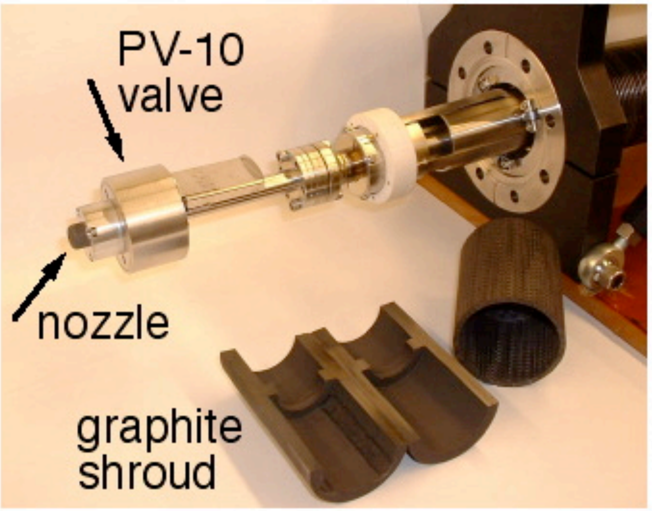


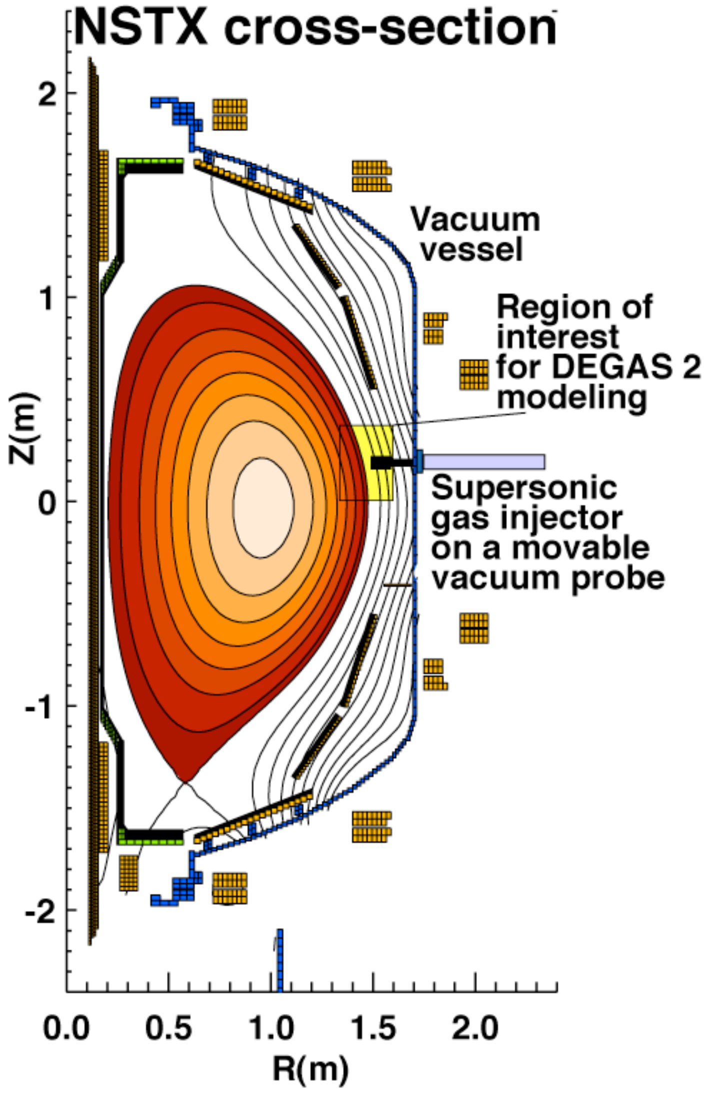
FY'04 status

- XMP-35 "SGI commissioning" successfully completed
- No exp. time was allocated for a physics experiment
- Preliminary results are encouraging: higher fueling efficiency, high gas jet collimation (expect higher wall saturation limit), good SOL penetration, compatibility with H-mode edge

Supersonic gas injector has become operational in FY'04

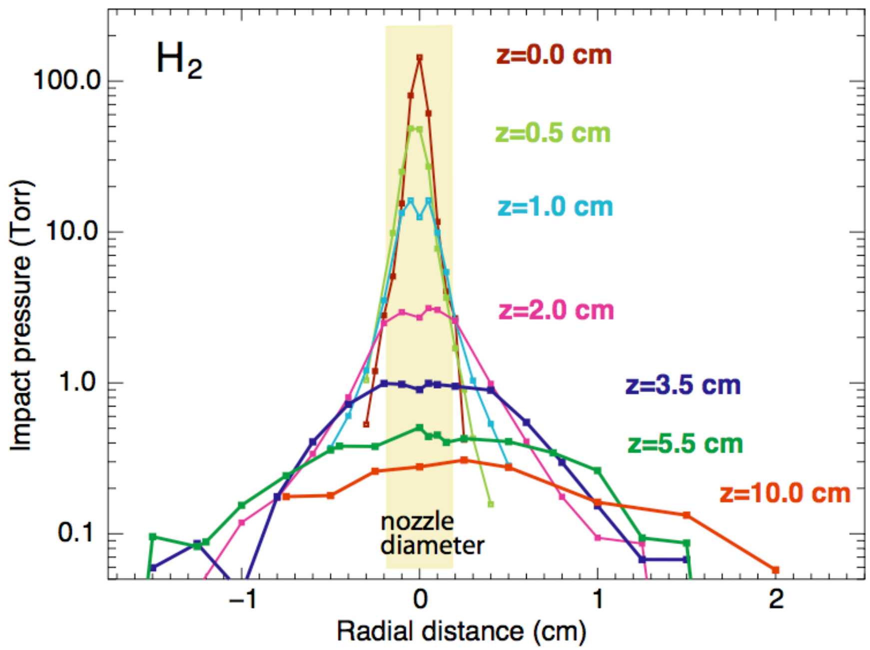


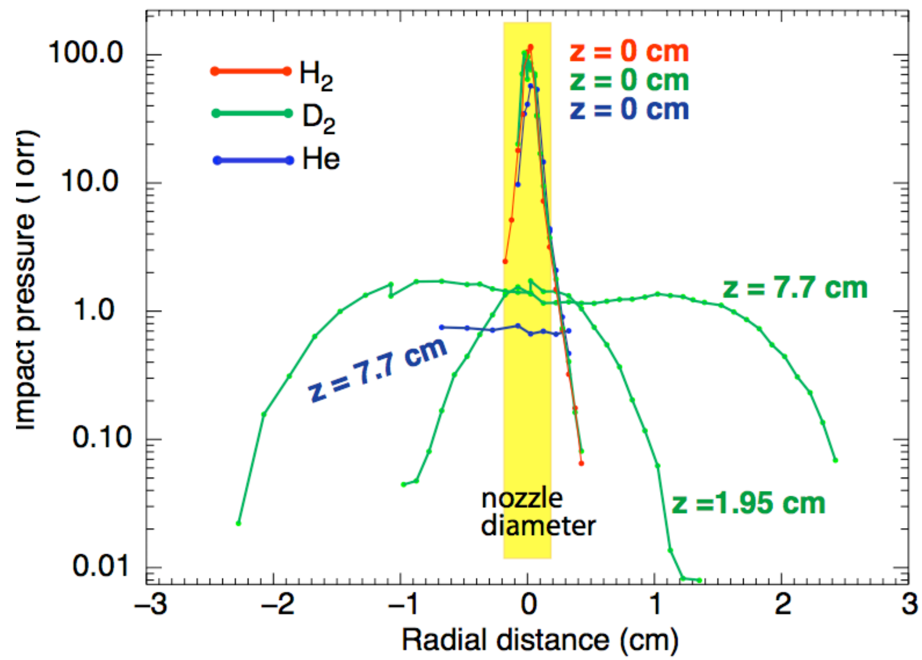




PPPL PRINCETON PLASMA PHYSICS LABORATORY

Off-line pressure measurements confirm high Mach number and highly collimated gas jet shape





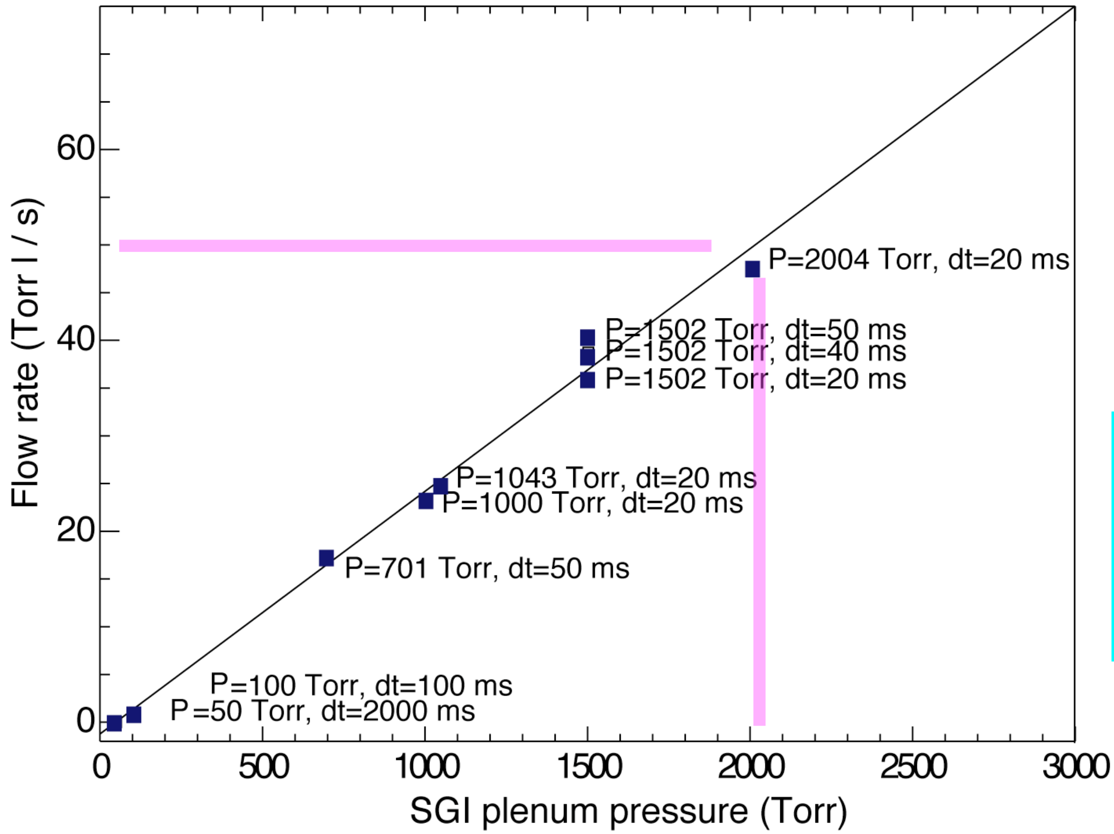
Jet divergence half-angle: 6^o - 25^o

D_2: *M = 4, T ~ 60 - 160 K, ρ ~ 5 x 10^{17} cm^{-3}, Re = 6000*

D_2: v_{therm} *~ 1100 m/s,* v_{flow} *= 2400 m/s*

$$u_{max} = \sqrt{\frac{2\gamma}{\gamma-1}\frac{kT_0}{m}},$$

Flow rate is measured *in situ* on NSTX



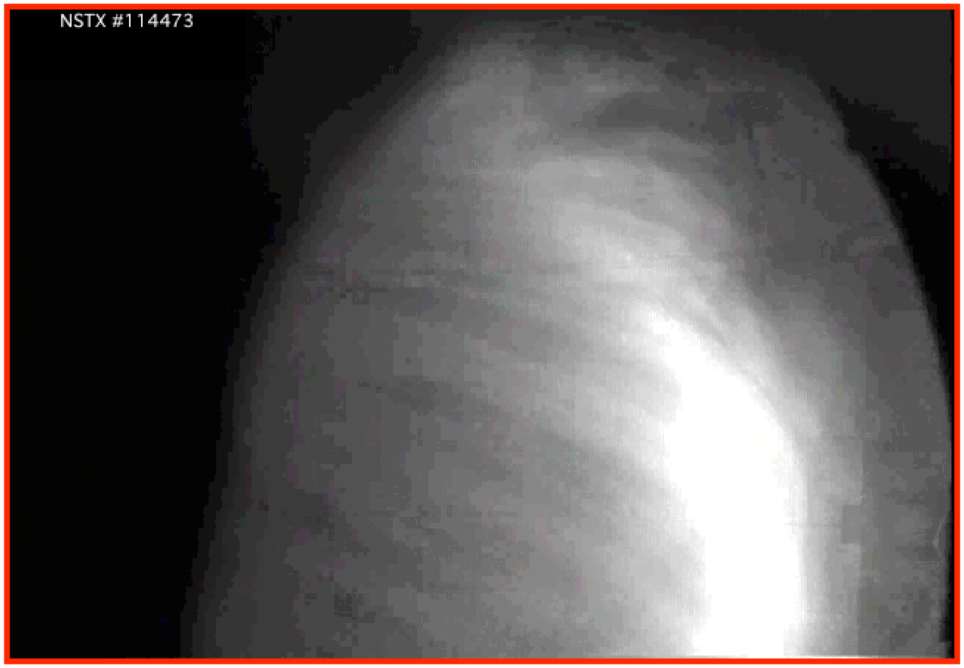
NSTX gas injector flow rates:
HFS: 10 - 50 Torr l /s
LFS: 20 - 150 Torr l /s

NSTX SGI will be operated at 50 Torr l /s (= 3.5 x 10^{21} molecules/s)

- Flow rate (Torr l / s): $\Gamma = V_{NSTX} \Delta P / \Delta t$
- Future SGI may require P_{plenum} > 2000 Torr

PPPL PRINCETON PLASMA PHYSICS LABORATORY

D_2 injections in 4-6 MW NBI heated plasmas (movies)



Shot 114473:

6 MW **high** β plasmas, injection at t=180 ms

R_{SGI}=1.604 m, Z_{SGI}=0.198 m
R_{sep}=1.49-1.52 m

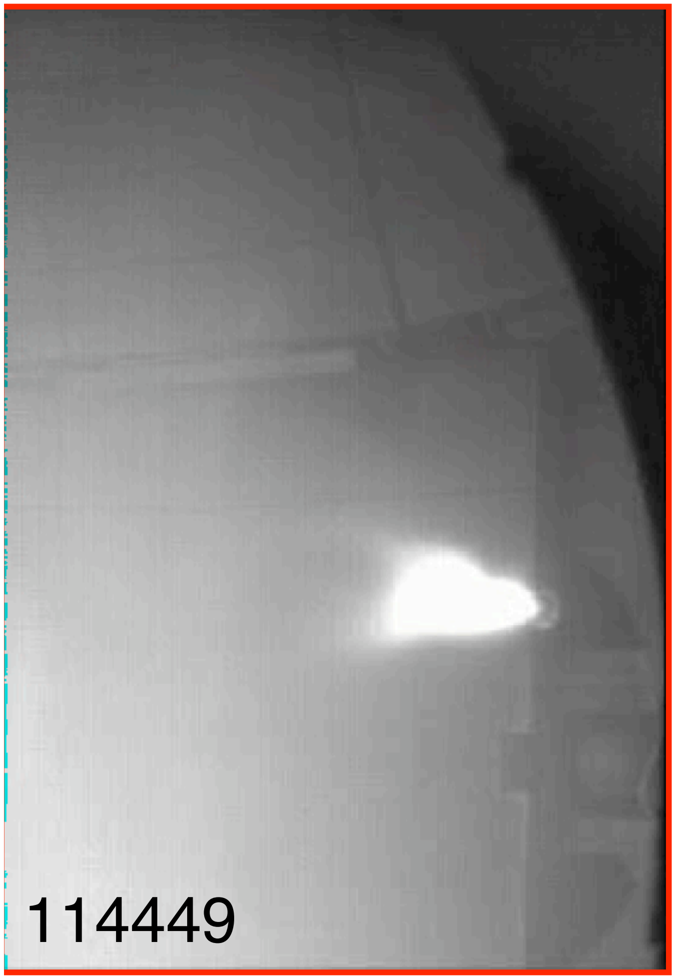
Shot 114475:

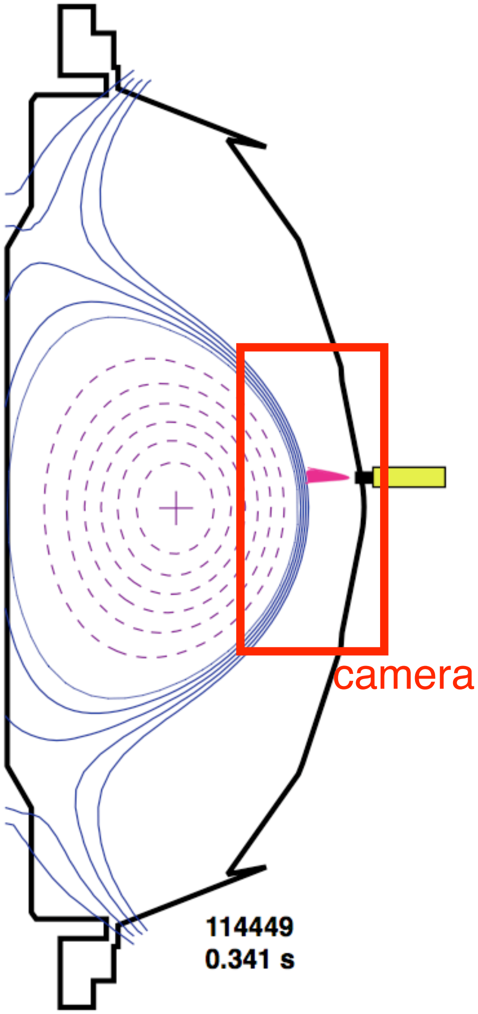
4 MW **H-mode** with type 1 ELMs, injection at t=300 ms

R_{SGI}=1.604 m, Z_{SGI}=0.198 m
R_{sep}=1.50-1.52 m

PPPL
PRINCETON PLASMA PHYSICS LABORATORY

Supersonic gas jet penetrates well through a wide scrape-off layer

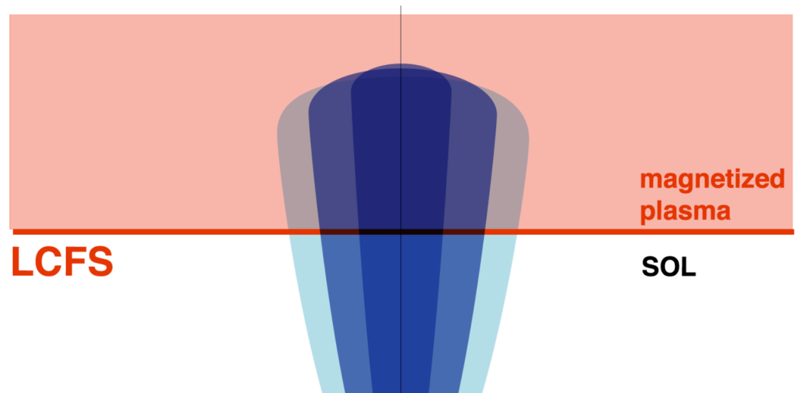




Injection in the end of discharge into a 25 cm SOL with $T_e < 5$ eV, $n_e < 5 \times 10^{12}$ cm^{-3} plasma

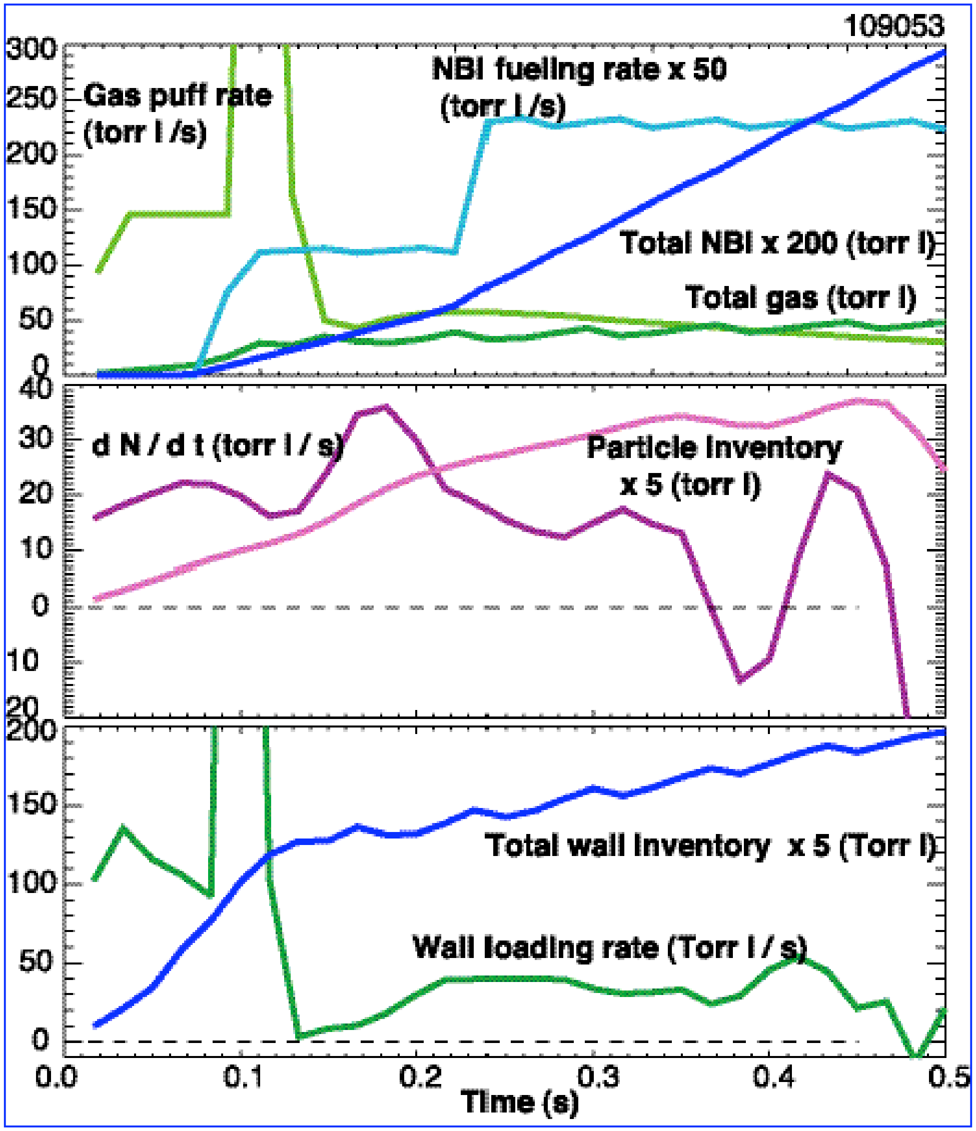
Gas jet penetration mechanism

- Single particle model is inapplicable
- Gas jet retains shape due to compressible flow considerations
- Gas jet eventually ionizes and creates a plasmoid
- Gas jet retains cluster-molecular-atomic-ion structure
- SOL/edge electrons with low T_e do not fully penetrate gas jet
- Plasmoid can not penetrate into the magnetized plasma due to insufficient velocity and high plasma kinetic and magnetic pressure
- Modeling must include particle, momentum, energy balance (Braginskii) equations with detailed reaction rates and neutral transport

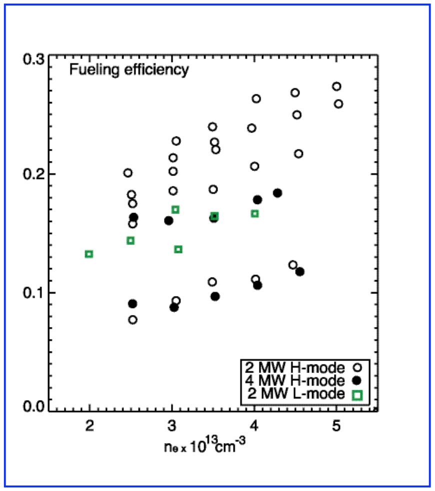


(UEDGE+DEGAS 2)

SGI is an important element in the NSTX density control program



- Conventional gas injector fueling efficiency low (< 0.15)
- High efficiency fueling will help control density in plasmas with recycling control (cryopump or lithium)
- At present recycling flux is $\Gamma_{div} < 5 \times 10^{23}$, $\Gamma_{MC} < 5 \times 10^{22}$ i/s



$$\frac{dN_p}{dt} = \Gamma_{gas} + \Gamma_{NBI} + \Gamma_{NBI\_cold} + \Gamma_{NBI\_cryo} + \Gamma_{wall} + \Gamma_{pump} + \frac{dN_n}{dt}$$

What we would like to *do* with SGI

- Start-up fueling
- Development of long-pulse fueling scenario -
  - L-mode flat-top fueling
  - H-mode access and flat-top fueling
- ELM control

What we would like to *measure* with D_2

- Fueling efficiency as a function of SGI - LCFS distance

$$\eta = \frac{dN_i / dt}{\Gamma}$$

- Characterize edge plasma conditions (T_e, n_e, n_0, magnetics, plasma rotation, impurities)
- Determine impact on core plasma performance (τ_e, τ_p, E_{stored})
- Determine impact on wall saturation limit

Fueling experiments with D_2

Ohmic L-mode plasmas

- Set-up an LSN (PF2L) shot (2-3 shots) $\kappa=1.8-1.9$, $\delta=0.5$, drsep=-2, outer gap 7-10 cm (R_{LCFS} = 150-154 cm)
- Scan SGI-LCFS distance by 1 cm (5-8 shots). SGI setup: 100 ms pulse, start at 200 ms
- Do 10 min GDC between shots
- Use SGI instead of Inj#1, #2 for start-up (5 shots)

Aux. Heated L- and H-mode plasmas

- Do a small scan around optimal SGI position
- Do injections into ELM-free H-mode flat-top
- Do injections into ELM-y H-mode

H-mode access with SGI fueling

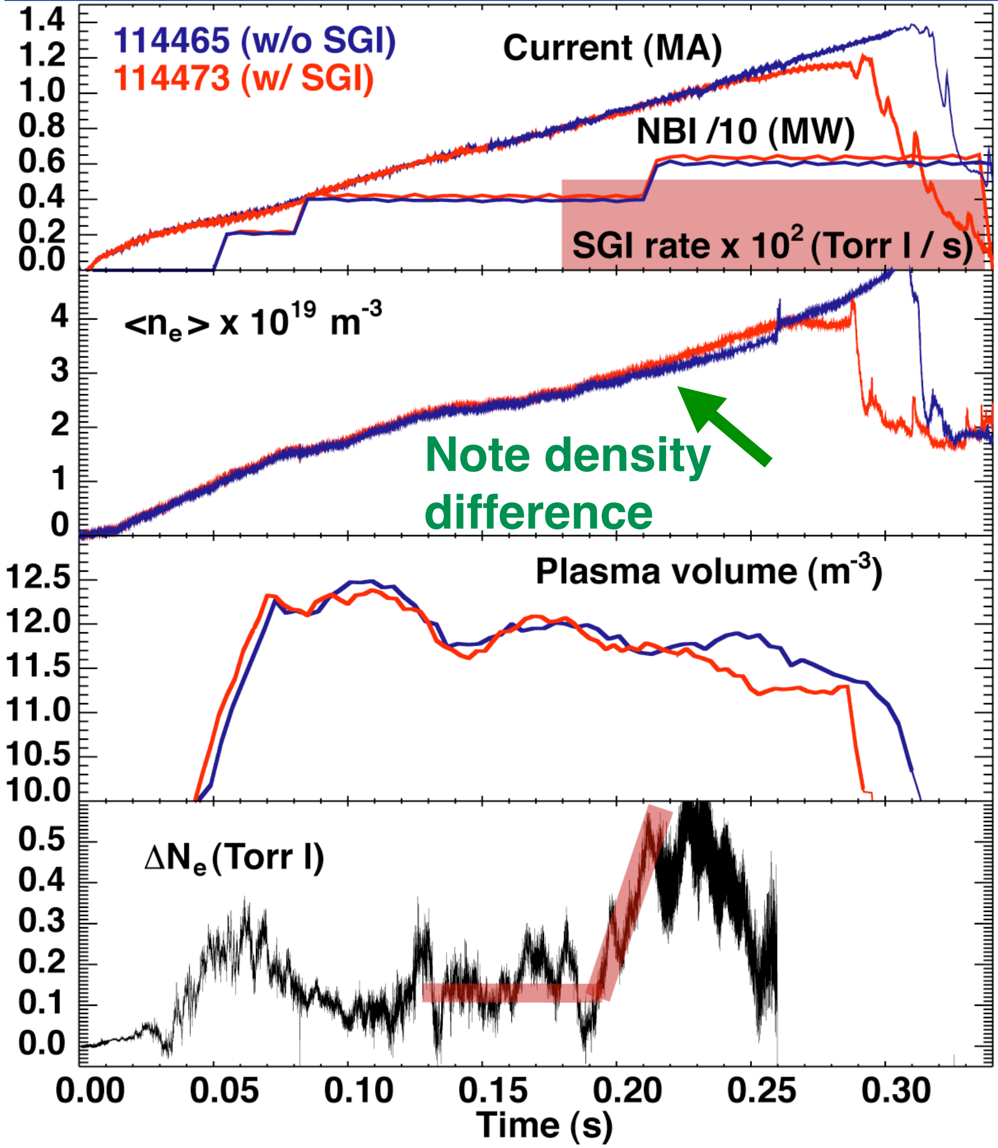
- Poloidal fueling location matters for the historically developed H-mode access scenarios on NSTX (R. Maingi)
- HFS-fueled LSN H-modes are most reproducible, L-H threshold lower (R. Maingi)
- XP 440 "Early H-mode" produced long H-mode plasmas with LFS fueling only. Required every 2^{nd} He conditioning shot and 5+5 min He GDC.
- Use the XP 440 template (112548) and replace the conventional LFS injector with SGI, attempt to reach higher n_e with less gas and less wall saturation
- Inject D_2 in an HFS-fueled LSN H-mode to obtain higher density

ELM control with SGI

- ELM Type I, III, V have been observed on NSTX
- Gas and pellet injection is a proven ELM mitigation technique (change ELM type from I to III, change frequency and amplitude of type III by means of increasing power flow through the edge)
- Use SGI to inject D_2 and/or He to control edge power flow and/or pedestal T_e, n_e, p_e to delay ELMs, or change ELM type

Backup

Supersonic gas jet fueling efficiency η is 3-4 times higher than η of a conventional gas puff



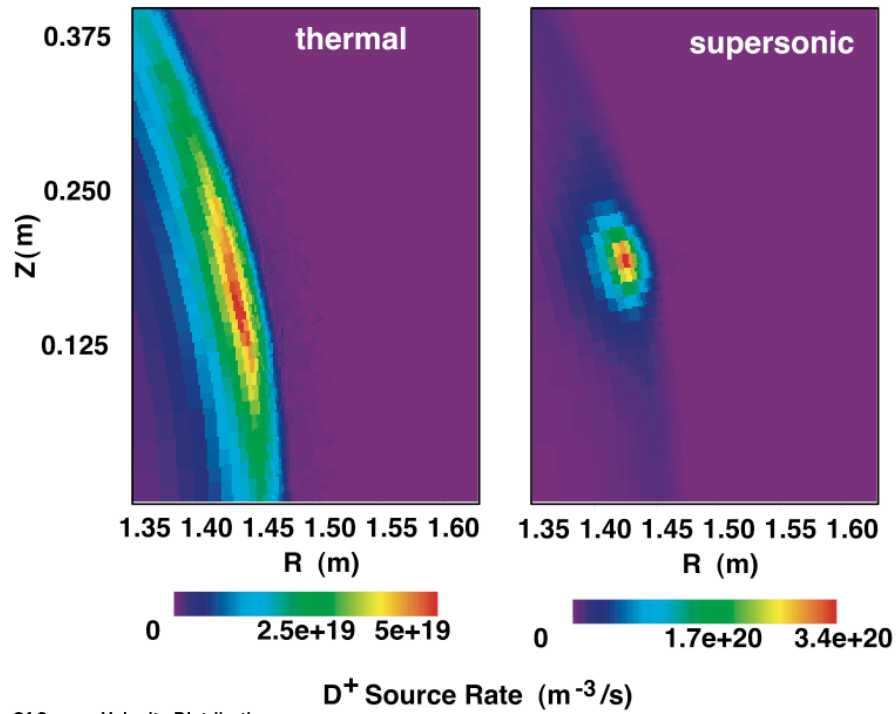
- Compare two 6 MW NBI high-β pulses with and without supersonic gas injection
- Fueling efficiency

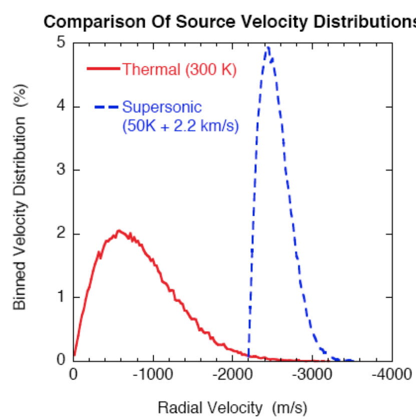
$$\eta = \frac{dN_i/dt}{\Gamma_{gas}}$$

- Γ_{gas}~ 50 Torr l / s
- dN_e/dt = 0.4 / 0.025 = 16 T l / s
- η = 0.3-0.4
- **Preliminary result - based on one shot**

DEGAS 2 neutral transport modeling consistent with general features of supersonic gas injection

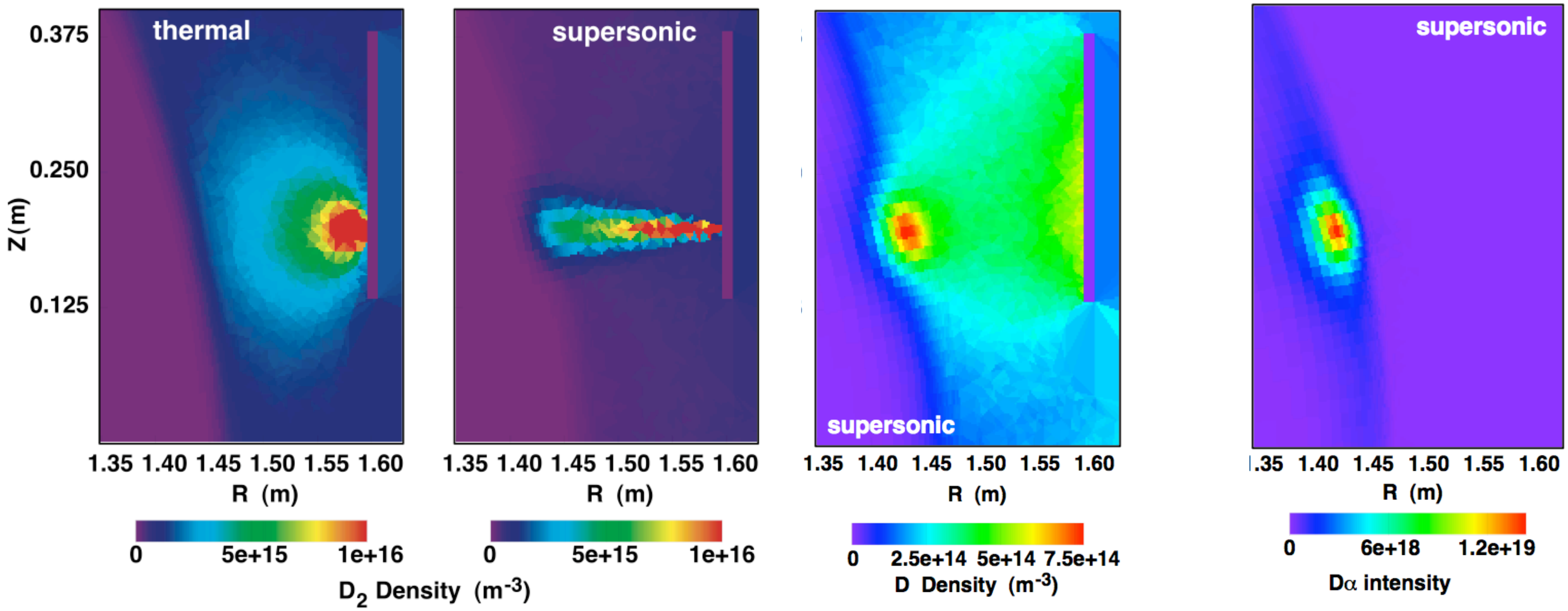
- DEGAS 2 neutral transport model
- Conventional D_2 injection: *T = 300 K*
- Supersonic D_2 injector: *T= 50 K,* v_{flow} *= 2200 m/s*
- Not self-consistent: fixed T_e, n_e, are used
- D_2 injected from a 5 mm nozzle
- **Good starting point for experiment interpretation**





DEGAS 2
D. P. Stotler

DEGAS 2 neutral transport modeling consistent with observed features of supersonic gas injection



Molecular density

Atomic density

D_α intensity

DEGAS 2
D. P. Stotler

PPPL PRINCETON PLASMA PHYSICS LABORATORY