XP516: Supersonic gas jet fueling experiments on NSTX

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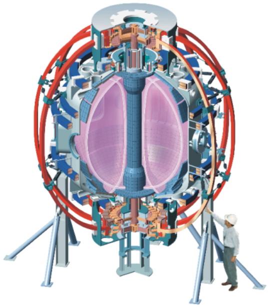
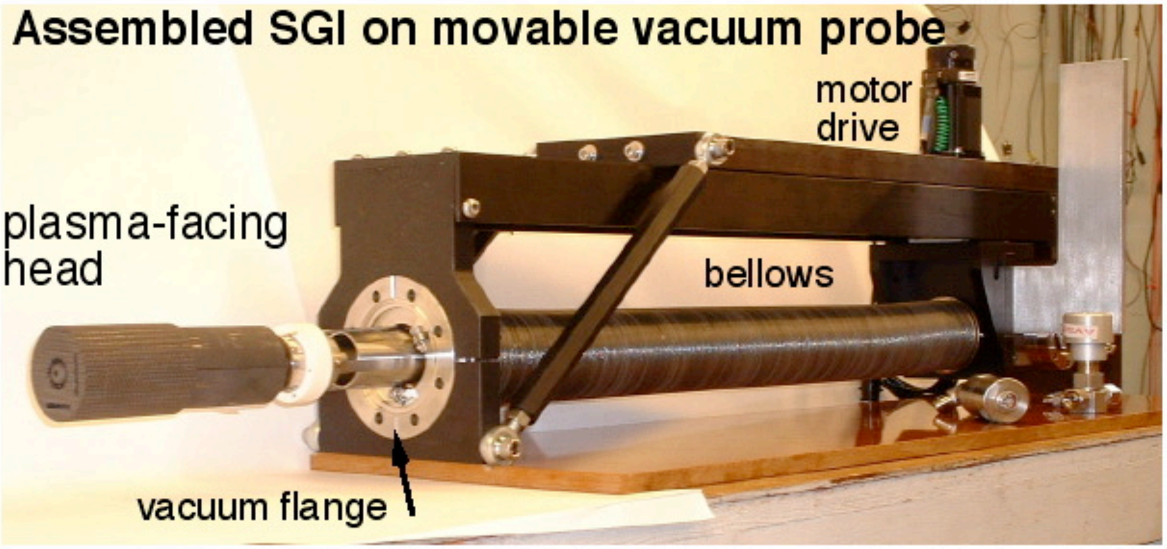
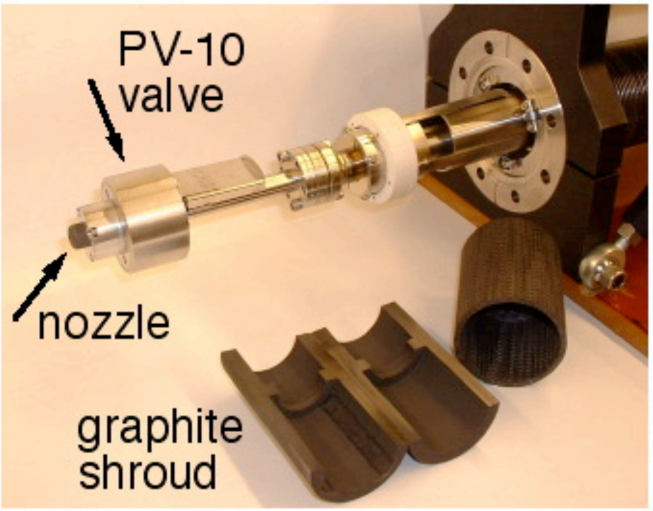


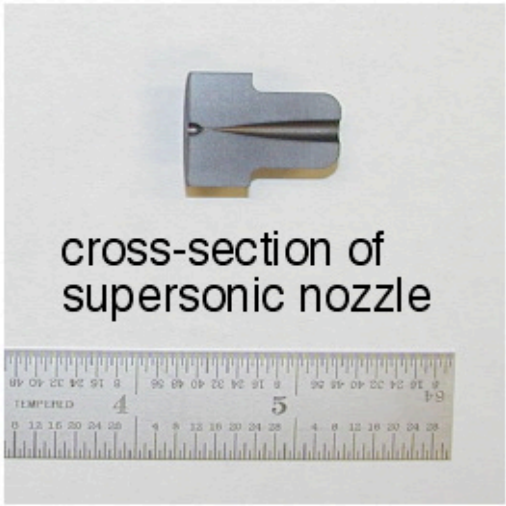
FY'04 status

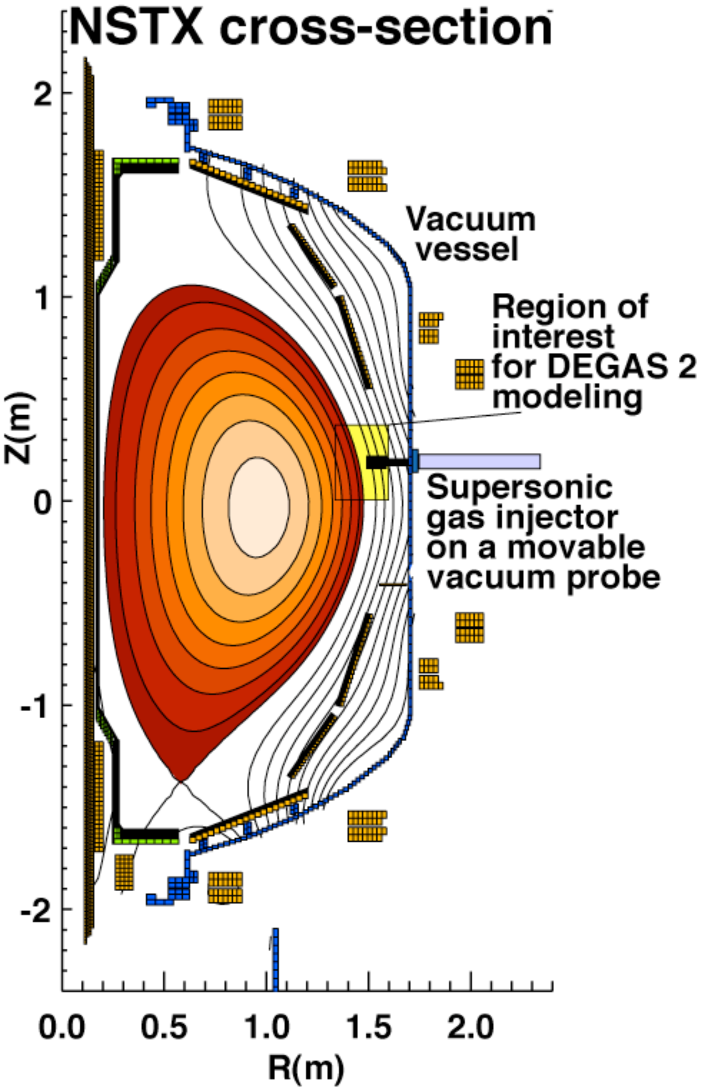
- XMP-35 "SGI commissioning" successfully completed
- No exp. time was allocated for a physics experiment
- Preliminary results are encouraging: higher fueling efficiency, high gas jet collimation (expect higher wall saturation limit), good SOL penetration, compatibility with H-mode edge

Supersonic gas injector has become operational in FY’04

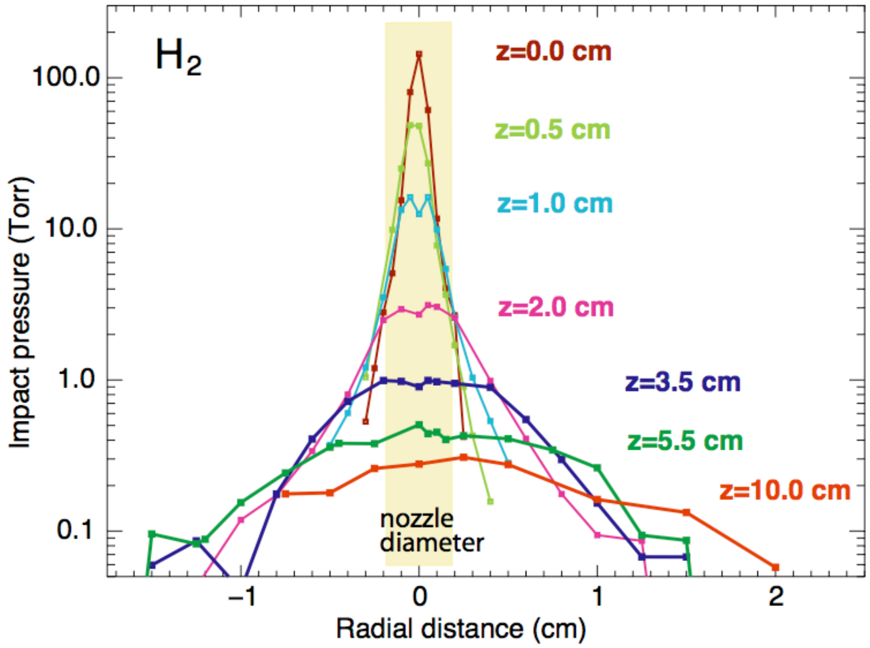


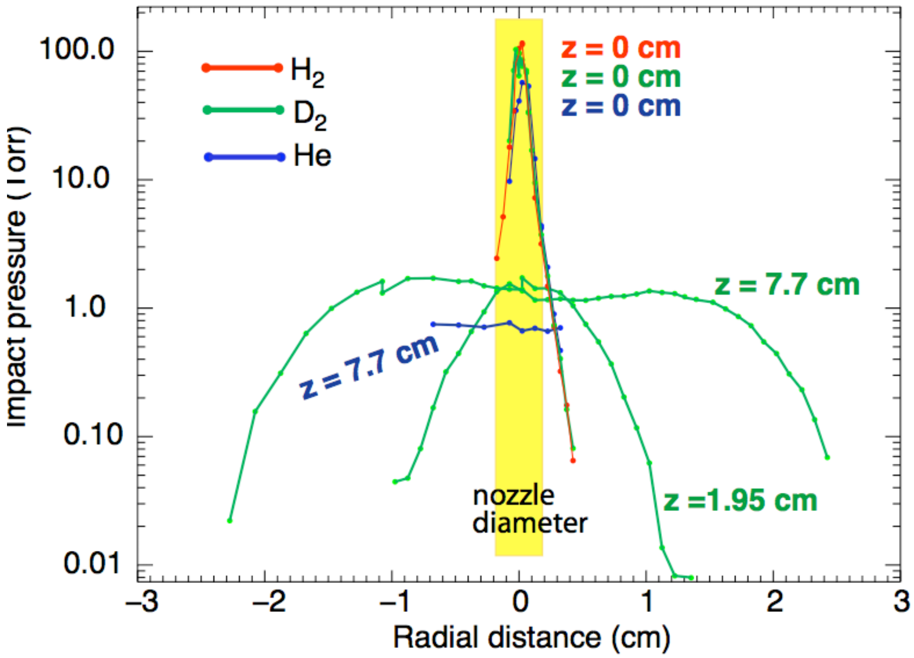






Off-line pressure measurements confirm high Mach number and highly collimated gas jet shape





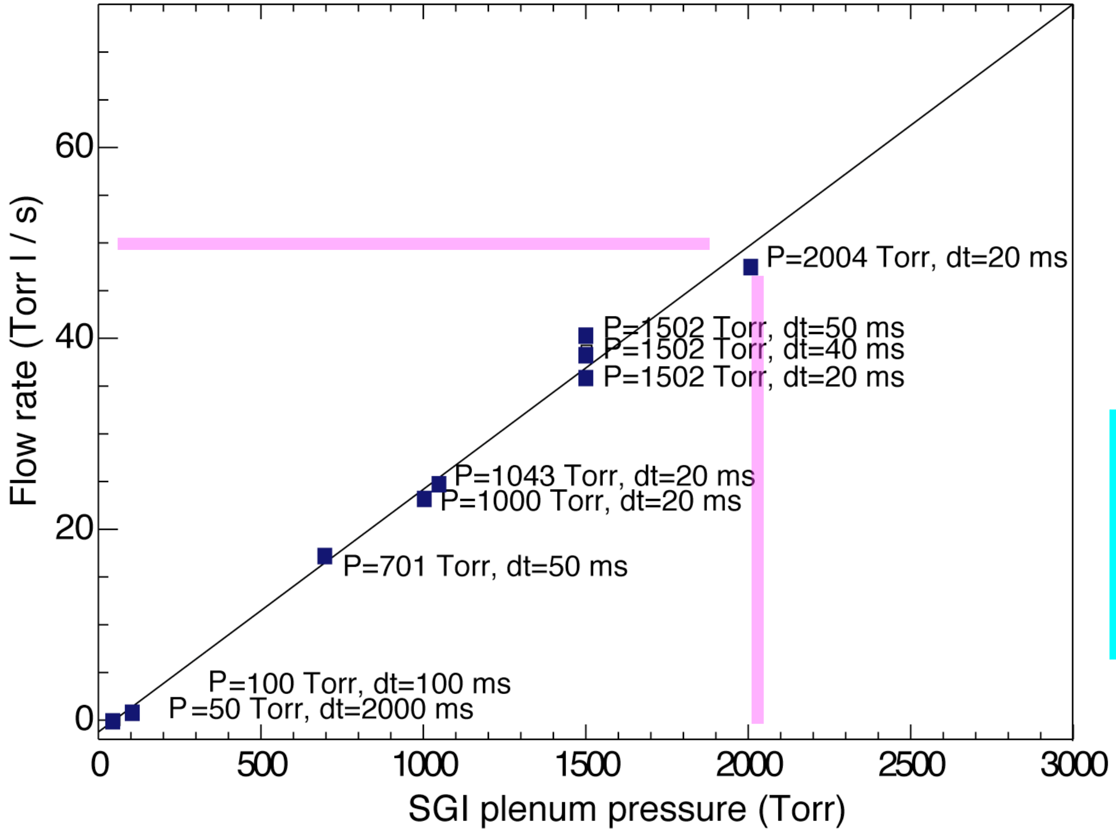
Jet divergence half-angle: 6^o - 25^o

D_2: *M = 4, T ~ 60 - 160 K, $\rho \sim 5 \times 10^{17}$ cm^{-3}, Re = 6000*

D_2: $v_{therm} \sim 1100$ *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

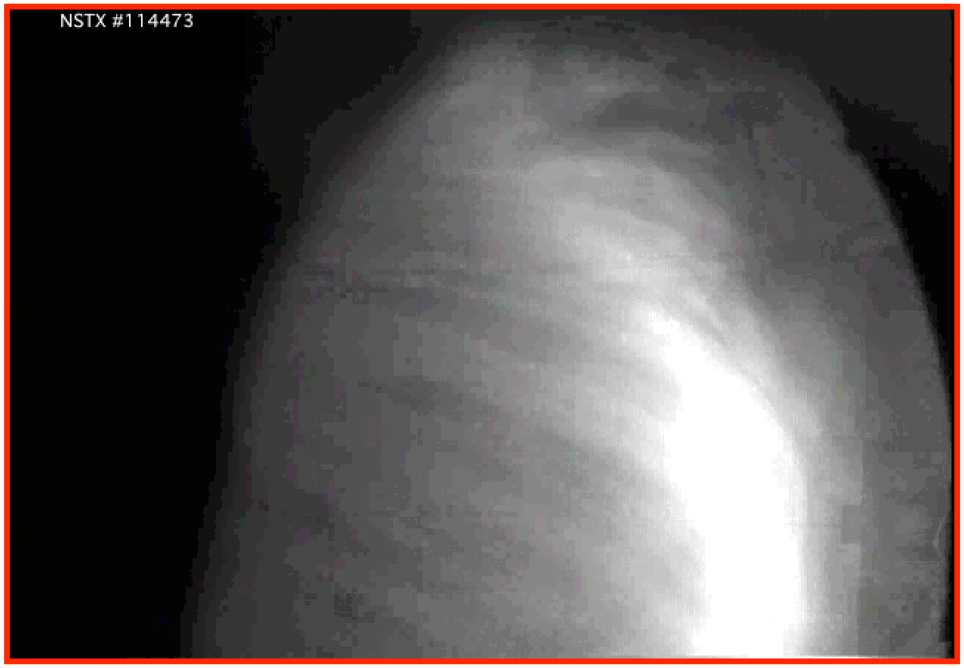


NSTX gas injector flow rates:
HFS: 10 - 50 Torr l /s
LFS: 20 - 150 Torr l /s

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

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

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



Shot 114473:

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

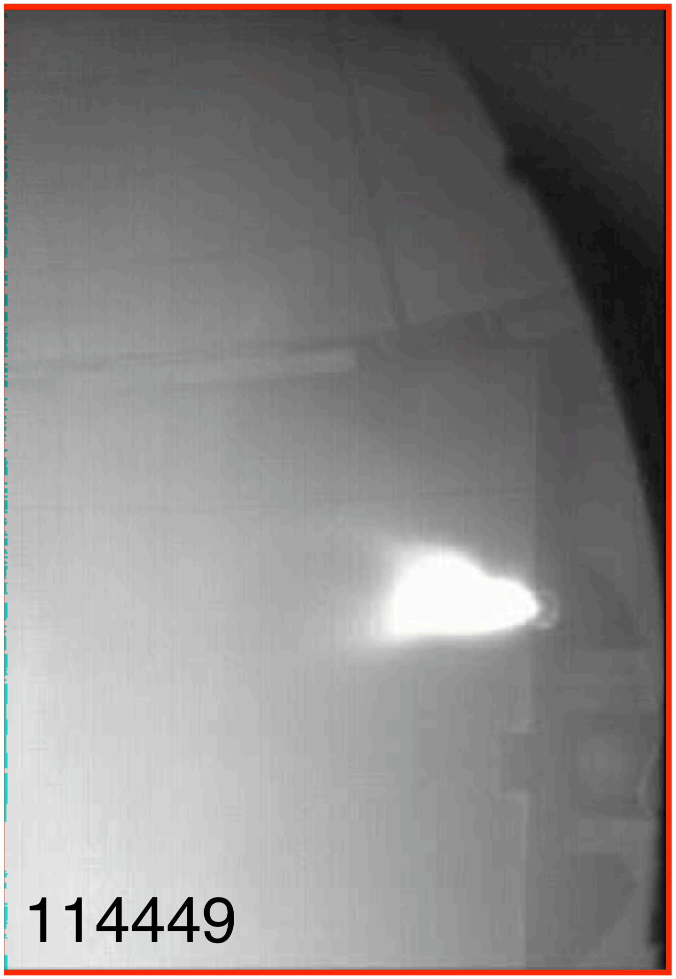
R_{SGI}=1.604 m, Z_{SGI}=0.198 m
R_{sep}=1.49-1.52 m

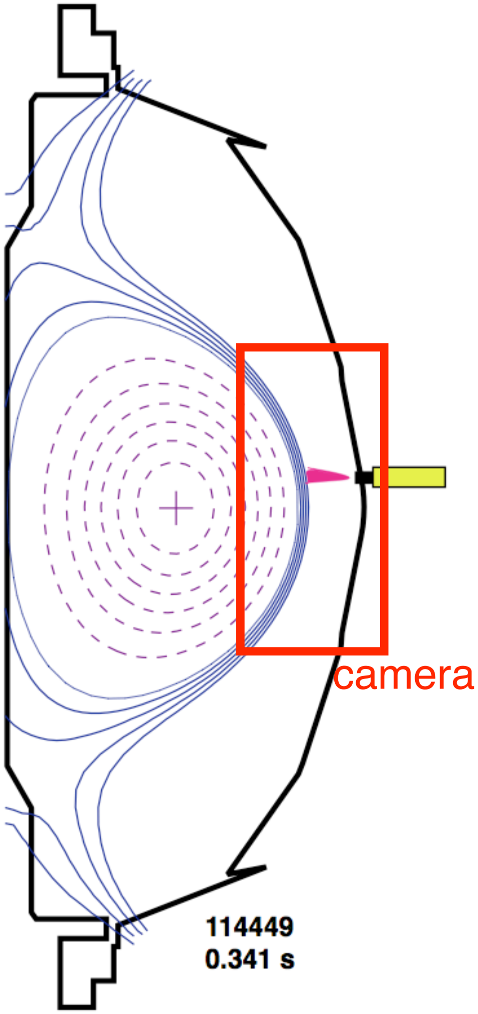
Shot 114475:

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

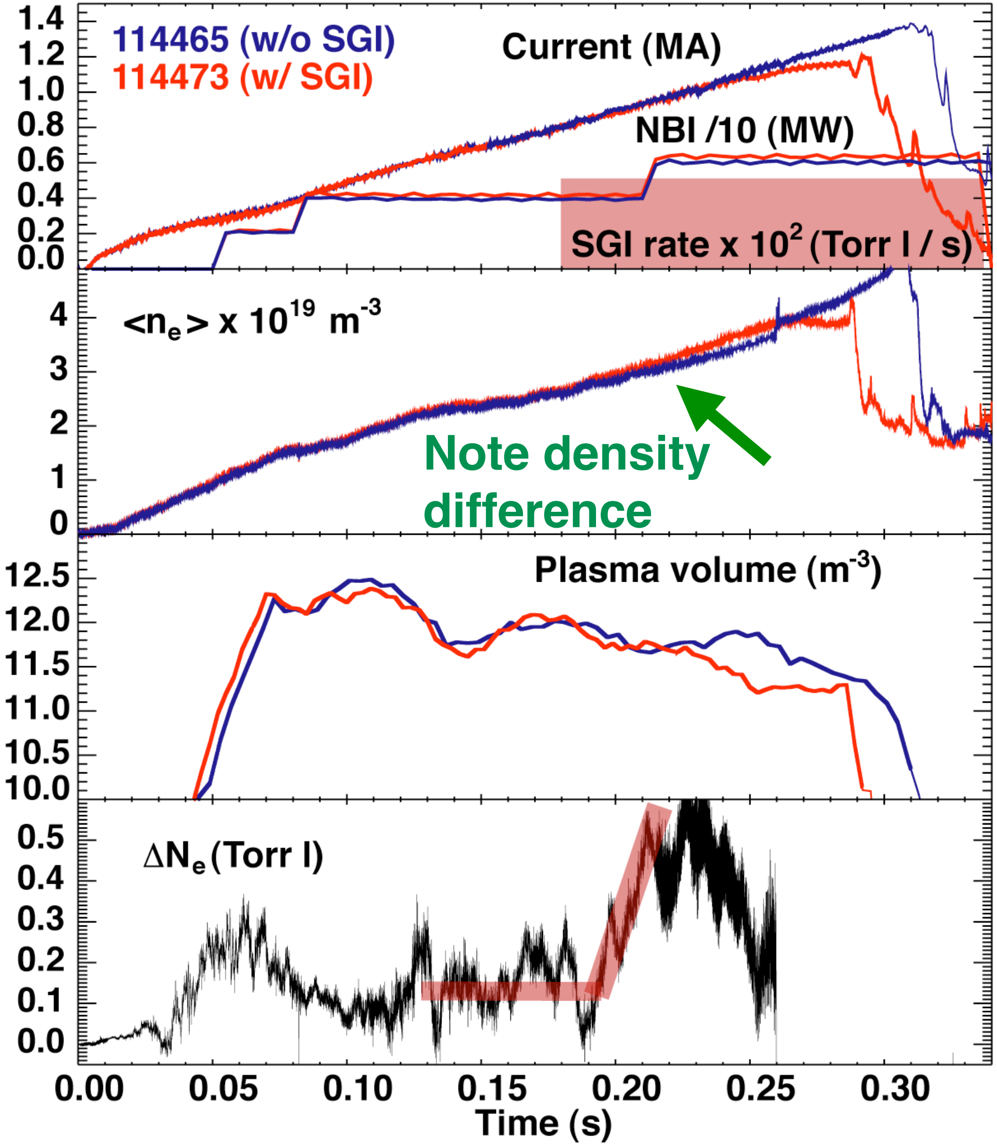
Supersonic gas jet penetrates well through a wide scrape-off layer





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

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



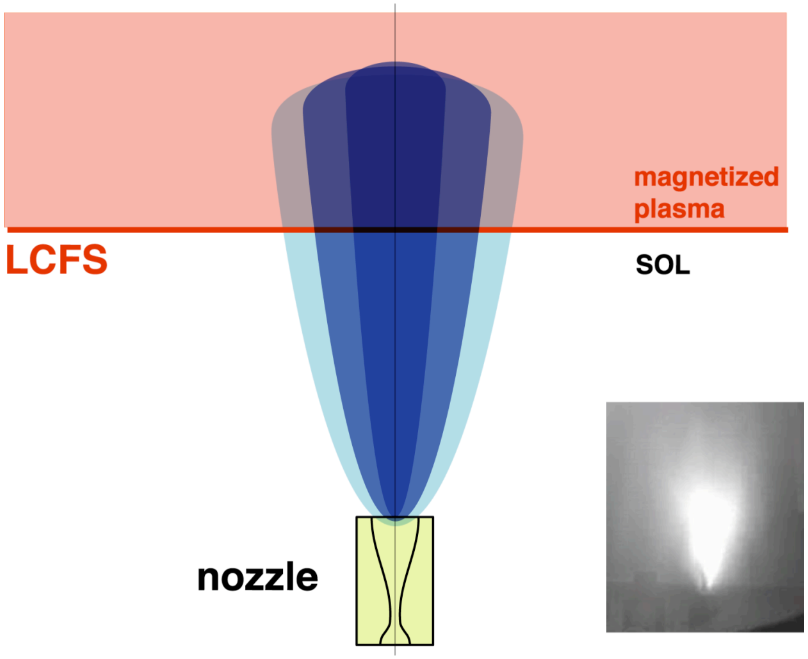
- Compare two 6 MW NBI high-β pulses with and without supersonic gas injection
- Fueling efficiency

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

- 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**

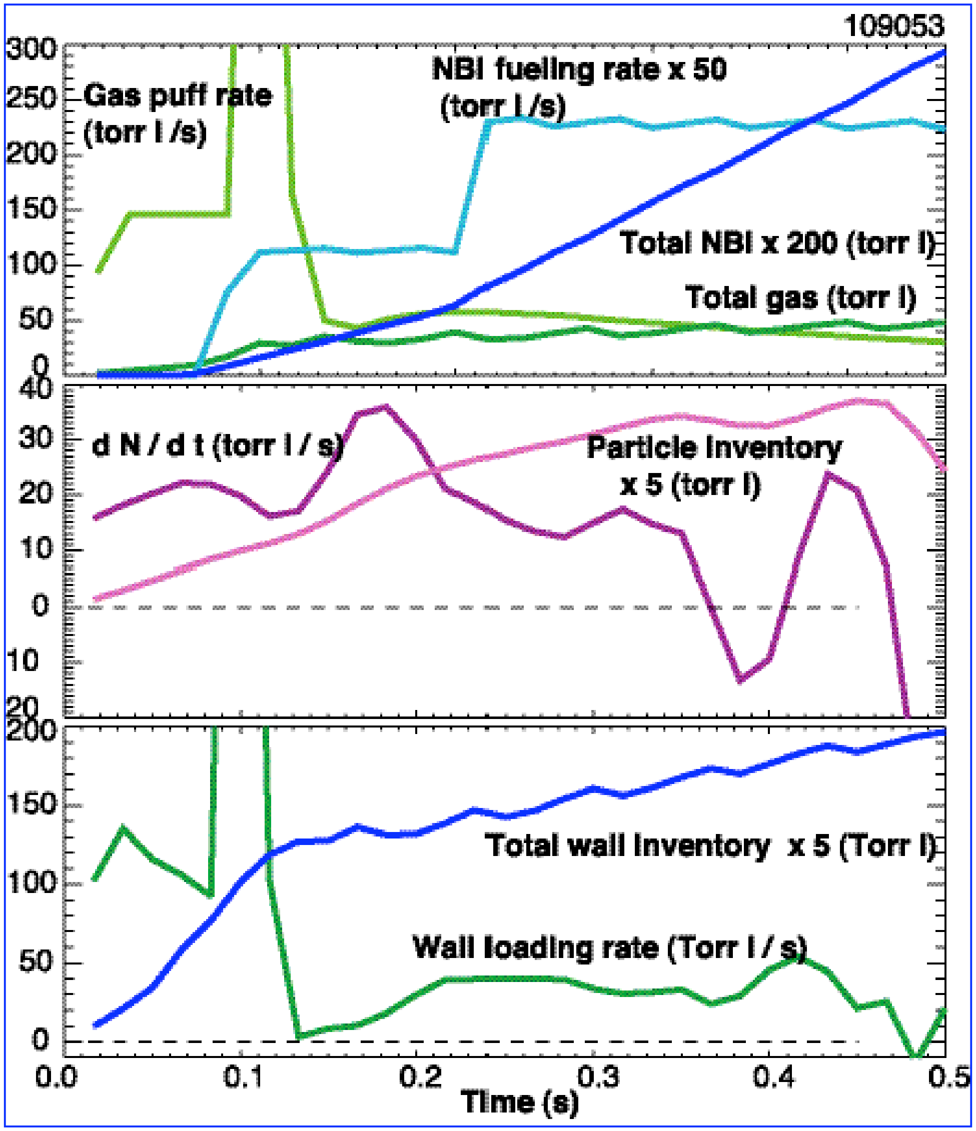
Gas jet penetration mechanism

- Single particle model is inapplicable
- Gas jet retains shape due to compressible flow physics
- Gas jet eventually ionizes and creates a high density 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 deep into the magnetized plasma due to insufficient velocity and high plasma kinetic and magnetic pressure
- Self-consistent modeling must include particle, momentum, energy balance (Braginskii) equations with detailed reaction rates and neutral transport

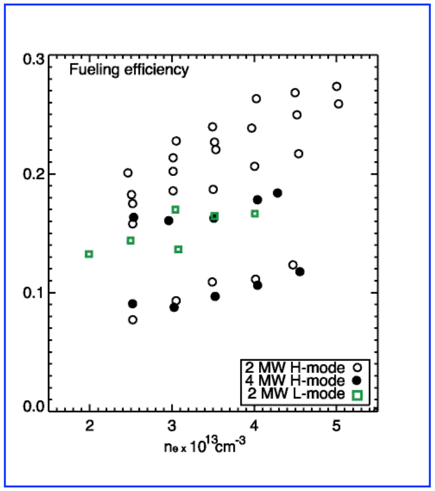


(UEDGE+DEGAS 2)

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 in XP516

- Fueling in the initial phase of plasma discharge
- L-mode fueling characterization and optimization
- H-mode access and flat-top fueling

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 experiment in L-mode

Ohmic L-mode plasmas (10-13 shots)

- Set-up an LSN (PF2L) shot (2-3 shots)
  κ=1.8–1.95, δ=0.4–0.5, drsep=-2, outer gap 7-10 cm
  (R_{LCFS} = 150-154 cm)
- Scan SGI-LCFS distance by 1-2 cm (8-10 shots).
  SGI setup: 70-100 ms pulse, start at 200 ms
- Do 10 min GDC between shots

- Use SGI instead of Inj#1, #2 for initial plasma density ramp (5 shots), continue fueling with Inj#1 and CS injector

Fueling experiment in H-mode

NBI-heated H-mode plasmas (10-13 shots)

H-mode tolerance to supersonic gas jet

- Set-up an ELM-free of smal ELM H-mode shot (2-3 shots) LSN with PF2L, $\kappa=2.0$, $\delta=0.55$, drsep=-1, outer gap 10 cm (R_{LCFS} = 148-150 cm)
- Scan SGI-LCFS distance by 2 cm (4 shots). Start at R=158 cm, scan SGI drive inward. SGI setup: 100-200 ms pulse
- Do 10 min GDC between shots

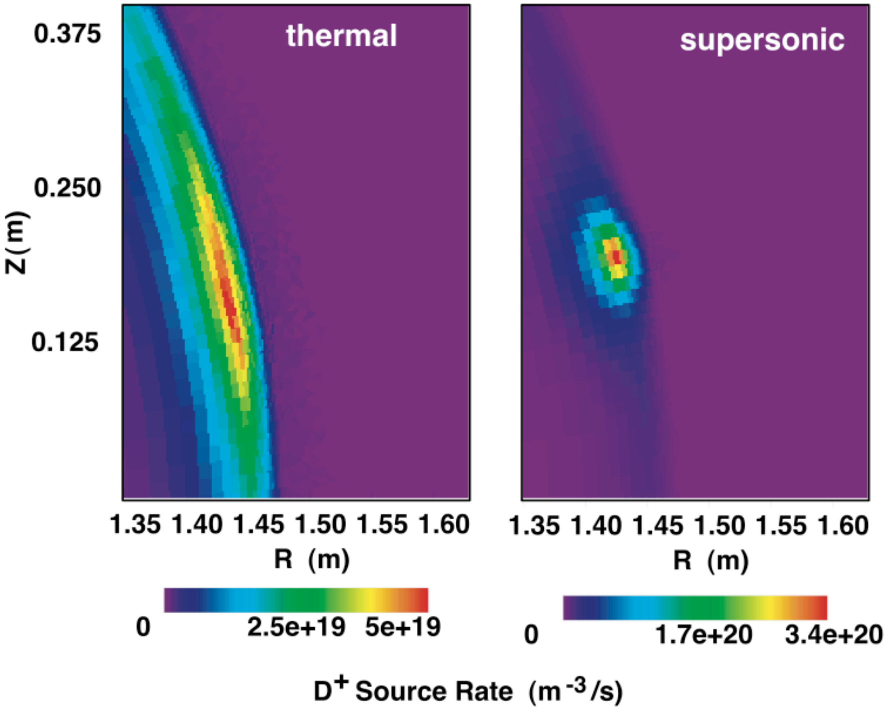
H-mode access with supersonic gas jet

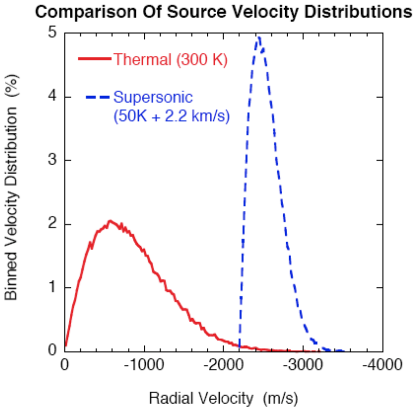
- Replace CS injector with SGI and repeat for three SGI flow rates (30, 45, 60 Torr l / s). SGI location will be determined from above experiment

Backup

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

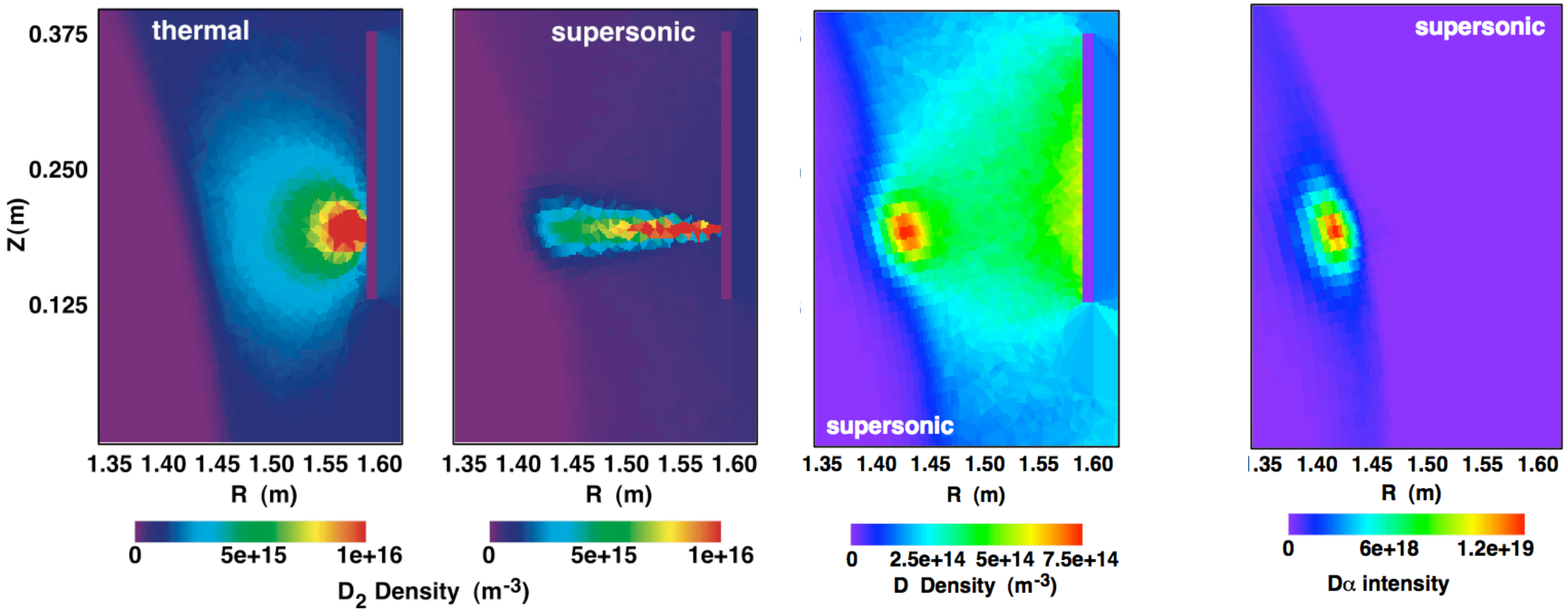
- DEGAS 2 neutral transport model
- Conventional D_2 injection: $T = 300\ K$
- Supersonic D_2 injector: $T = 50\ K,\ \ v_{flow} = 2200\ m/s$
- Not self-consistent: fixed T_e, n_e, are used
- D_2 injected from a 5 mm nozzle
- **Good starting point for experiment interpretation**





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
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