Supported by Office of Fusion Energy Sciences · Office of Science

Supersonic gas jet fueling experiments in NSTX*

V. A. Soukhanovskii (LLNL),
H. W. Kugel, R. Kaita, A. L. Roquemore, M. G. Bell,
R. E. Bell, D. A. Gates, T. Gray, B. P. LeBlanc,
J. E. Menard, D.P. Stotler, K. Williams (PPPL),
R. Raman (U. Washington),
C.E. Bush, R. Maingi (ORNL),
K. C. Lee (UC-Davis),
R. Maqueda (Nova Photonics),
and the NSTX team

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

Contributed Oral NO1.14

48th APS – DPP Meeting

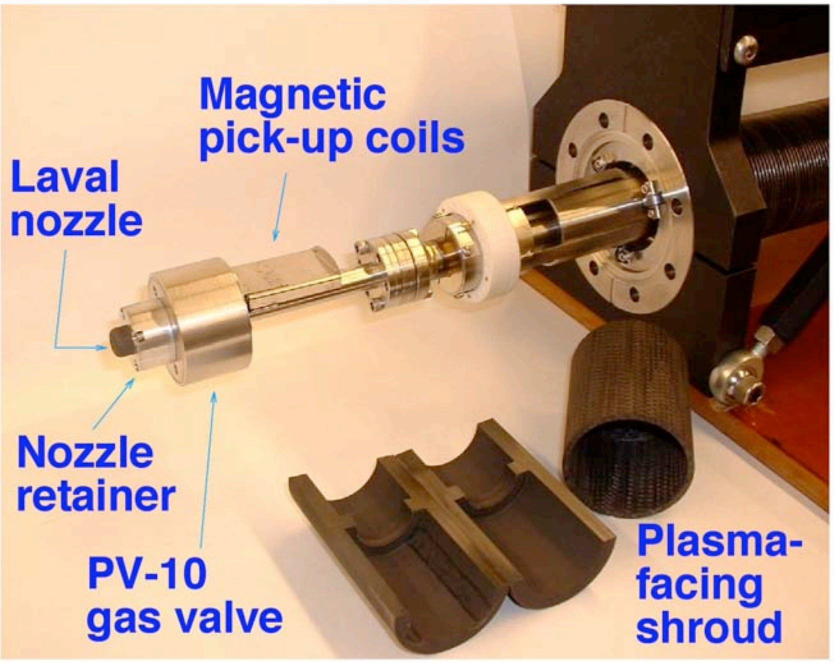
30 October - 3 November 2006
Philadelphia, PA

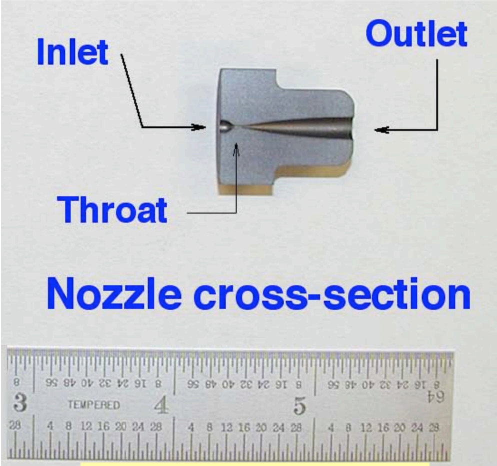
- Culham Sci Ctr
- U St. Andrews
- York U
- Chubu U
- Fukui U
- Hiroshima U
- Hyogo U
- Kyoto U
- Kyushu U
- Kyushu Tokai U
- NIFS
- Niigata U
- U Tokyo
- JAERI
- Hebrew U
- Ioffe Inst
- RRC Kurchatov Inst
- TRINITI
- KBSI
- KAIST
- ENEA, Frascati
- CEA, Cadarache
- IPP, Jülich
- IPP, Garching
- ASCR,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

---

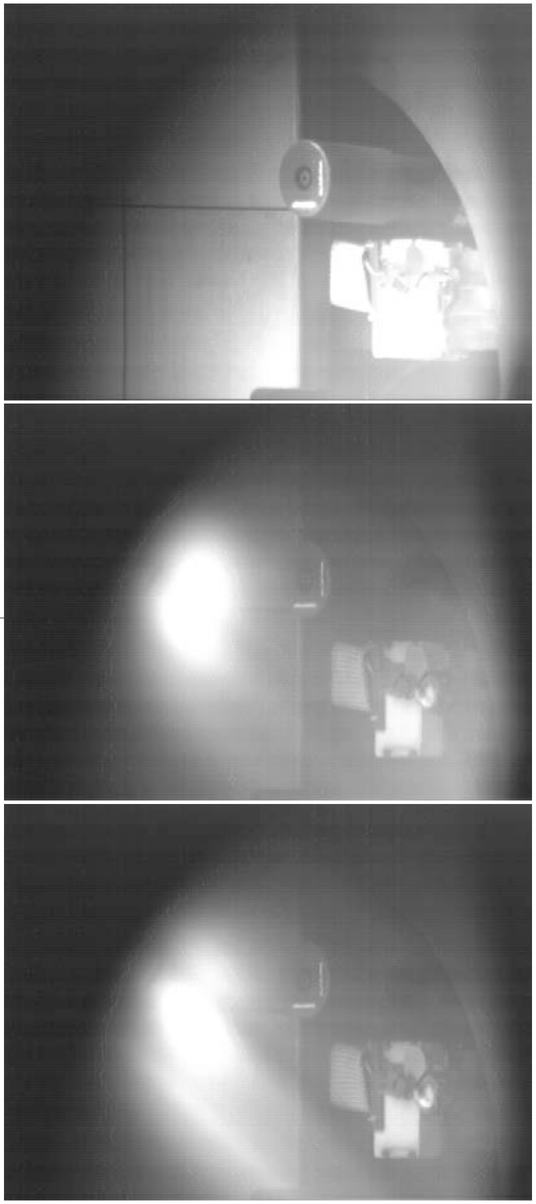
* This research was supported by the U.S. Department of Energy under contracts No. W-7405-Eng-48, DE-AC02-76CH03073, DE-AC05-00OR22725, and W-7405-ENG-36.

H-mode fueling optimization and density control are studied on NSTX using supersonic gas jet





L = 23.4 mm
d_{throat} = 0.254 mm

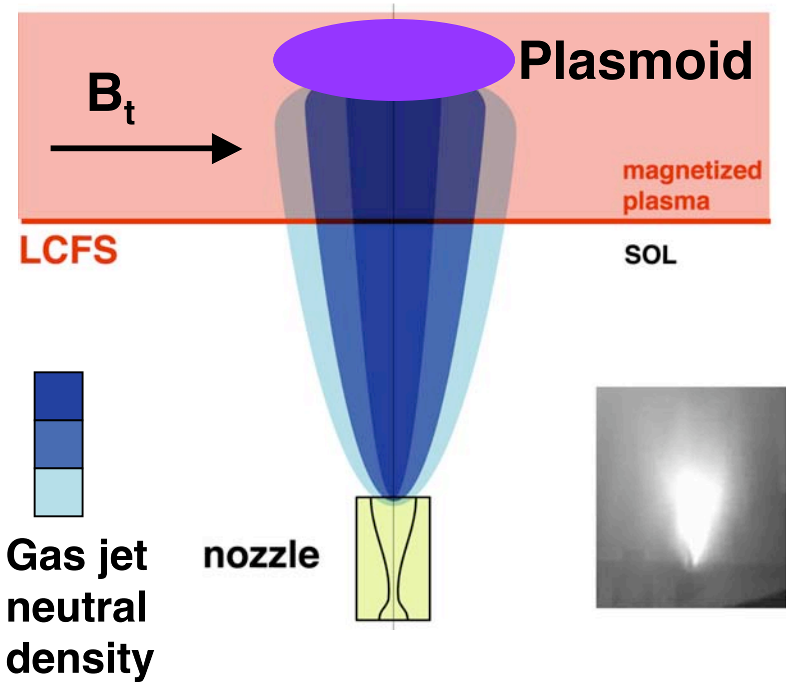


Supersonic gas injector installed on NSTX in 2004, experiments conducted in 2005-2006

- NSTX SGI is operated at flow rates 20-65 Torr l /s ($1.5 - 4.5 \times 10^{21}$ s^{-1}) - unique fueling tool
- Supersonic deuterium jet:
  - ✓ Jet divergence half-angle: 6° - 25° (measured)
  - ✓ Mach number $M = 4$ (measured)
  - ✓ Estimated: T ~ 60 - 160 K, $n < 5 \times 10^{23}$ m^{-3}, $Re = 6000$, $v_{flow} = 2400$ m/s , $v_{therm} \sim 1100$ m/s

Supersonic gas jet penetration mechanism is different than that of conventional gas injection

- Unlike conventional gas injection, penetration depth of supersonic gas jet cannot be described by single neutral particle ionization / charge exchange penetration model
- Supersonic gas jet is a low divergence high pressure, high density gas stream with low ionization degree - bulk edge/SOL electrons do not fully penetrate gas jet
- High density plasmoid blocks jet from deep penetration into magnetized plasma
- Depth of penetration is ultimately determined by jet pressure and plasma kinetic and magnetic pressure
- Desirable for fueling are molecular clustering and/or droplet formation in jet achieved at very high pressure and cryogenic temperatures

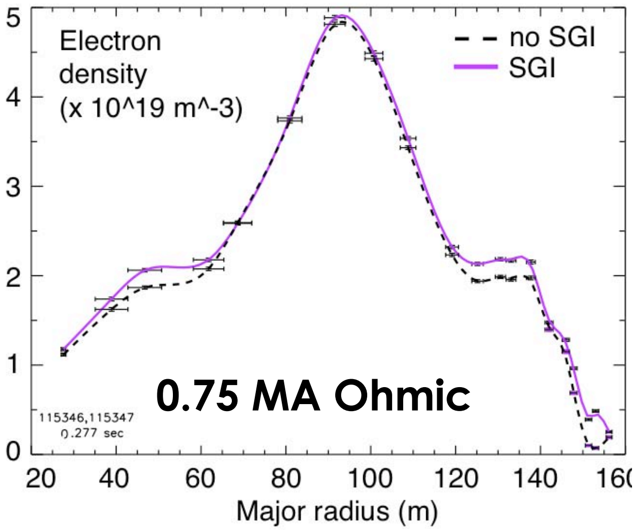


References: Rozhansky et al. NF 46 (2006) 367
Lang et. al. PPCF 47 (2005) 1495

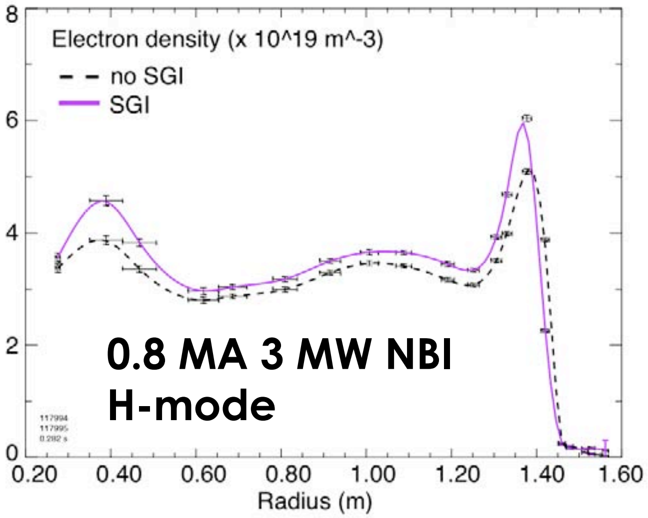
Supersonic gas jet weakly perturbs plasma edge

During supersonic gas injection

- ✓ In ohmic plasmas edge density rise is often observed
  - ✓ In H-mode plasmas, n_e “ear” height and width often increase, edge/pedestal and/or core T_e decrease by < 15 %

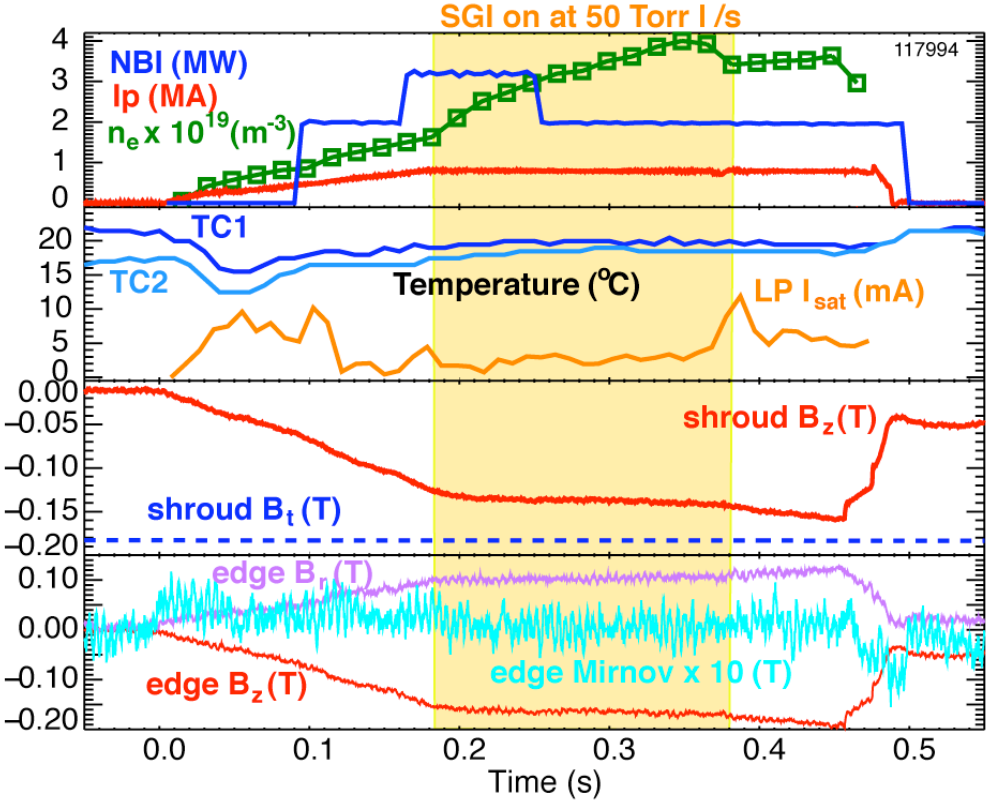


0.75 MA Ohmic

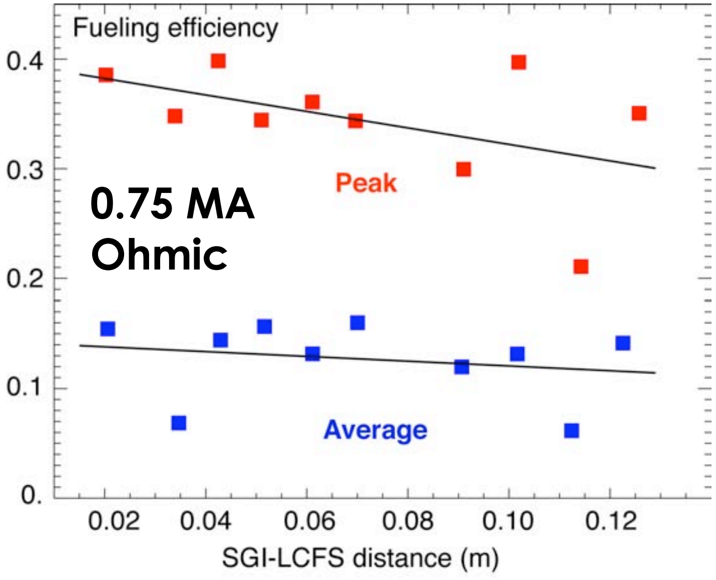


0.8 MA 3 MW NBI H-mode

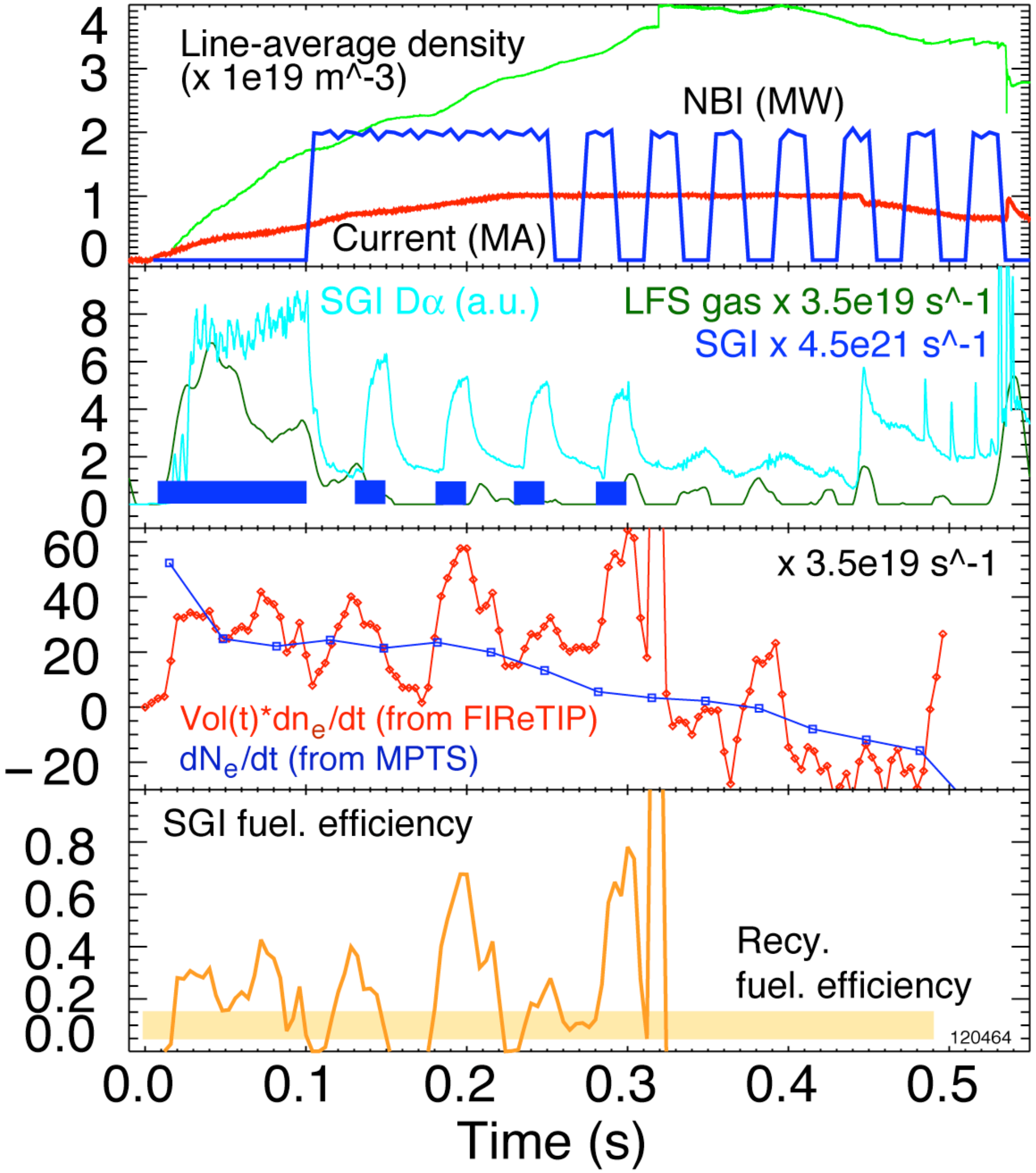
- SGI Langmuir probe does not typically show T_e reduction or I_{sat} increase
- Magnetic sensors on SGI do not show any EM perturbations
- Plasma turbulence filaments (“blobs”) or ELM perturbations traverse through gas jet plasmoid
- SGI remains at room temperature
- In ohmic plasmas, SGI-LCFS distance held at 2-15 cm
- In NBI-heated plasmas, SGI-LCFS distance held at 6-8 cm



Supersonic gas jet fueling efficiency is x 2-5 higher than that of conventional gas injection

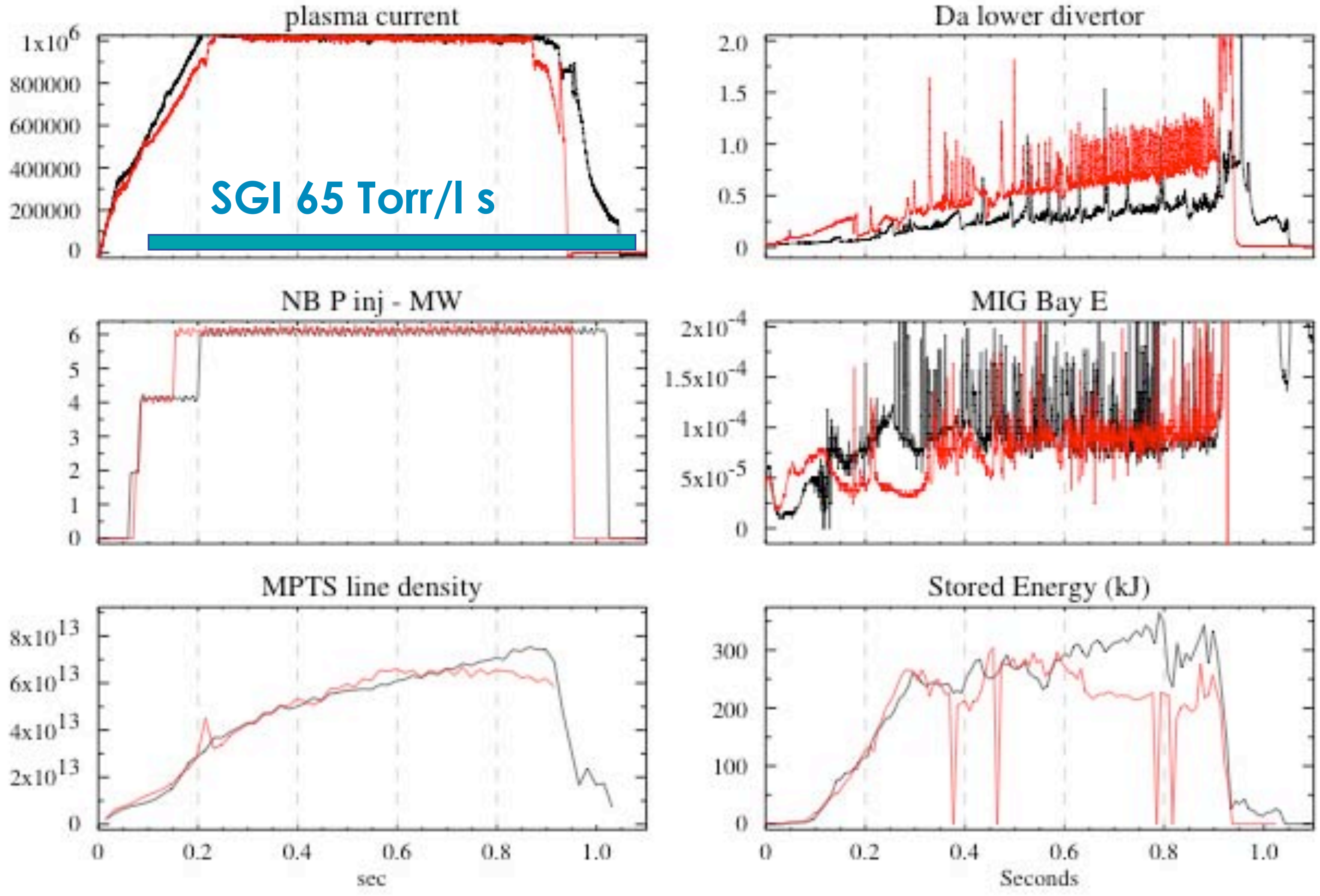


- Instantaneous fueling efficiency (FE) is calculated as $dN_e/dt * \Gamma^{-1}$
- In ohmic plasmas, FE is a function of SGI-LCFS distance (SGI at $\Gamma \sim 40$ Torr l /s) in LSN configuration
- FE in inner wall -limited plasmas higher than in diverted config.'s
- FE in LSN H-mode plasmas 0.1-0.4 (SGI at $\Gamma \sim 65$ Torr l /s ~ 4.2 x 10^{21} s^{-1}).



IW-limited L-mode target plasma for lithium experiments

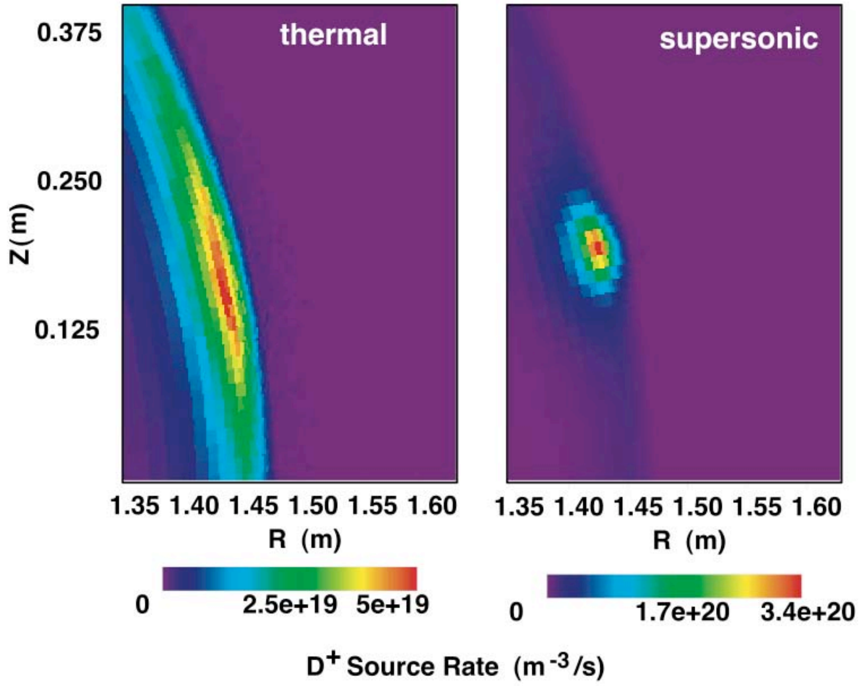
Encouraging initial results obtained toward the goal of reducing uncontrolled HFS fueling

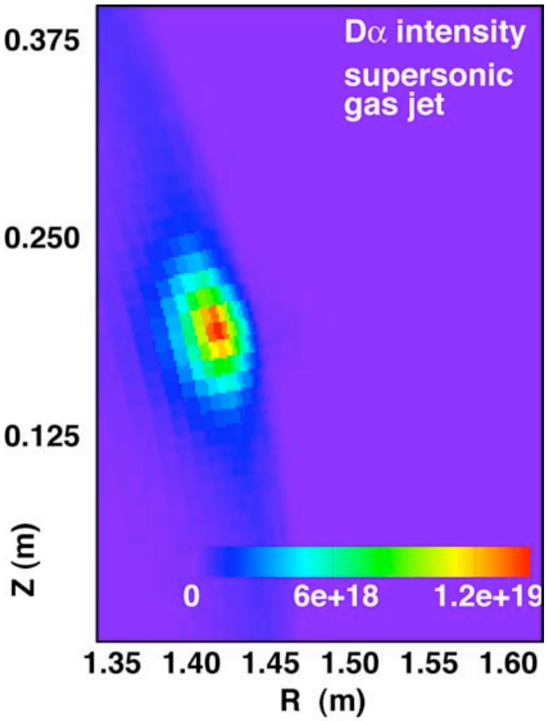


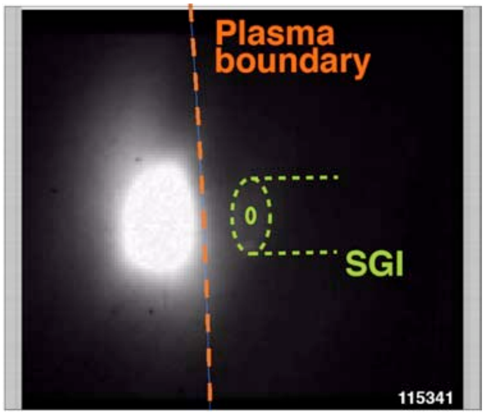
- Shown two discharges with full **HFS fueling** and **reduced HFS + SGI fueling**
- HFS fueling rate reduced up to a factor of 20
- Experiment was run when multi-pulse SGI capability was not yet available - further optimization is to be done

- With SGI fueling ELMs change from small and type I to type III
- H-mode power threshold lower with SGI than with conventional LFS gas

DEGAS 2 simulations help develop supersonic gas jet penetration mechanism model







- DEGAS 2 is a Monte Carlo neutral transport code
- Conventional gas injection: T = 300 K, Supersonic gas injector: T = 50 K + v_{flow} = 2200 m/s
- Not self-consistent: fixed T_e, n_e, etc are used
- Simulation results suggest that higher supersonic jet fueling efficiency may be a result of gas jet proximity to plasma and low gas jet divergence
- Further development of the fluid model is in progress

Summary and future work

- SGI injects deuterium at $\Gamma < 5 \times 10^{21}$ particles/s in quantities 0.1 - 0.3 of NSTX plasma inventory in a multi-pulse and/or continuous fashion with measured fueling efficiency 0.1 - 0.4

- Reliable H-mode access and low power threshold (< 2 MW NBI) in SGI-fueled H-mode discharges

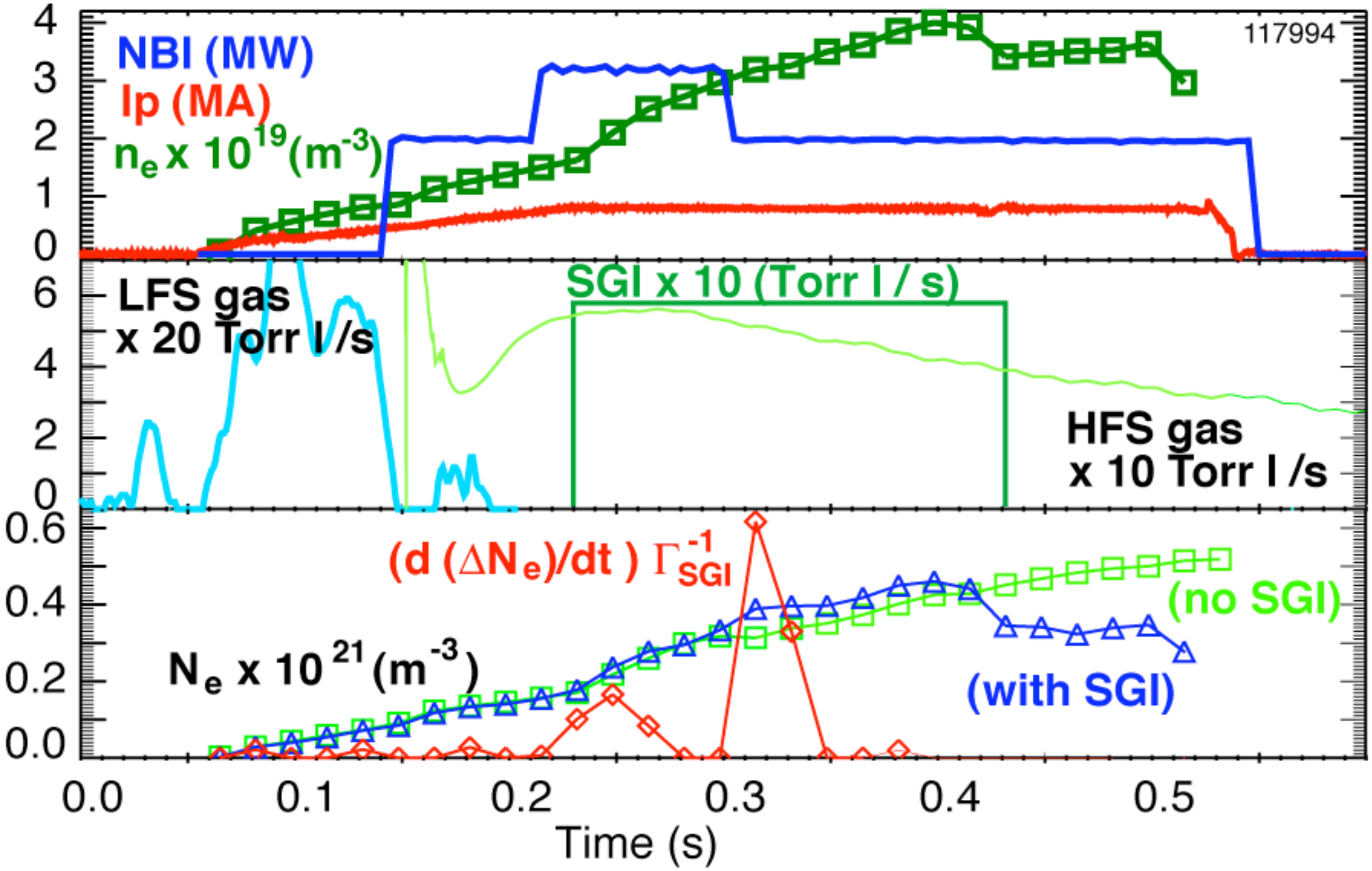
- Progress has been made in development of SGI-fueled H-mode scenario with reduced (up to 20) high field side fueling rate demonstrating the possibility of density control with SGI. SGI-fueled double-null H-mode plasmas demonstrate different ELM character (type III ELMs vs small and type I ELMs)

- Controlled and localized fueling provided in lithium active pumping experiments

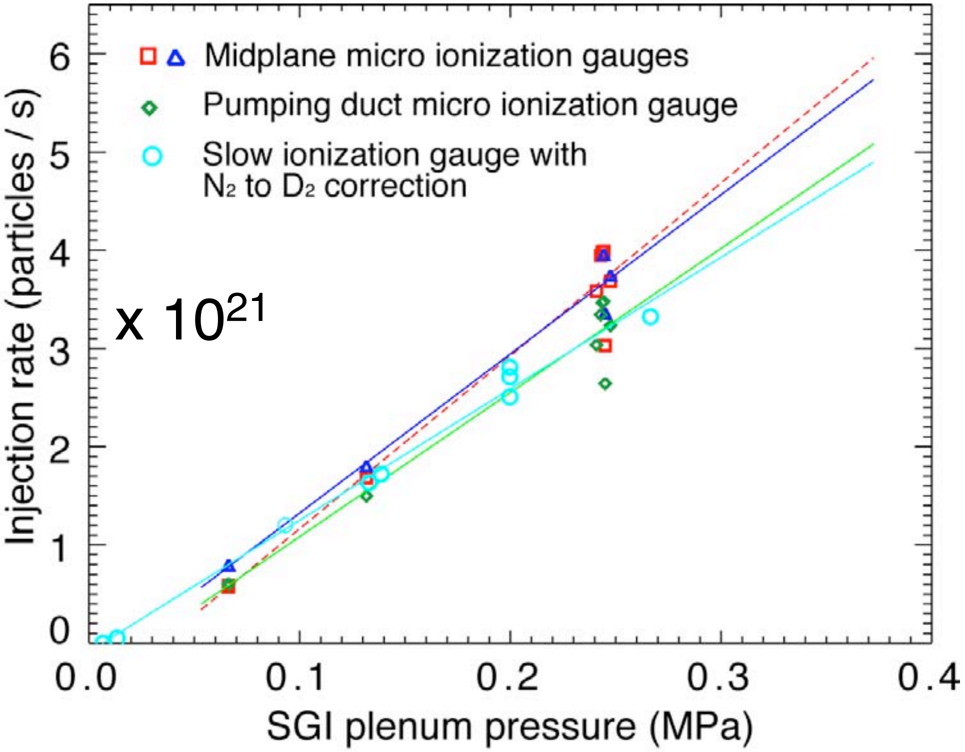
nstx.pppl.gov/sgi

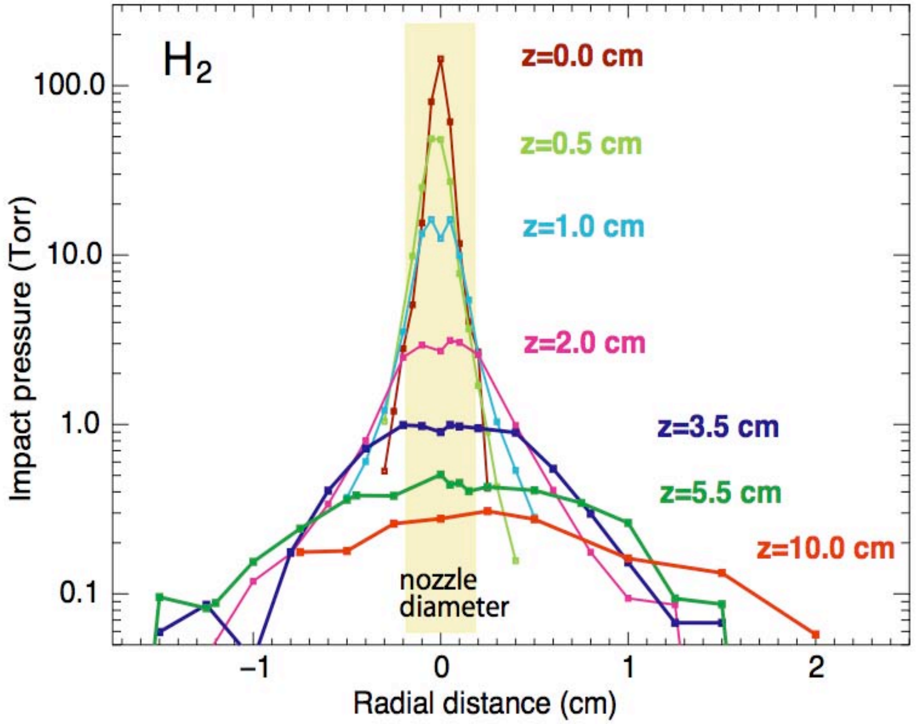
- Hardware improvements under consideration:
  - Independent gas handling system (D_2, other gases, e.g. He, CD_4)
  - Increase SGI plenum pressure from 2500 to 5000 Torr - improved penetration expected
  - Density feedback with SGI using Plasma Control System

Backup slides



SGI parameters characterized off-line and *in situ*



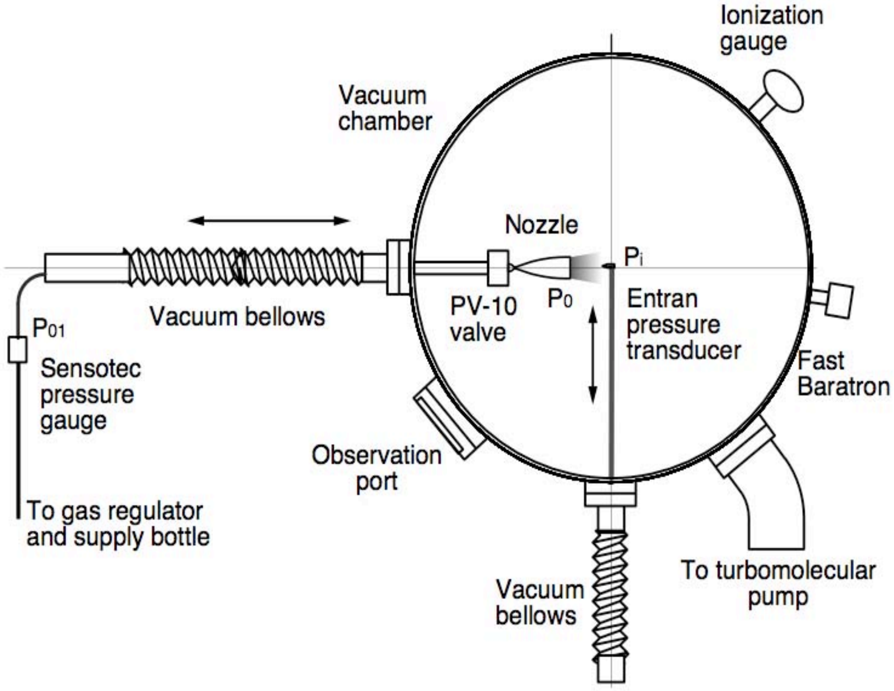


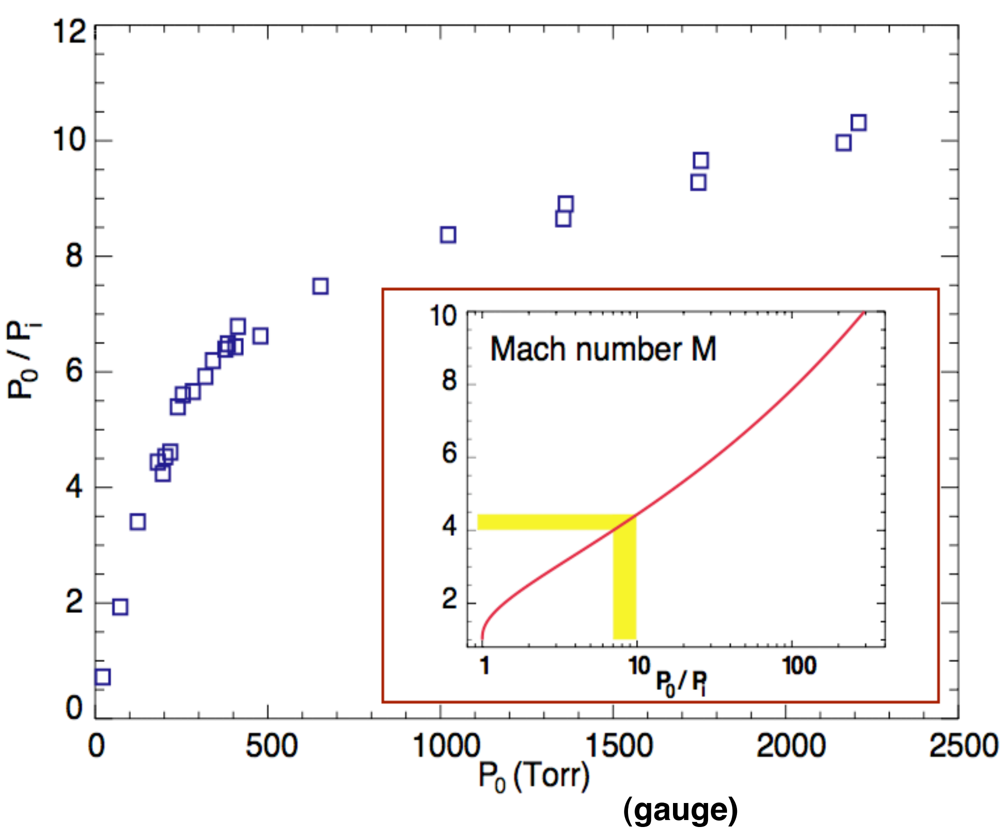
- NSTX SGI is operated at flow rates 20-65 Torr l /s (1.5 - 4.5 x 10^{21} s^{-1})

- Hydrogen or Deuterium jet:
  - ✓ Jet divergence half-angle: 6° - 25° (measured)
  - ✓ *M* = 4 (measured)
  - ✓ Estimated: T ~ 60 - 160 K, *n* < 5 x 10^{23} m^{-3}, Re = 6000, v_{therm} ~ 1100 m/s, v_{flow} = 2400 m/s

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

M = 4 is obtained from Rayleigh-Pitot law

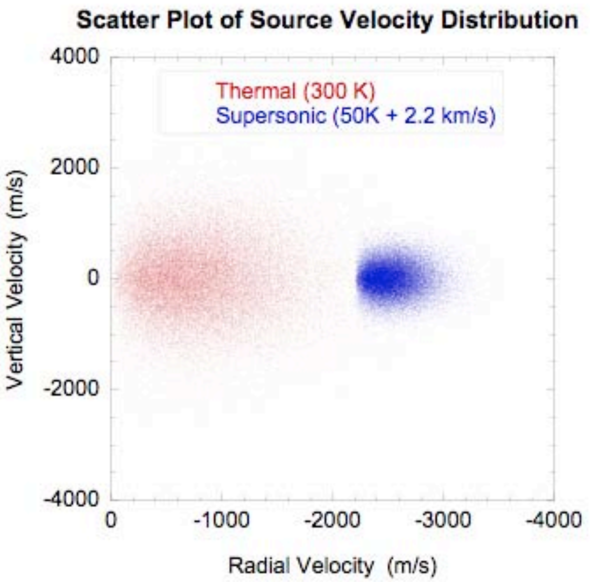


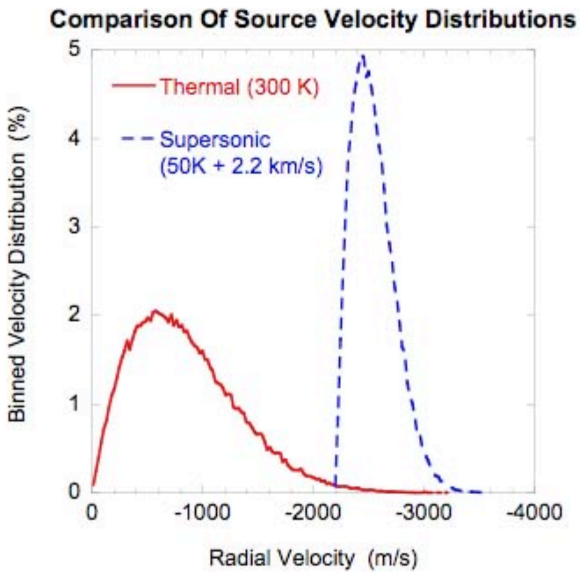


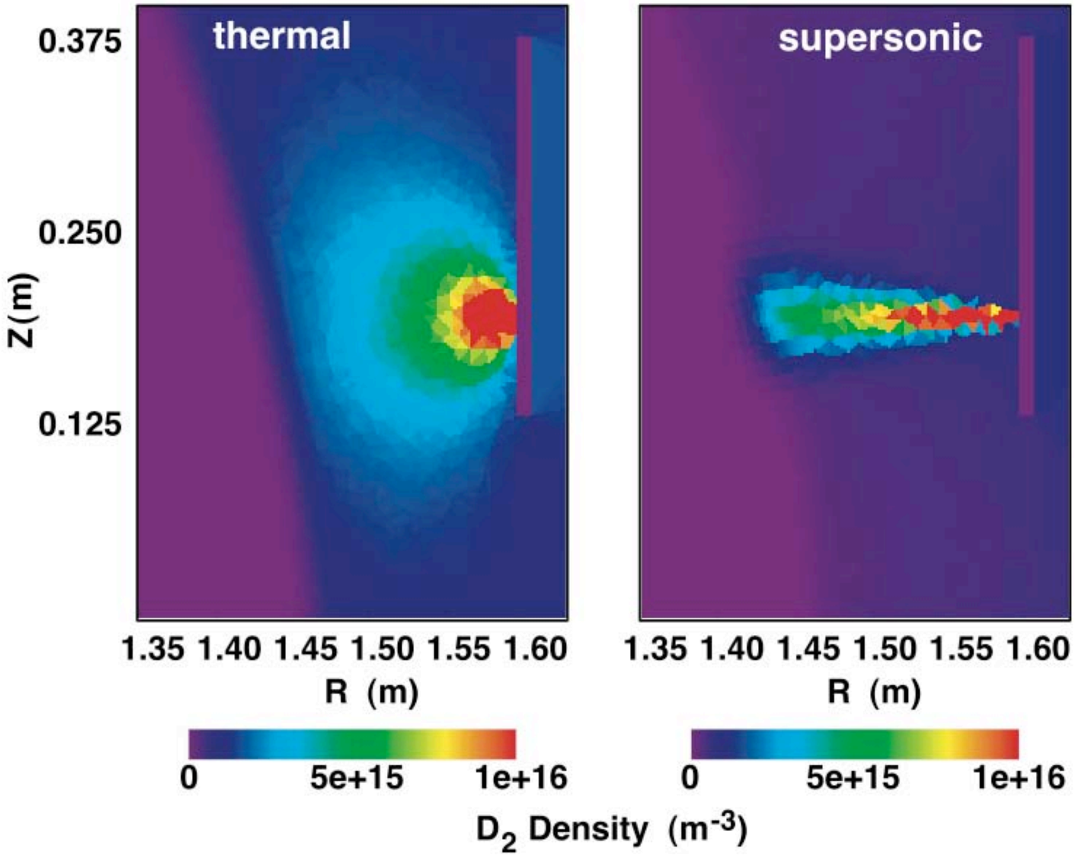
$$\frac{P_i}{P_0} = \left(\frac{(\gamma+1)\,M^2}{(\gamma-1)\,M^2+2}\right)^{\gamma/(\gamma-1)}\left(\frac{\gamma+1}{2\gamma M^2-(\gamma-1)}\right)^{1/(\gamma-1)}$$

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

DEGAS 2 simulation details


Scatter Plot of Source Velocity Distribution


Comparison Of Source Velocity Distributions



D. P. Stotler