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XP 912: H-mode fueling comparison with SGI and conventional gas injection

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Supersonic gas jet fueling is a unique fueling technique studied on NSTX

- Future large tokamaks will still use gas injection to control and sustain local density
  - in front of RF antennas
  - in SOL and divertor
- Supersonic gas injector (SGI)
  - was installed on NSTX in 2004, experiments conducted in 2005-2006 in ohmic, L- and H-mode discharges
- Supersonic gas injector – Upgrade
  - Upgraded to 5000 Torr plenum pressure capability and multi-pulse capability in 2007
- Supersonic gas jet fueling has been studied on other fusion plasma devices
  - Limiter tokamaks (HL-1M, Tore Supra)
  - Divertor tokamaks (ASDEX-Upgrade, JT-60U, HL-2A)
  - Divertor Stellarator (W7-AS)

Results with SGI fueling on NSTX include

- Reliable H-mode access
- Reduced edge pressure
- Developments of H-mode scenario with SGI fueling and reduced (by up to 95 %) HFS fueling
- SGI-fueled double-null H-mode plasmas demonstrate different ELM regime (type III ELMs vs small and type I ELMs with HFS fueling)
- Measured fueling efficiency 0.1 – 0.4
- At high rate prolonged SGI injection – occasional X-point MARFE formation (depend on impurity/ conditioning?)

Goals for XP 912 (0.5 day)

- Compare fueling efficiency of SGI and LFS CGI
- Study pedestal characteristics and pedestal fueling
  - Analytic (e.g., Mahdavi's) models of pedestal fueling
  - Study relation between SOL, pedestal and core desities
- Response of wall and divertor sources to gas injection
  - Recycling
  - Carbon
- Formation of X-point MARFE during SGI and LFS CGI

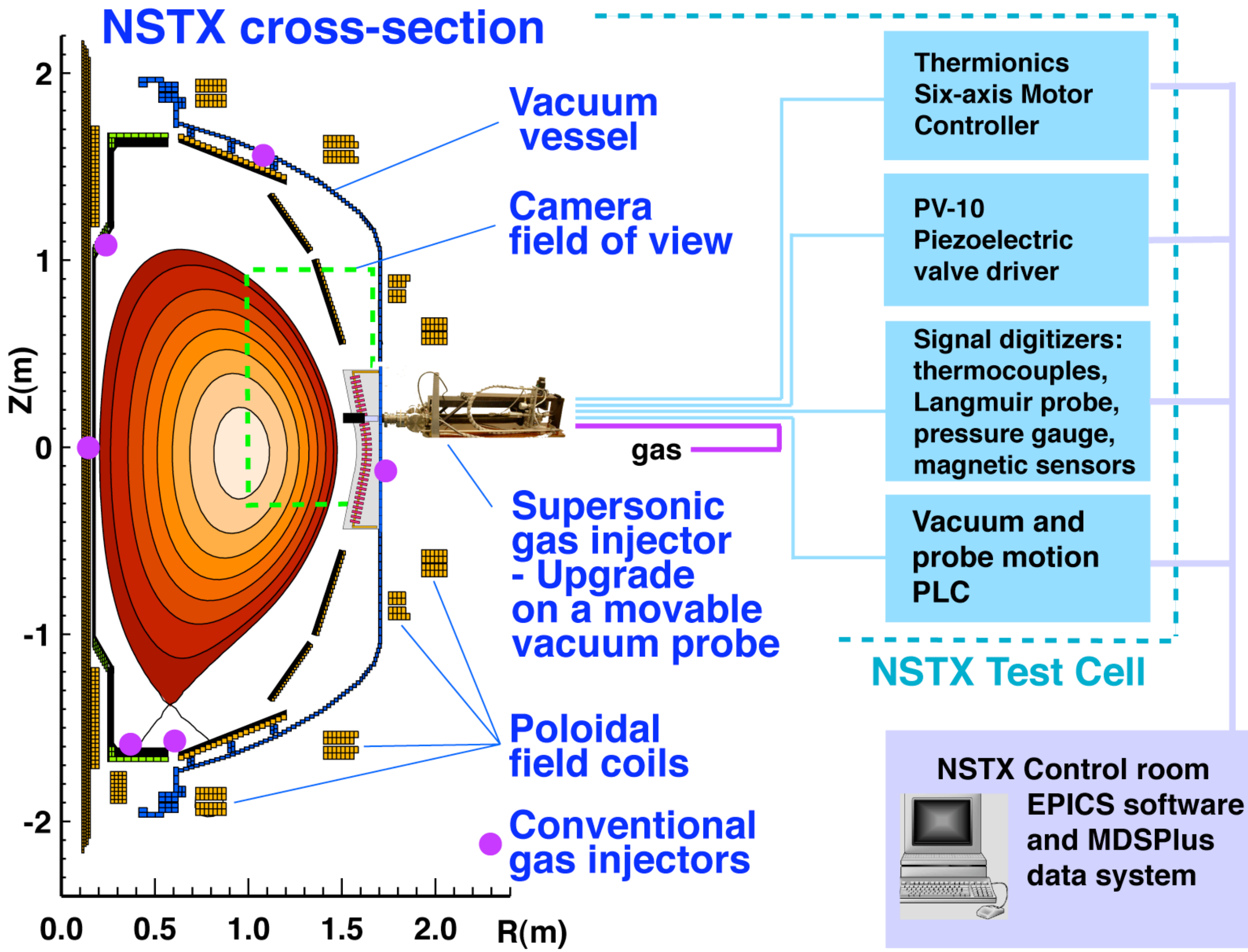
Shot plan for XP 912 (0.5 day)

1. **Comparison of SGI and CGI in discharge front-end (up to 5 shots)**
   - Run a fiducial 0.8 MA, 6 MW discharge with high field side fueling.
   - Replace the LFS injector with an identical SGI pulse
   - The SGI will be operated at R=1.56 - 1.58 m

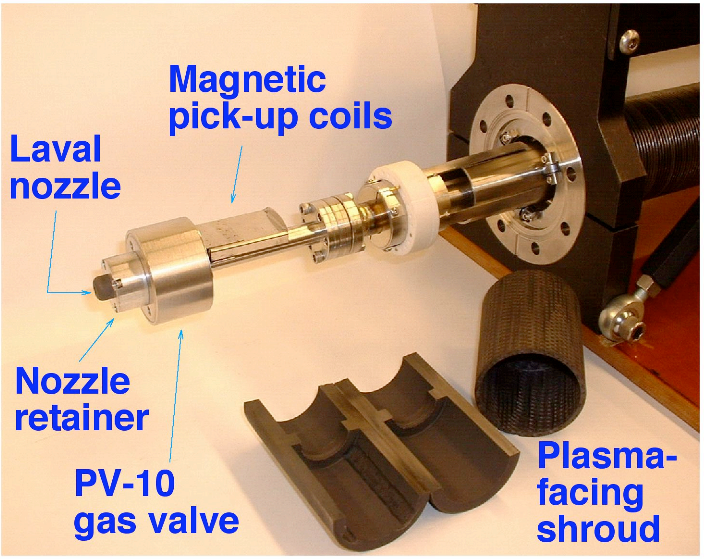
- **H-mode fueling with SGI and CGI (up to 10 shots)**
  - Obtain a reference H-mode discharge with reduced HFS fueling (up to 3 shots)
  - Start with HFS plenum pressure 300-500 Torr and SGI
    - SGI setup: R=1.56 - 1.58 m, Plenum pressure 5000 Torr, Timing to match the HFS fueling profile
  - Adjust SGI timing to optimize H-mode discharge
  - Repeat with CGI (Injector # 2) at identical rate and timing
  - Use MPTS relative laser timing to get the “gas on – gas off” conditions

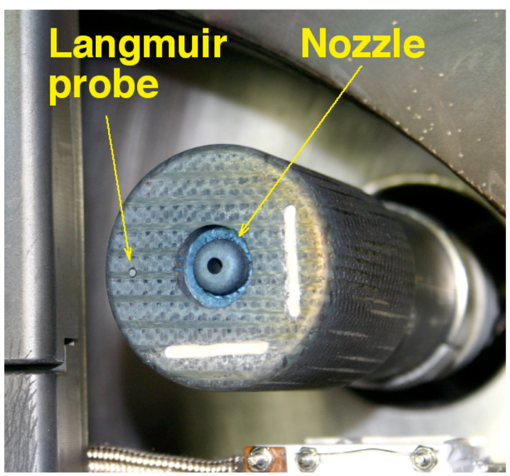
Extras

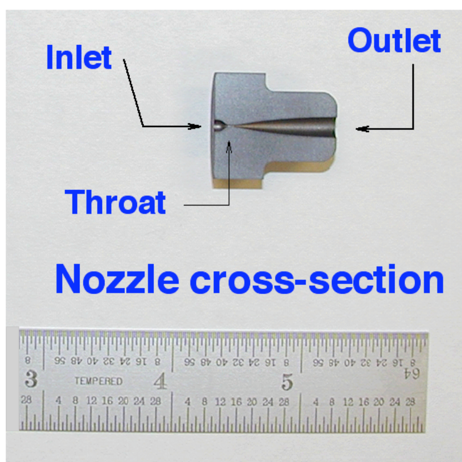
Supersonic gas injector is a complex computer-controlled high gas pressure apparatus



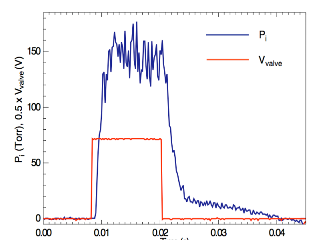
Supersonic gas injector consists of Laval nozzle and piezoelectric valve

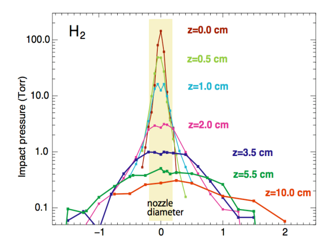




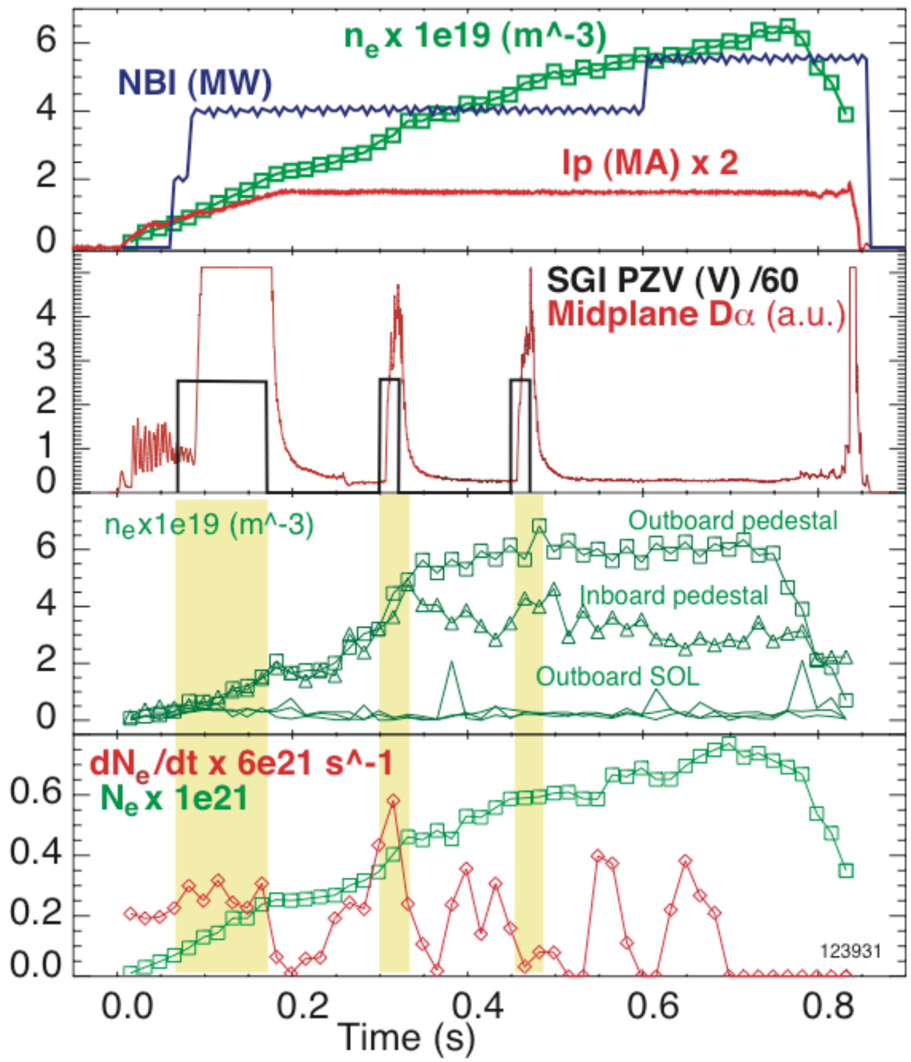


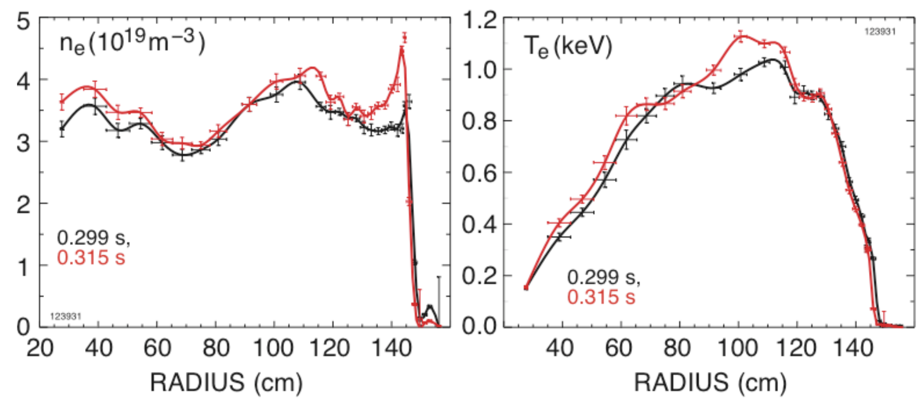
- SGI-U is operated at flow rates 20-130 Torr l /s ($1.5 - 9.0 \times 10^{21}\ s^{-1}$)
- Supersonic deuterium jet properties:
  - Jet divergence half-angle: $6^o - 25^o$ (measured)
  - Mach number $M = 4$ (measured)
  - Estimated: T ~ 60 - 160 K, $n < 5 \times 10^{23}\ m^{-3}$, $v_{flow} = 2.4$ km/s, $v_{therm} \sim 1.1$ km/s
  - Nozzle $Re = 6000$





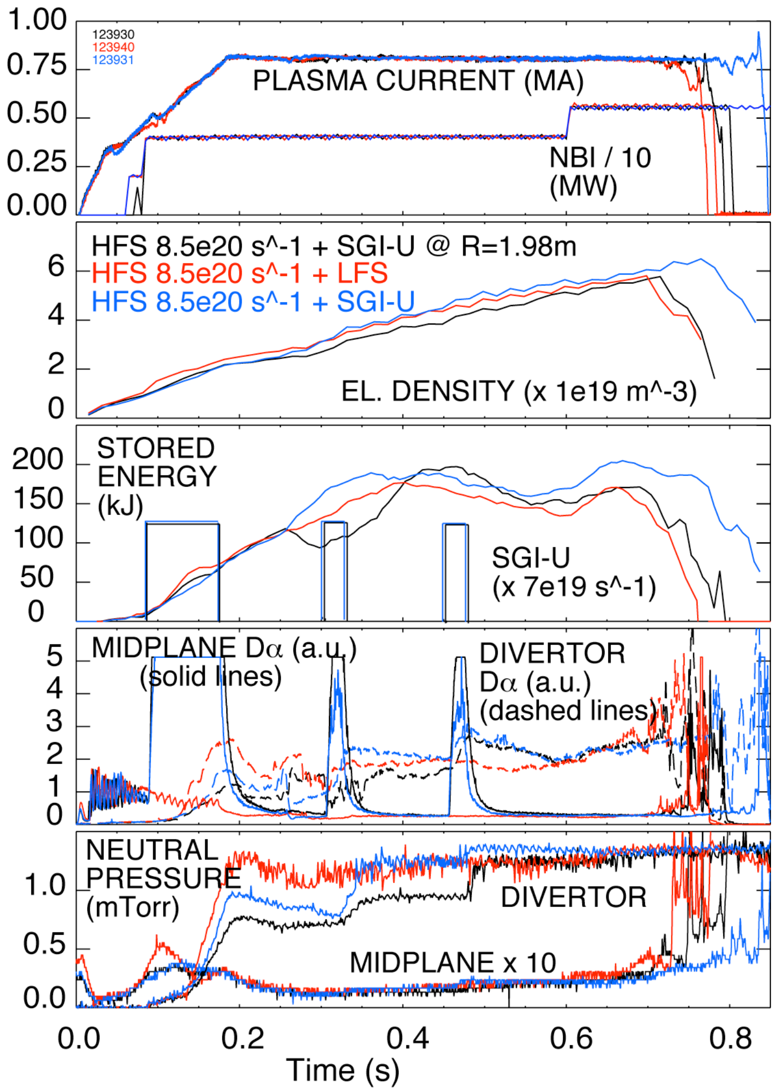
Supersonic gas jet ionizes in SOL, deposits ions in H-mode pedestal region





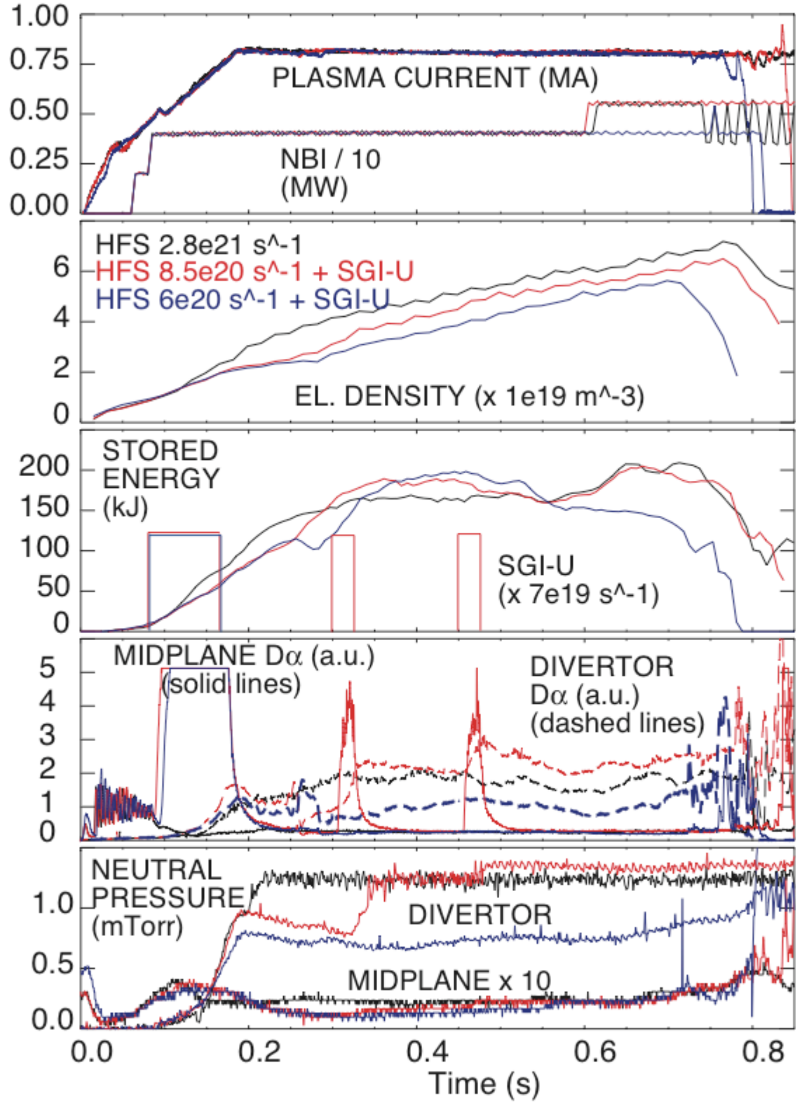
- In H-mode plasmas, n_e "ear" height and width increase, edge / pedestal and/or core T_e decrease by 10-15 %
- Supersonic gas jet does not penetrate beyond separatrix (typically stops at 0.5-6 cm from separatrix)

SGI-U fueling favorably compares to conventional gas injection fueling



- Three discharges with different fueling are compared:
  - reduced HFS rate + LFS similar to SGI-U
  - reduced HFS + SGI-U at R=1.57 m
  - **reduced HFS+SGI-U at R=1.98 m**
- In the SGI-U-fueled discharges
  - divertor pressure lower
  - divertor recycling lower
  - midplane pressure lower
- When SGI-U is closer to separatrix (R=1.57 m vs **R=1.98 m**) - higher plasma density is obtained
- However, all fueling methods result in high divertor ionization source, and monotonic density rise : need active pumping for mitigation

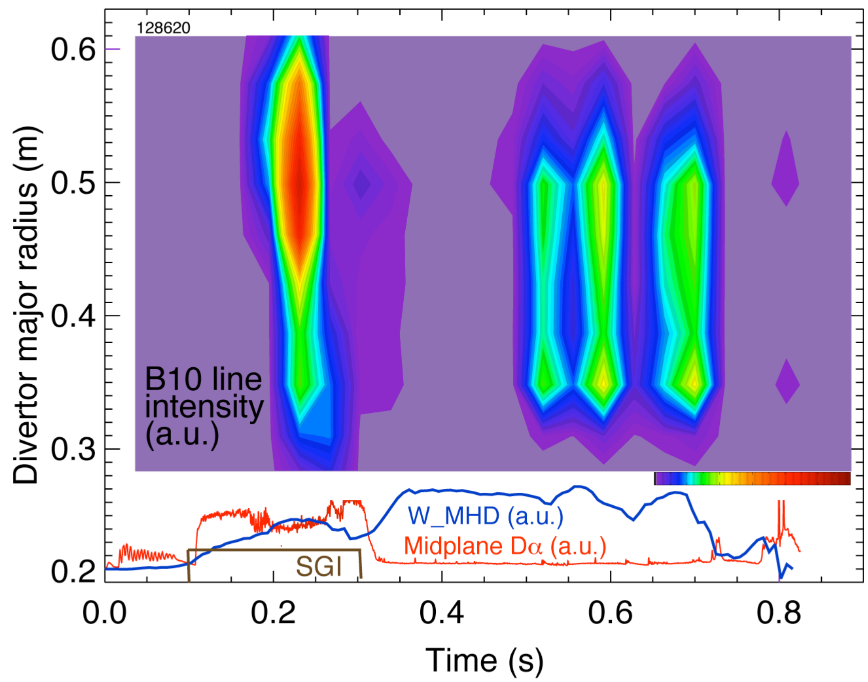
Reduced density H-mode plasmas with complementary SGI-U fueling are obtained



- Three discharges with different fueling are compared:
  - reduced HFS rate + SGI-U
  - more reduced HFS + SGI-U
  - **high HFS rate**

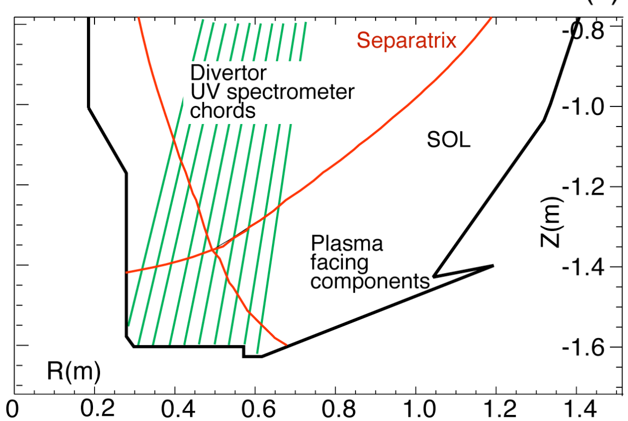
- Best fueling scenario - reduce HFS rate to the lowest possible, and add SGI-U

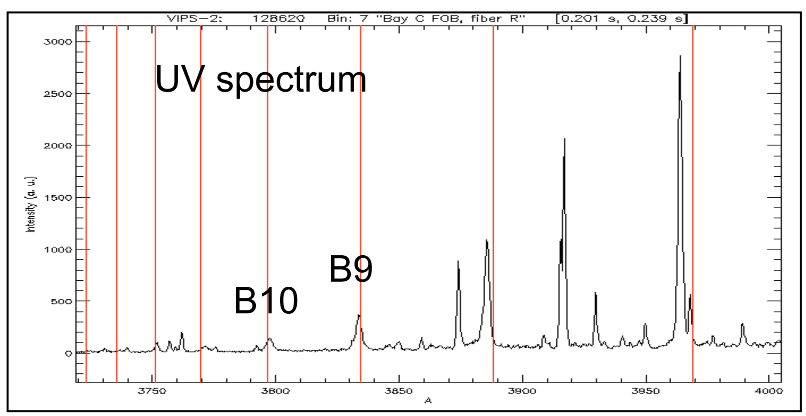
X-point MARFE forms during SGI-U fueling, leading to weak degradation in confinement



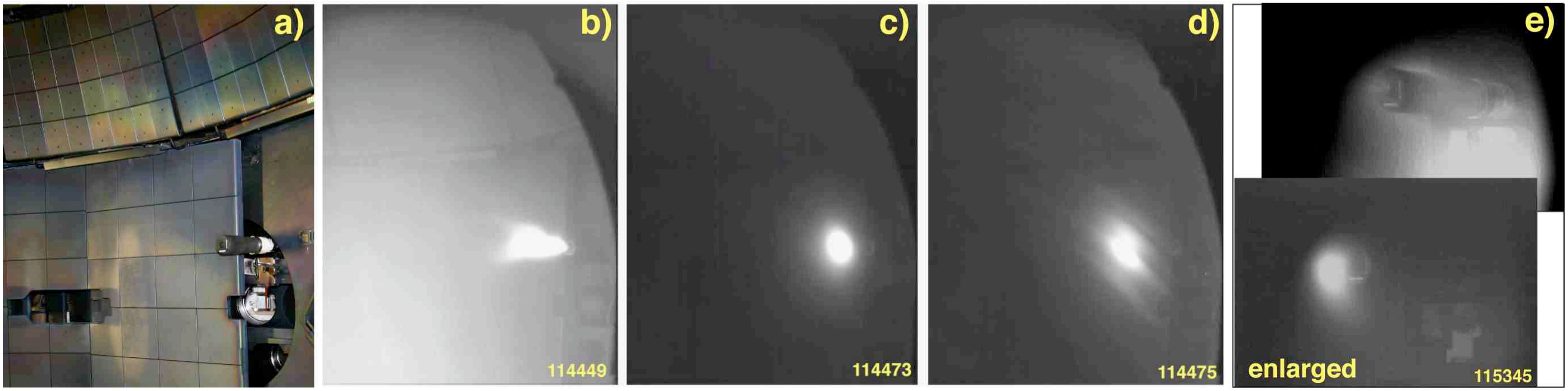
- X-point MARFE appears during SGI-U injection
- Weak impact on confinement
- MARFE is detected by spatially and temporally resolve spectra of divertor Balmer series (B9, B10, B11

lines)

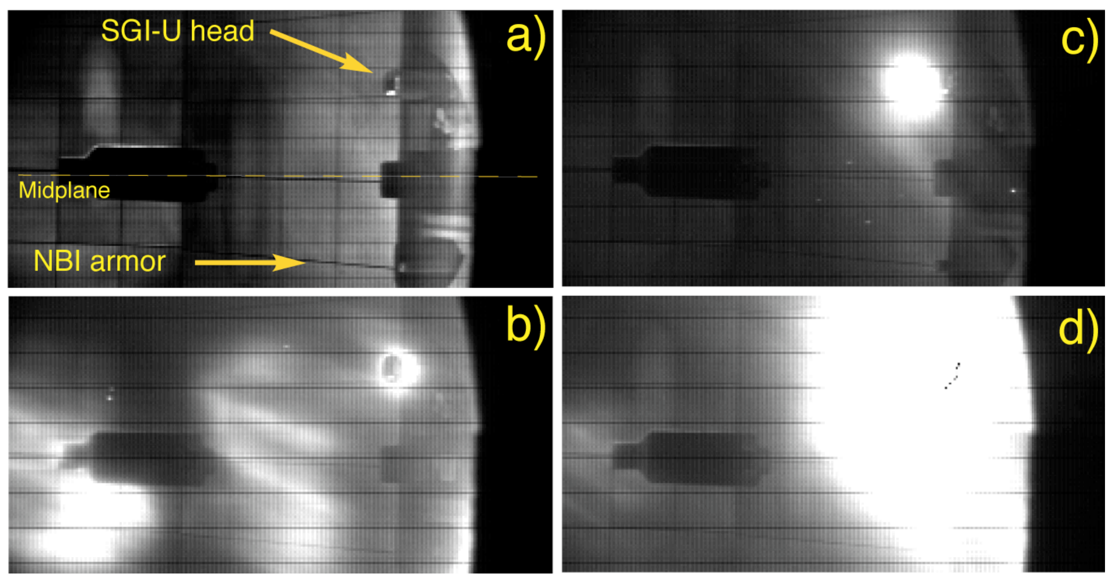




Fast camera shows localized supersonic deuterium jet interaction with SOL plasma

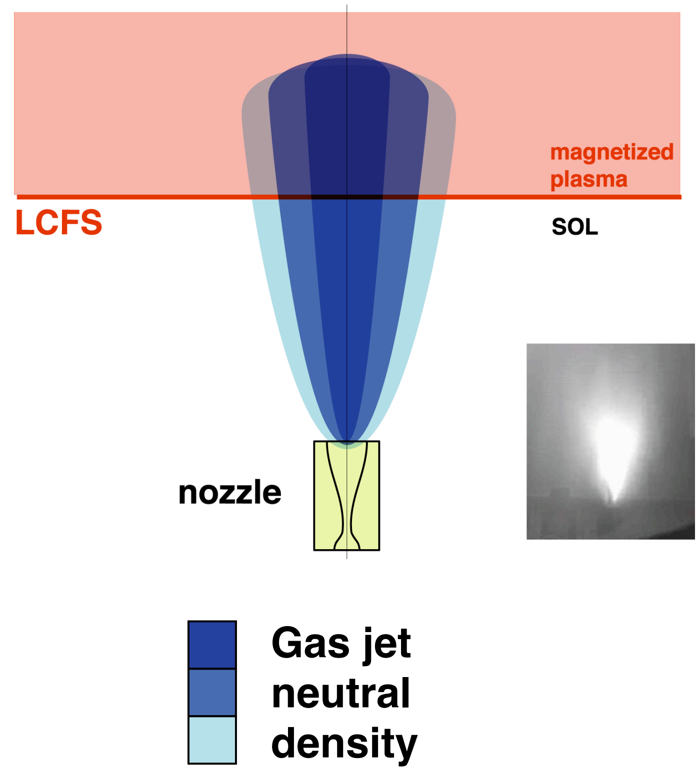


- Plasmoid located 0.5-6 cm from separatrix, - ionization source in SOL
- Size of Dα light-emitting region consistent with low jet divergence



High-density deuterium jet penetration through SOL relies on self-shielding from plasma

- 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
- Depth of penetration is determined by jet pressure and plasma kinetic and magnetic pressure
- High density plasmoid blocks jet from deep penetration into magnetized plasma
- 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