Improved Impurity Retention And Pedestal Performance In DIII-D Closed Divertor

by

L. Casali[1*]

with

T. Osborne[1], D. Eldon[1], B. Grierson[2], A. Leonard[1], A. McLean[3], E. Meier[4], J. Ren[5], M. Shafer[6], J. Watkins[7], H. Wang[1]

[1]General Atomics
2 Princeton Plasma Physics Laboratory
3 Lawrence Livermore National Laboratory
4 Zap Energy Inc
5 University of Tennessee Knoxville
6 Oak Ridge National Laboratory
7 Sandia National Laboratory

*Author contact: casalil@fusion.gat.com

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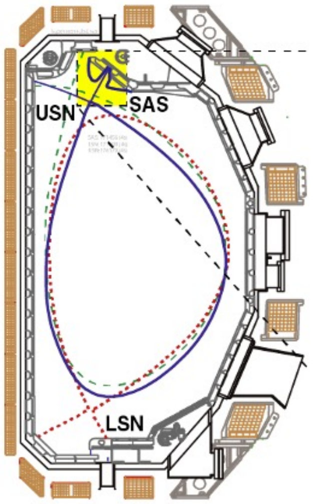
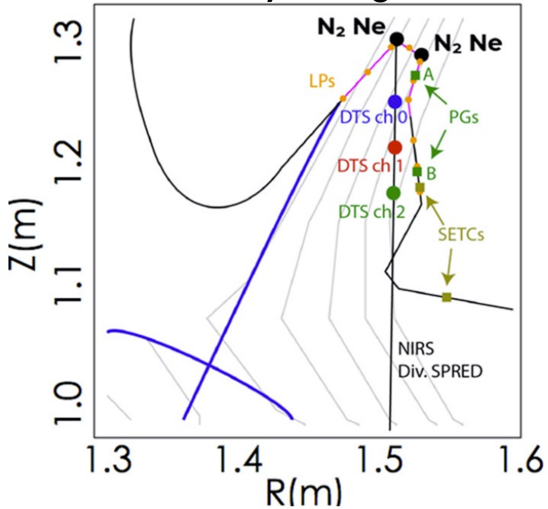
First Impurity Seeding Studies in the Small Angle Slot (SAS) Divertor at DIII-D



Impurities (N_2, Ne) injected simultaneously from gas valves at the corners of the slot



General info on recent SAS studies (no seeding):
H. Guo et al. NF 59 (2019)
L. Casali et al. NME 19 (2019)

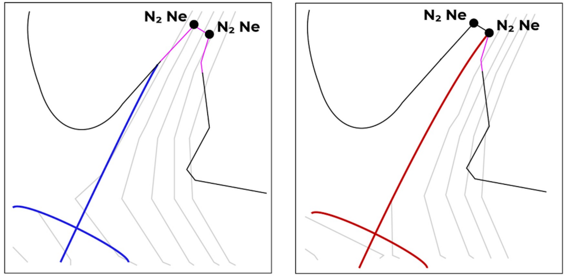
Suite of diagnostics in SAS:

- **Langmuir probes (LP_S)**
- **ASDEX neutral gauges (PGs)**
- **Surface eroding Thermocouples (SETCs)**
- **Vertical viewing chord:**
  - Spectroscopy (EUV/VUV SPRED, NIRS)
  - Divertor Thomson Scattering (DTS) local T_e, n_e

DIII-D NATIONAL FUSION FACILITY

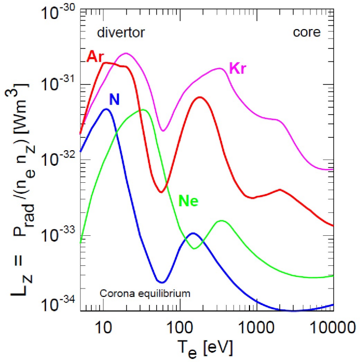
Outline

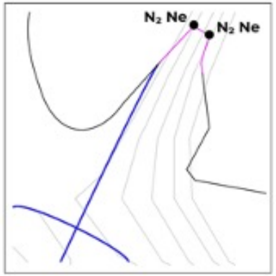
- Effect of divertor geometry: varying the OSP location, gas species fixed



Strike point at inner surface — Strike point at outer corner

- Effect of impurity species: varying the gas species (N, Ne), OSP location fixed





Strike point at inner surface

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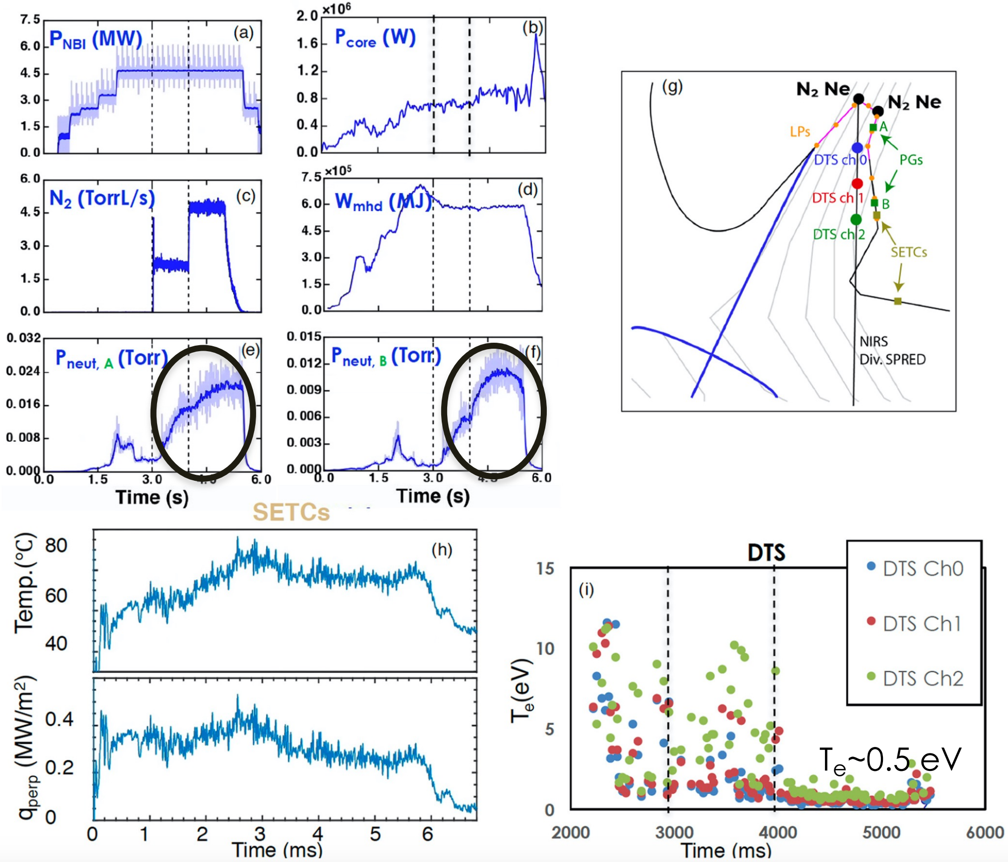
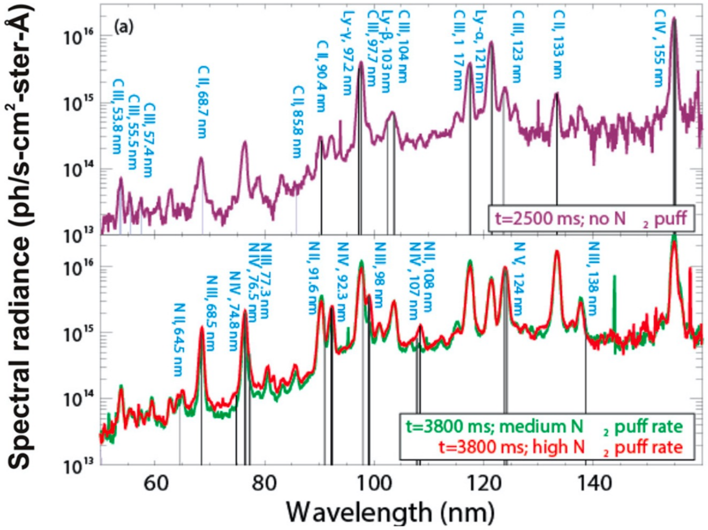
N_2 seeding in SAS induces detachment while the core is not significantly affected

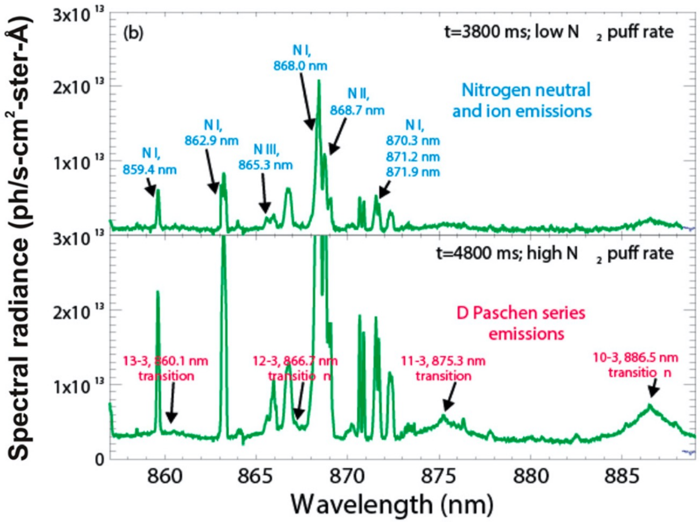
- **Significant neutral pressure rise (p_0>10 mTorr) occurs when N_2 is injected**
- **Reduction of heat flux in the SETCs**
- **Clear reduction in T_e with N_2 detected by different DTS channel**



L. Casali et al. PoP (2020)

Divertor Spectroscopy Confirms T_e < 2 eV with N_2 seeding





Absolutely calibrated (EUV/VUV):

- **Bright resonance N_2 lines**
- **Rapid increase in Lyman-β, 1026Å indicating T_e< 2 eV**
- **N is the dominant divertor radiator**

Absolutely calibrated spectrum from NIRS:

- **Paschen series of D lines, which appear only when T_e < 2 eV (bottom).**

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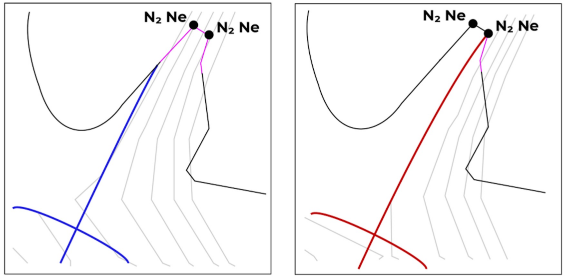
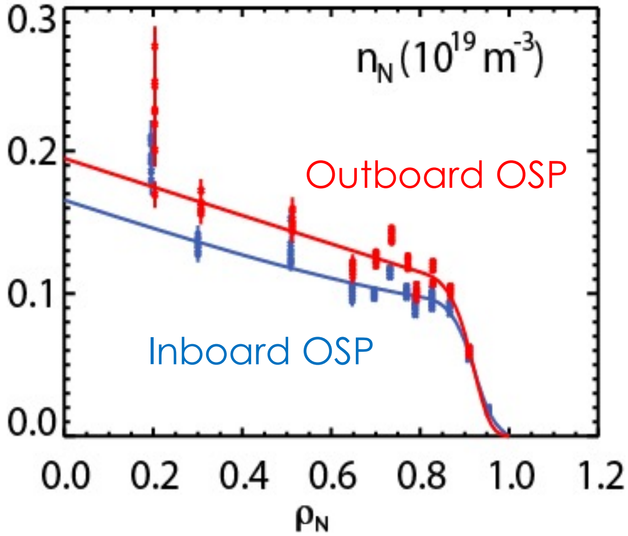
Higher Levels of Relative N_2 Contamination in the Core Found in the SAS with OSP at the Outer Corner

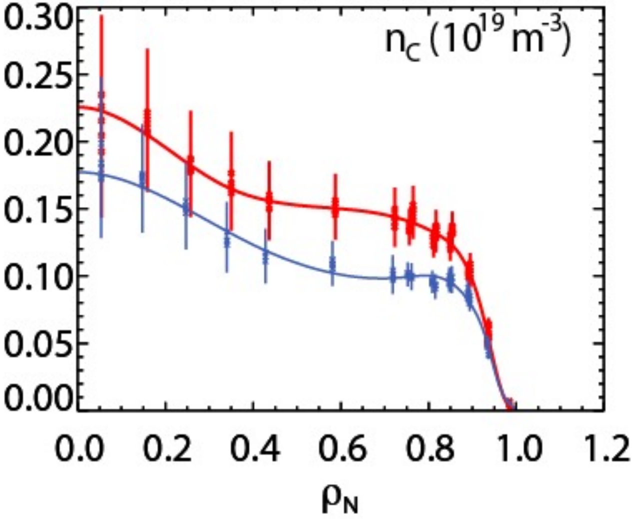
Effect of divertor geometry: vary the strike point location with a fixed gas species



Strike point at inner surface

Strike point at outer corner

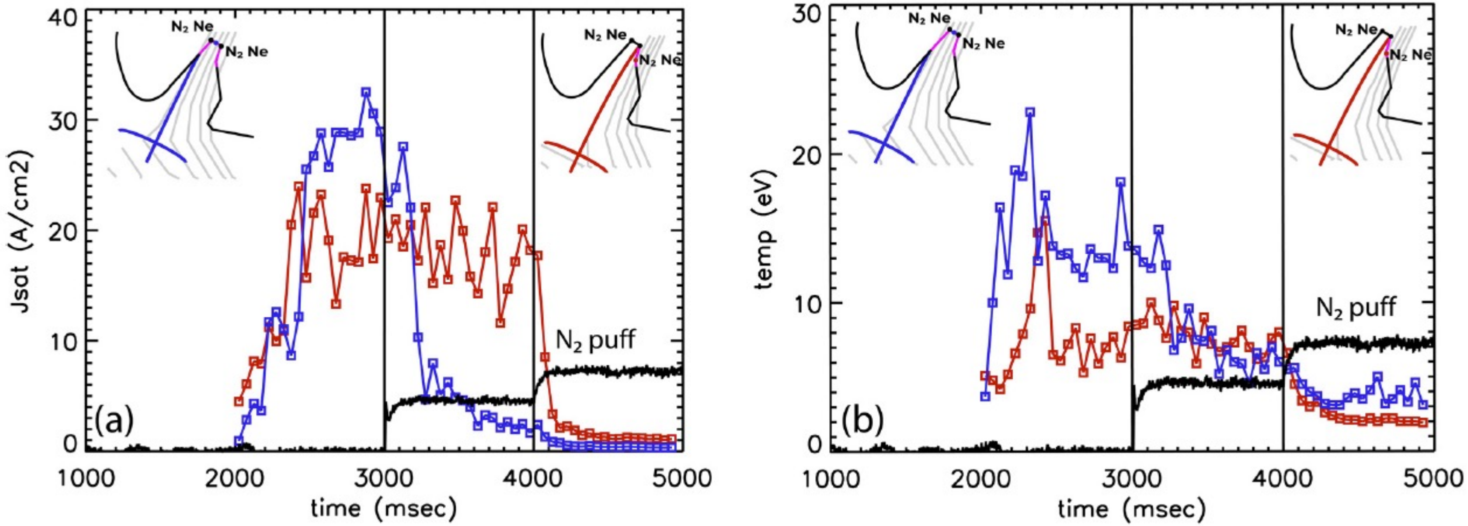




- Higher core N concentration consistently found with OSP at the outer corner
- This result holds for all the collected database at different power, different density

Dependence of Detachment on Strike Point Location

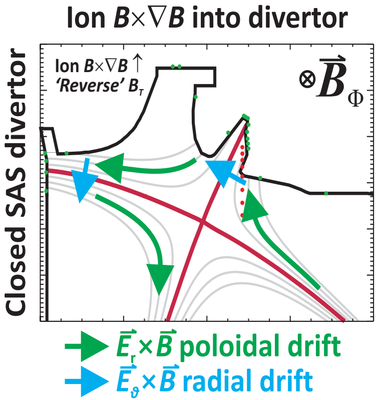
Matched nitrogen seeded discharges with different strike point location

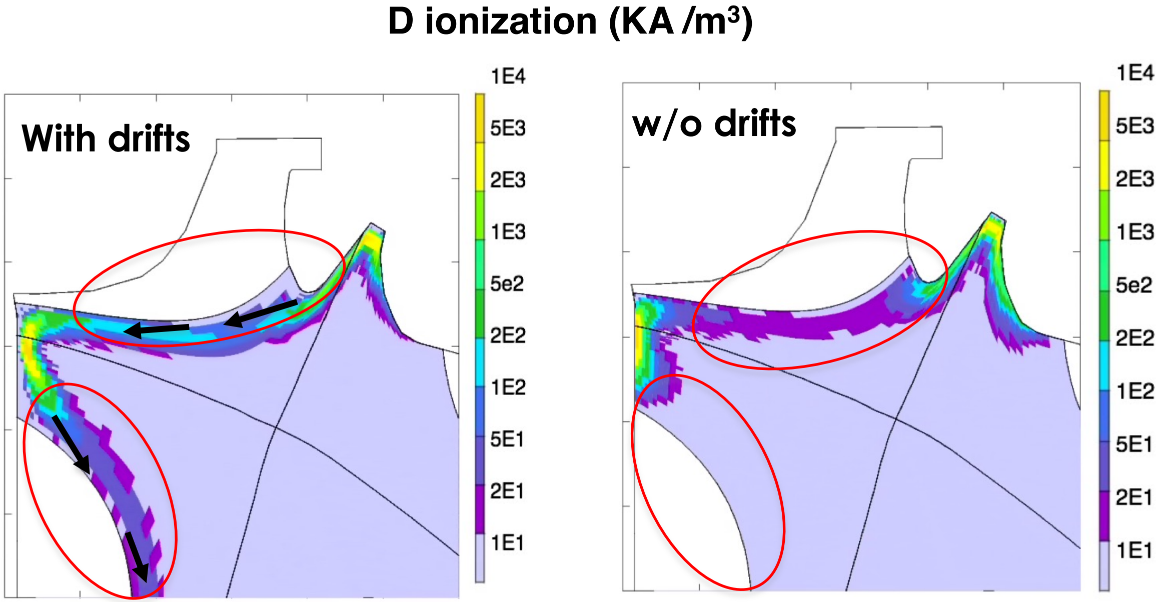


- LPs shows that detachment onset requires less N_2 puff with OSP at the inboard side
- Results are confirmed by DTS and divertor spectroscopy measurements

With grad-B into divertor, more ionization occurs in PFR and HFS far SOL due to drifts

SOLPS-ITER modeling with full drifts, n-n collisions, D+C+N/Ne performed for the first time at DIII-D





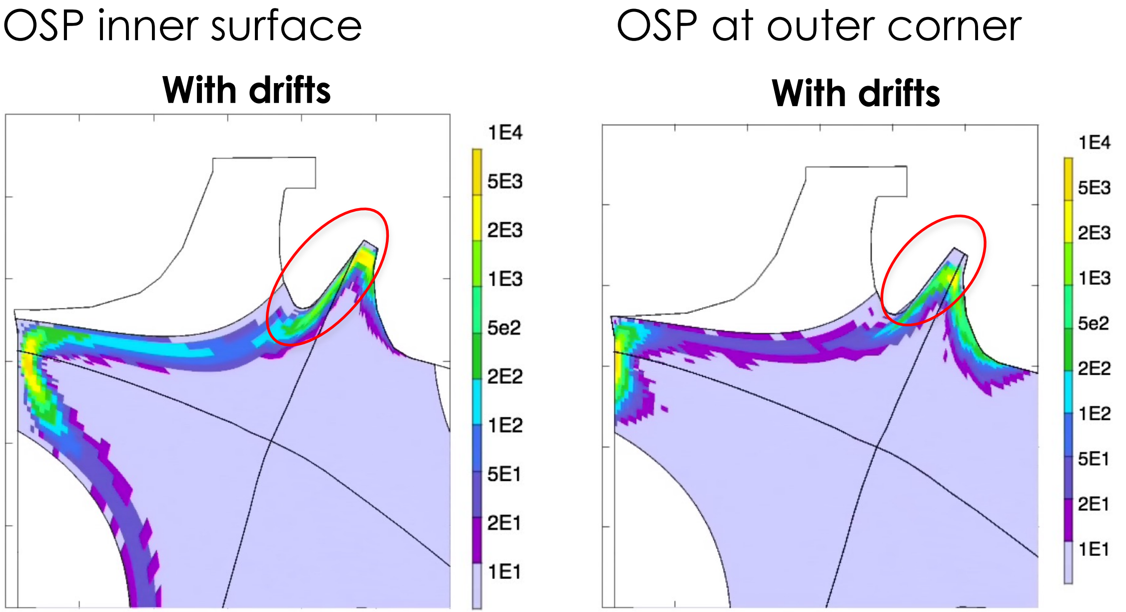
- Drifts shift the source radially towards the inner target
- Drifts are necessary to interpret our experiments here

L. Casali et al. PoP (2020)

Ionization Distribution Is Affected By Drifts And Divertor Geometry

D ionization (KA/m³)

Different strike point locations correspond to different wetted area with a different distribution of the D source



Source tightly trapped in the slot, within near SOL

Source out in the common flux region

Divertor Geometry Influences Plasma Flows Via Modification of the Ionization Source Affecting Impurity Transport

- **Flow reversal: flow away from the divertor occurs in a flux tube where the ionization source exceeds the ion loss**
  Krasheninnikov NF(1992), Stansfield JNM(1995), Isler PoP(1997), Boedo PoP (1998)

- **Impurity transport: main ions flow+ drifts**

$$v_{pol} = \frac{B_{pol}}{B} v_{\|} + v_{pol}^{ExB}$$

Drifts

$$v_{\|I} \approx v_{\|i} + \frac{\beta}{\alpha} \tau m_I^{-1} \nabla_{\|} T_i$$

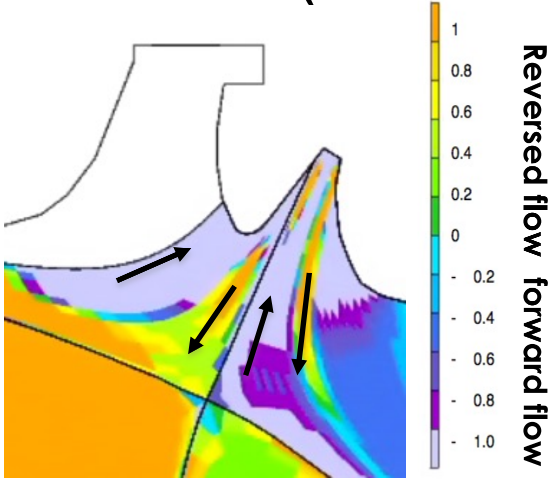
Impurity
Poloidal velocity

Impurity parallel
velocity

Main ion parallel velocity

I. Senichenkov et al. PPCF (2019)
E. Sytova et al. NME (2019)

Main ion flow (kA/m²)



Effect of closure:
- Neutral trapping
- Shift in pressure balance

L. Casali et al. NF (2020)
L. Casali et al. CPP (2018)
B. Covele APS (2018)

Reduced Ion and Impurity Leakage with OSP at the Inboard Side

Poloidal flows with different OSP

Flow reversal for both main ions and impurities

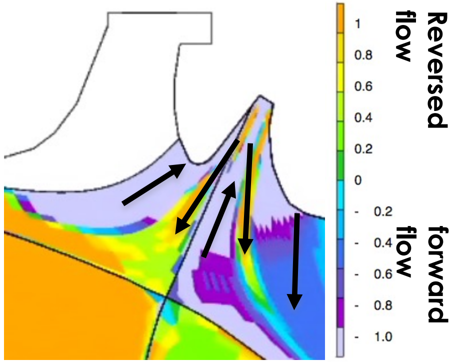
-> all forces are directed away from target

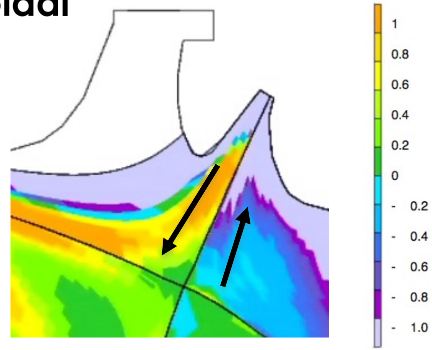
-> leakage

Inboard OSP

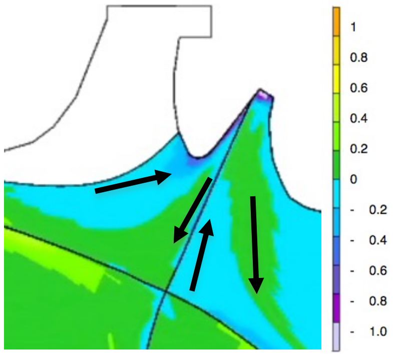
Corner OSP

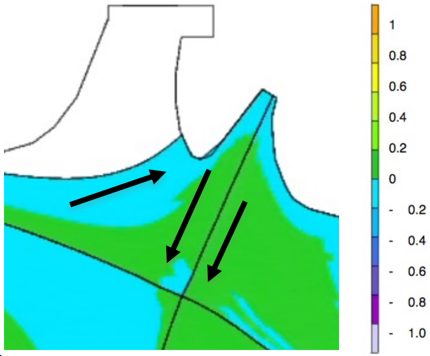
Main ion poloidal Flow (kA/m²)





N poloidal flow (KA/m²)





- N_2 is better retained in the divertor with inboard OSP:
  - Reduced core N_2
  - Less N_2 amount needed for detachment

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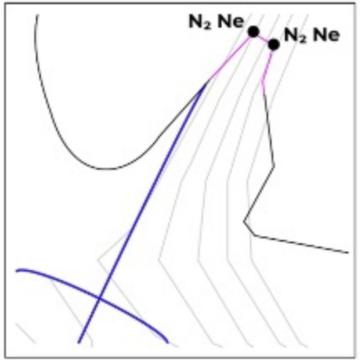
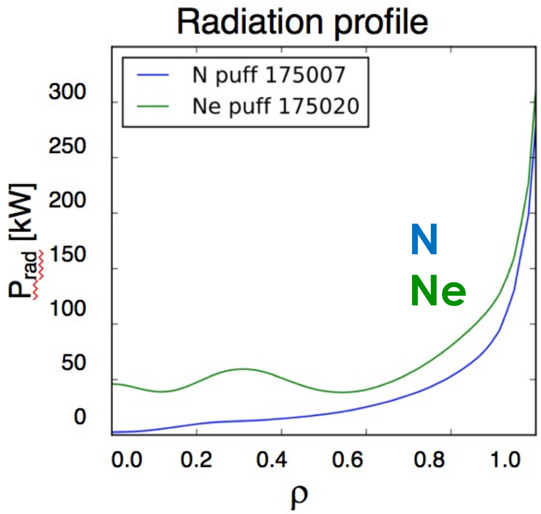
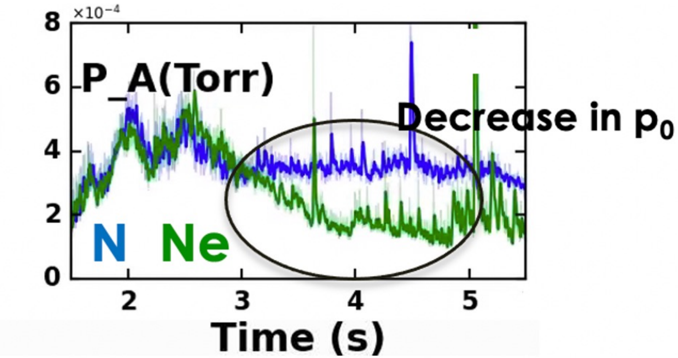
For N/Ne Matched Input Parameters, Ne Increases Radiation In The core While Neutral Pressure In The Slot Decreases

Effect of impurity species: OSP location fixed, varying the gas species (N, Ne)



Strike point at inner surface

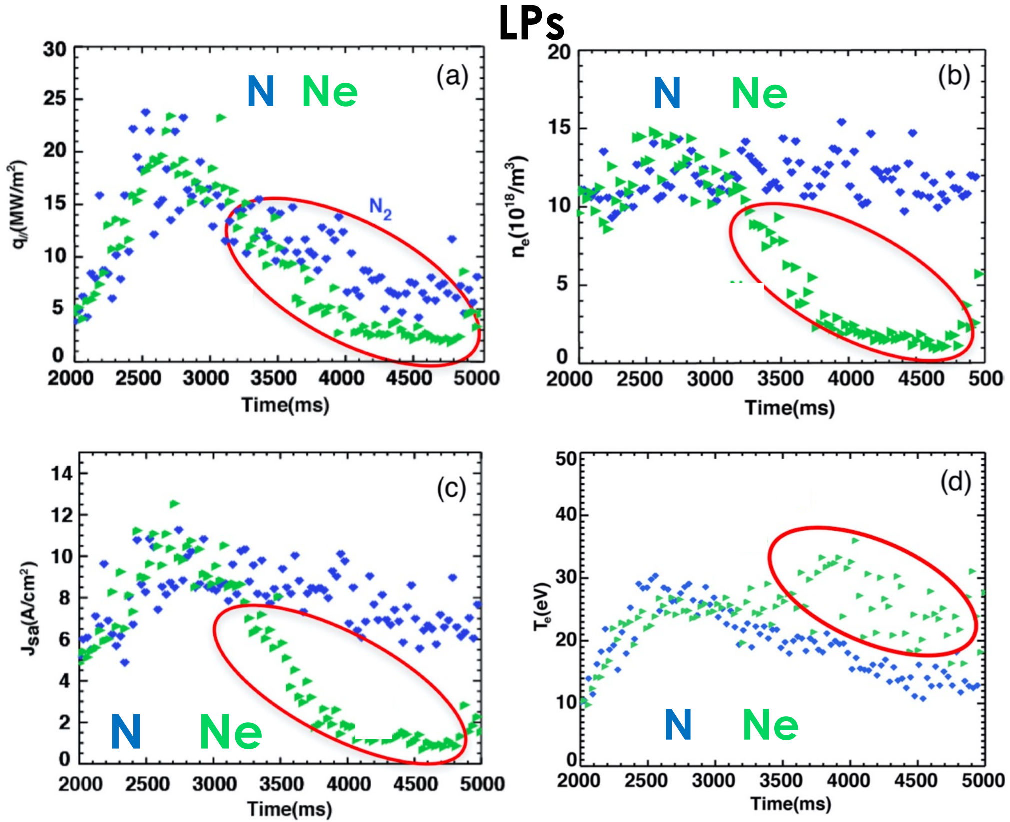




Dissipation: - N through $P_{rad,divertor}$

- Ne through power loss upstream

Both N and Ne Reduce Target $q_{||}$ at OSP But with Ne Particle Flux Down Into the Divertor is Dramatically Reduced



- How can a large reduction of the target heat flux be achieved with T_e being high?
- With Ne: most of the power loss with Ne takes place upstream

SOLPS-ITER: N Accumulates In The Low T_e Regions At Target, Ne Penetrates In The Core, Ne Dissipates Upstream

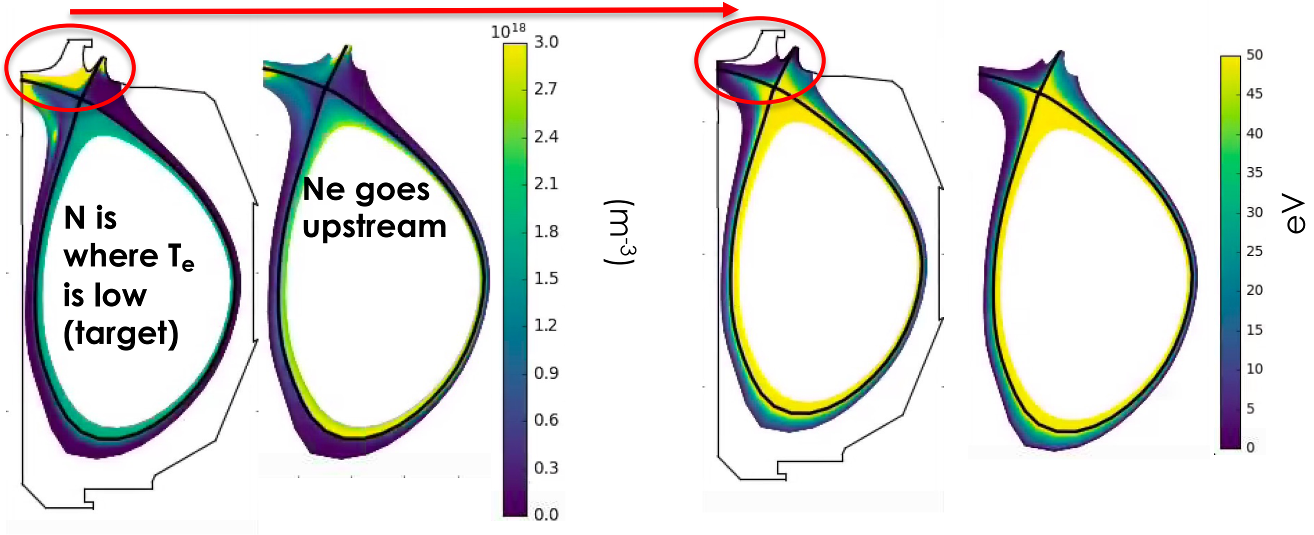
SOLPS-ITER modeling

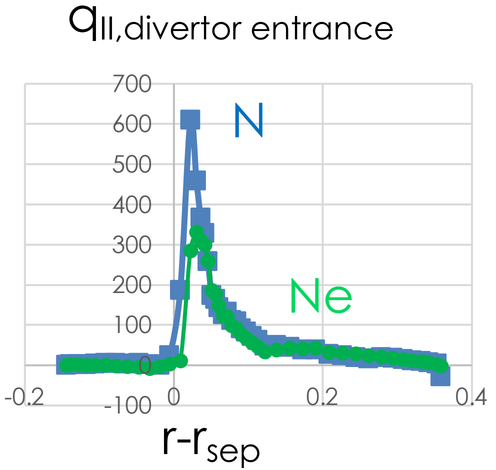
Impurity density

N Ne

T_e

N Ne





- **N accumulates where T_e is low, Ne instead penetrates upstream**
- **This agrees with the experimental results that the core is more affected by Ne**

Pedestal Reacts Differently to N and Ne Seeding

Two-point model (P. Stangeby 2000):

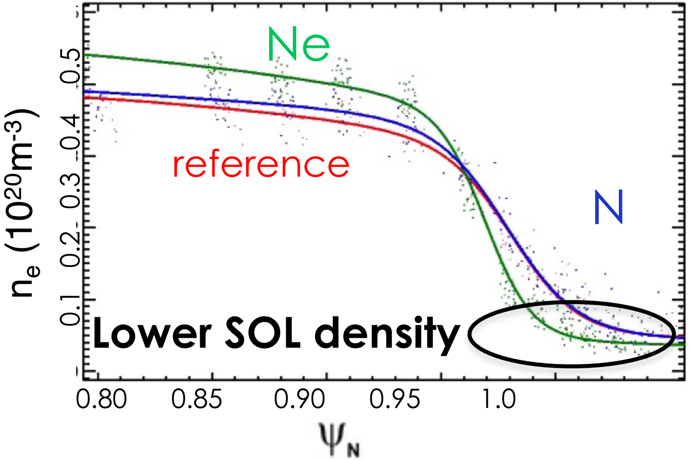
$$n_u \propto \frac{q_{\parallel}^{5/7}}{T_t^{1/2}} \frac{(1 - f_{rad})}{(1 - f_{mom})(1 - f_{conv})^{2/7}}$$

Power density

Radiative loss

- **Divertor and pedestal connected through heat flux and f_{rad}**
- **Neon reduces both $q_{\parallel}$ and (1-frad) due to mantle radiation**

Implication: for a given T_e at the target, less SOL density is required with Ne

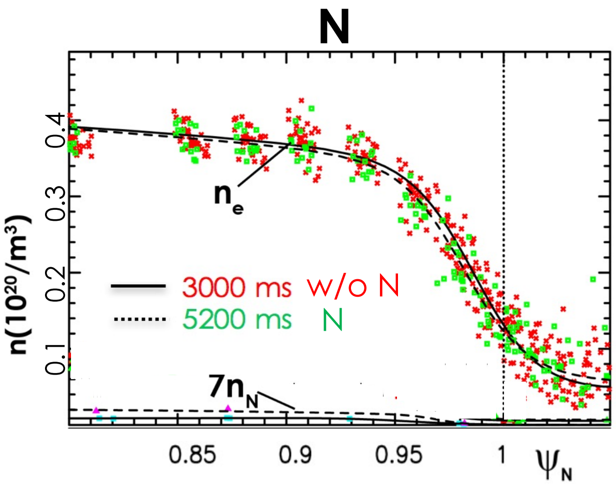


L. Casali et al. PoP (2020)

Different N/Ne Leakage Due To Different Ionization Potential

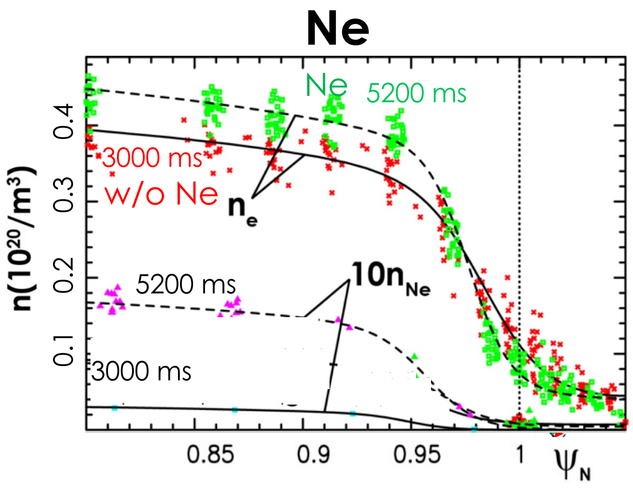
- Not much N goes in the core
- No change in pedestal

- Ne enters core
- Pedestal gradients steepen



Ionization potential for N (14.5 eV) : N ionizes close to the target: poloidal flow directed downstream, it is retained

Ne ionizes further upstream (21.6 eV) -> leakage



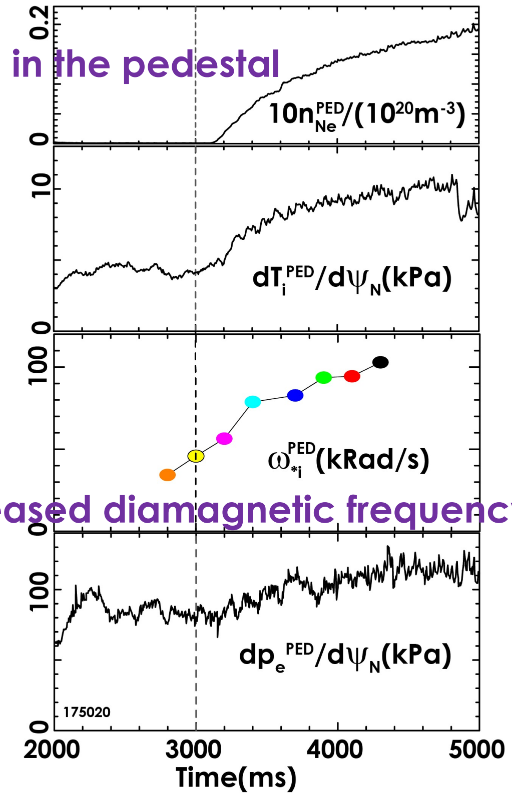
Ne concentration in the pedestal increases non-linearly via feedback mechanism with ELM frequency

Divertor

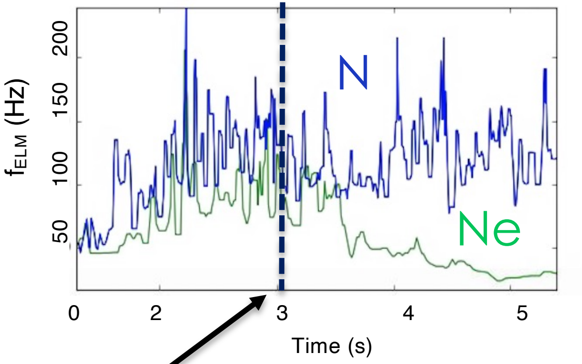
Ne pushed out of the divertor into the pedestal

Pedestal

Ne builds up in the pedestal



f_{ELM}



Start N_2/Ne puff

- **Increased pedestal stability through diamagnetic stabilization**
- **Radiative mantle**

  -> reduced f_{ELM}

Increased diamagnetic frequency

With lower f_{ELM}, less Ne is flushed out into the divertor

Conclusions

- Target shaping and drifts affect dissipation and impurity retention by redistributing the recycling source
- Reversal flow for both main ions and impurities has been found in SAS. The impact on the impurity transport explains the experimental finding that N_2 is better retained when the OSP is at the inner slanted surface
- N vs Ne seeding: different pedestal response consistent with the difference in ionization potential, divertor vs upstream dissipation
- Self-enhancing mechanism of Ne involves both divertor and pedestal physics

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