Far SOL Transport and Main Wall Plasma Interaction in DIII-D

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Abstract

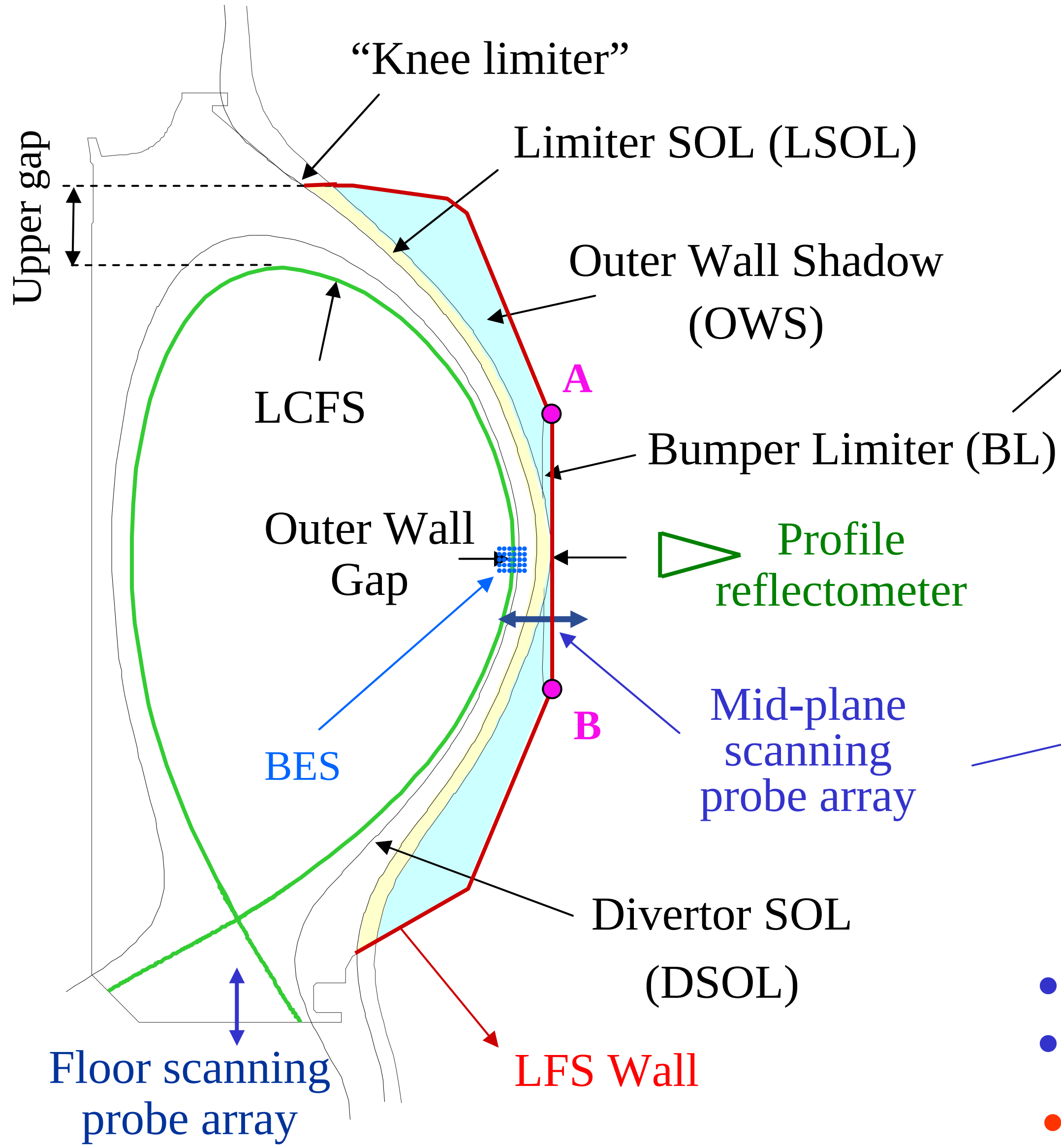
- Far Scrape-Off Layer (SOL) and near-wall plasma parameters in DIII-D depend strongly on the discharge parameters and confinement regime.
- In L-mode discharges cross-field transport increases with the average discharge density and flattens far SOL profiles, thus increasing plasma-wall contact.
- In H-mode between Edge Localized Modes (ELMs), plasma-wall contact is generally weaker than in L-mode.
- During ELMs plasma fluxes to the wall increase to, or above the L-mode levels.
- Depending on the discharge conditions ELMs are responsible for 30-90% of the ion flux to the outboard chamber wall.
- Cross-field fluxes in far SOL are dominated by large amplitude intermittent transport events that may propagate all the way to the outer wall and cause sputtering.
- In DIII-D a Divertor Material Evaluation System (DiMES) can be used to study erosion of different ITER-relevant materials in the lower divertor in USN or IWL discharges as a proxy to measure the first wall erosion.

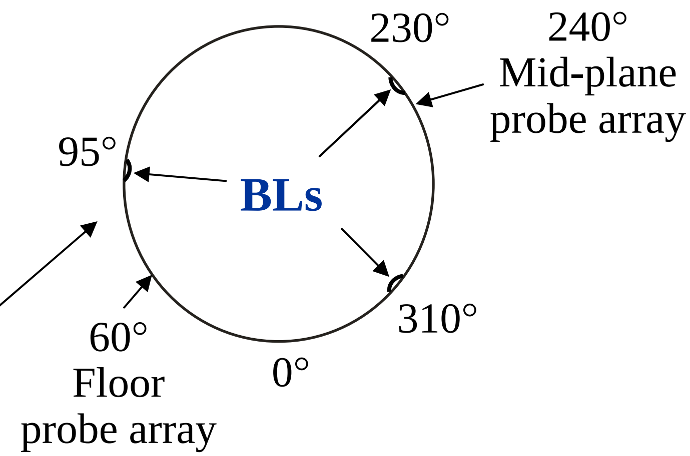
Motivation and Experimental Setup

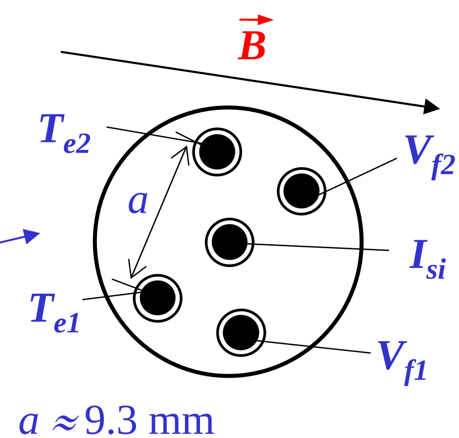
Motivation

- Plasma interaction with the first wall is of critical importance to ITER and future power reactors.
- Far SOL density profiles are often relatively flat implying either very high cross-field diffusion coefficients increasing towards the wall or non-diffusive character of the cross-field transport.
- Plasma density, electron temperature and time-resolved particle and heat fluxes in the SOL are intermittent in space and time.
- Fast edge diagnostics and turbulence simulation codes show the existence of coherent structures born near the LCFS and propagating radially towards the wall.
- Intermittent structures have been shown to account for up to 70% of the net cross-field particle and energy transport.
- In high-density L-modes, this convective transport may be fast enough to cause main chamber recycling to dominate the particle fuelling.
- Between ELMs in H-mode SOL cross-field transport is reduced, BUT
- During ELMS fluctuation levels and turbulent fluxes increase to or above L-mode levels and feature intermittent events similar to those in L-mode
- ELMs can be responsible for a significant fraction of the main wall plasma fluxes
- High transient loads caused by intermittent transport events and ELMs can result in increased erosion and eventual damage to the main chamber elements

Structure of the Low Field Side SOL and diagnostic arrangement





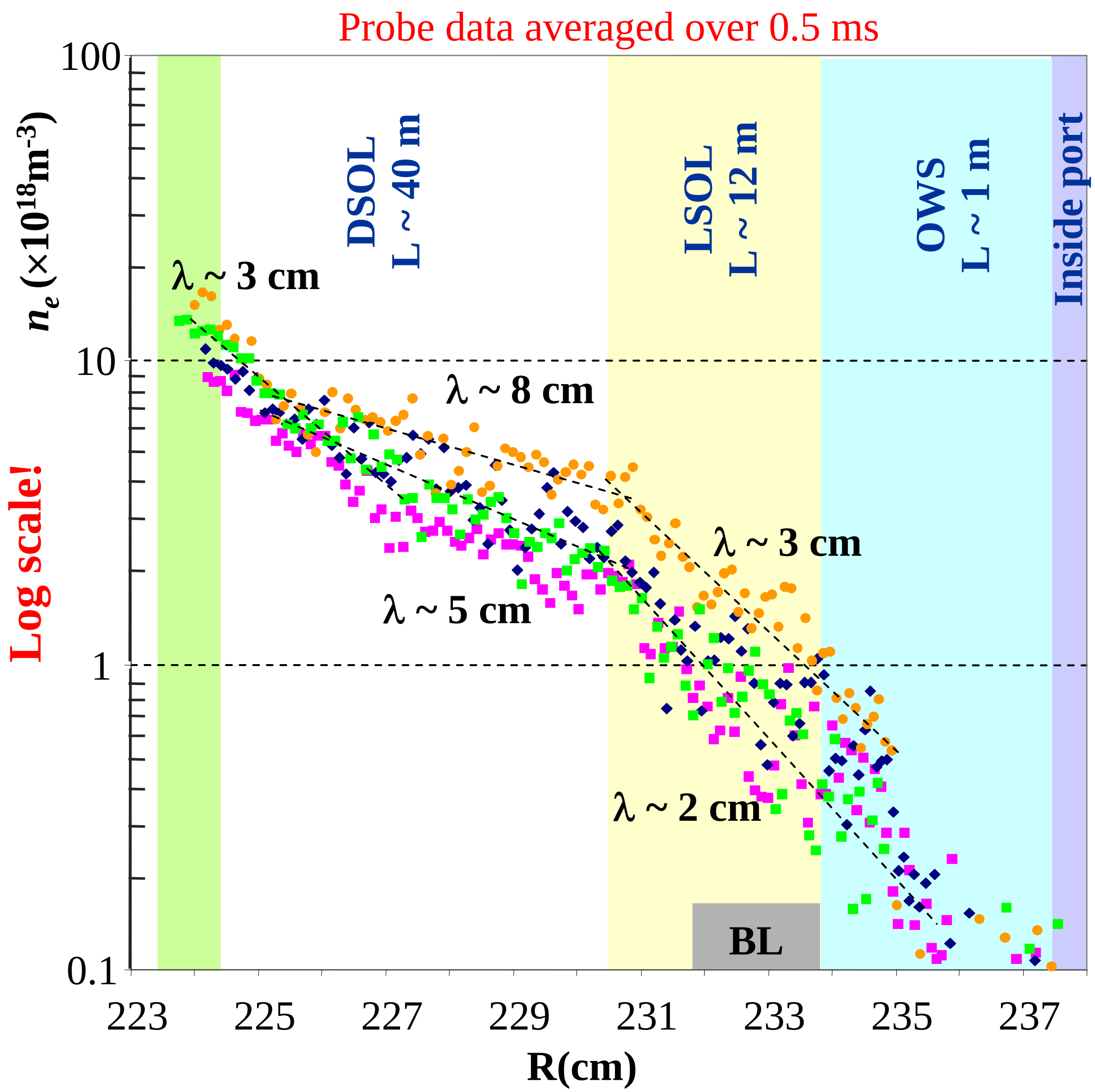


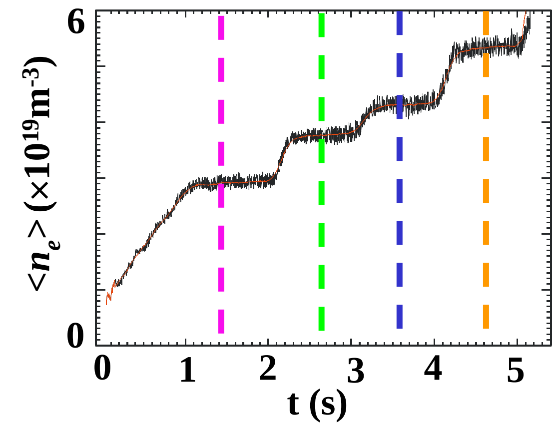
Outer Wall = LFS Wall between A and B

- Spatial resolution: ~ 2 mm
- Temporal resolution: 1 μs
- Minimum resolved values:
  I_{sat} ~ 1 mA, n_e ~ 10^{11} cm^{-3}, T_e ~ 3 eV

SOL Profiles in L-mode:
Effect of the Discharge Density and Wall Gaps

SOL density in L-mode increases with the average discharge density





LSN L-mode

B_T = 2 T, I_p = 1 MA

q_{95} ~ 3.8

- f_{Gw} ~ 0.27
- f_{Gw} ~ 0.35
- f_{Gw} ~ 0.4
- f_{Gw} ~ 0.5

$$f_{GW} = \langle n_e \rangle / n_{GW} = \frac{\langle n_e \rangle \left(10^{20}\,\mathrm{m}^{-3}\right)}{I_p(\mathrm{MA}) * \pi (a(\mathrm{m}))^2}$$

Profiles show a clear break when entering the LSOL region

Bumper limiters do not affect profiles

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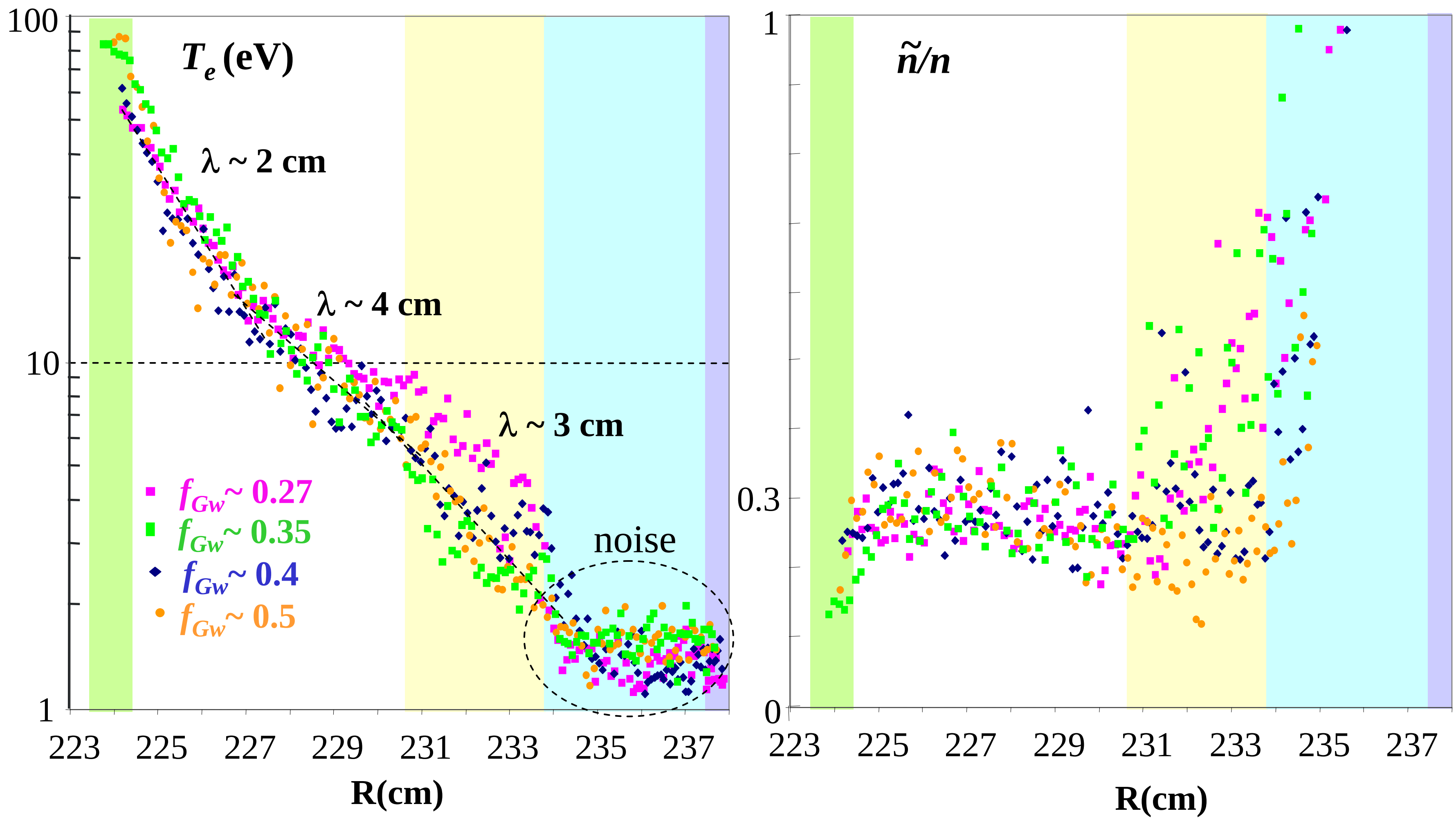
T_e and relative density fluctuation profiles do not change with density



- SOL temperature decays faster than density
- Relative fluctuation levels are flat and do not change with average density
- Absolute fluctuation levels increase with density

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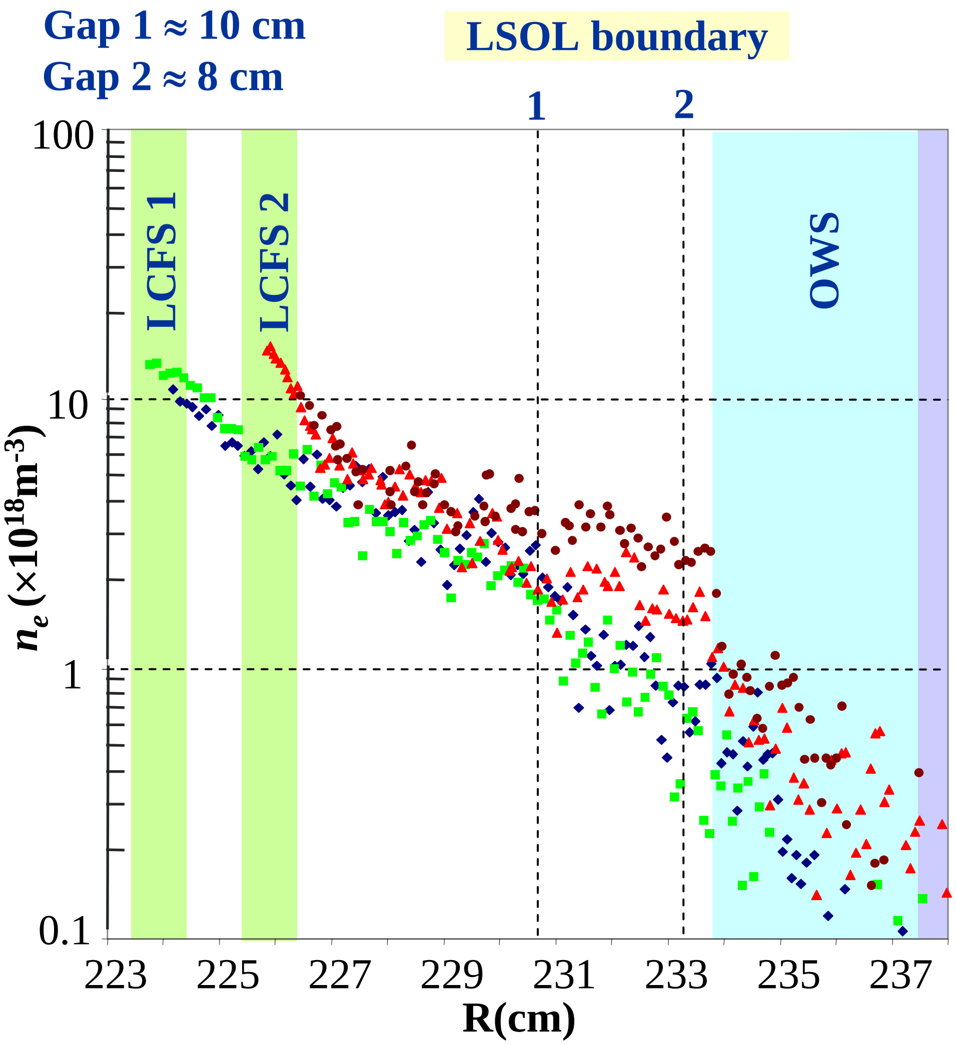
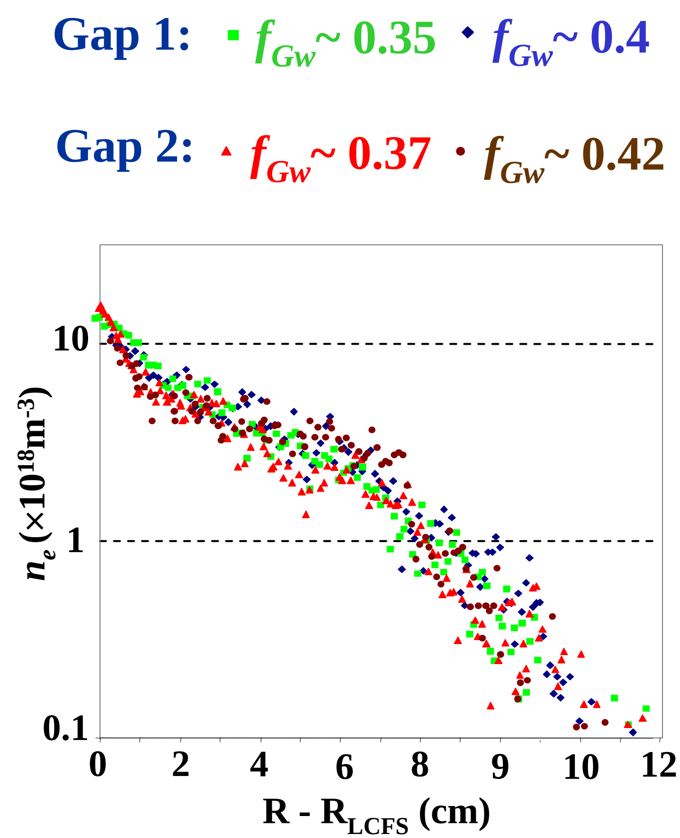
Far SOL density increases with decreasing outer wall gap





Same data aligned with respect to LCFS

Far SOL density is about a factor of 4 higher with smaller outer wall gap

However, the total ion flux to the LFS wall is probably comparable between the two gaps

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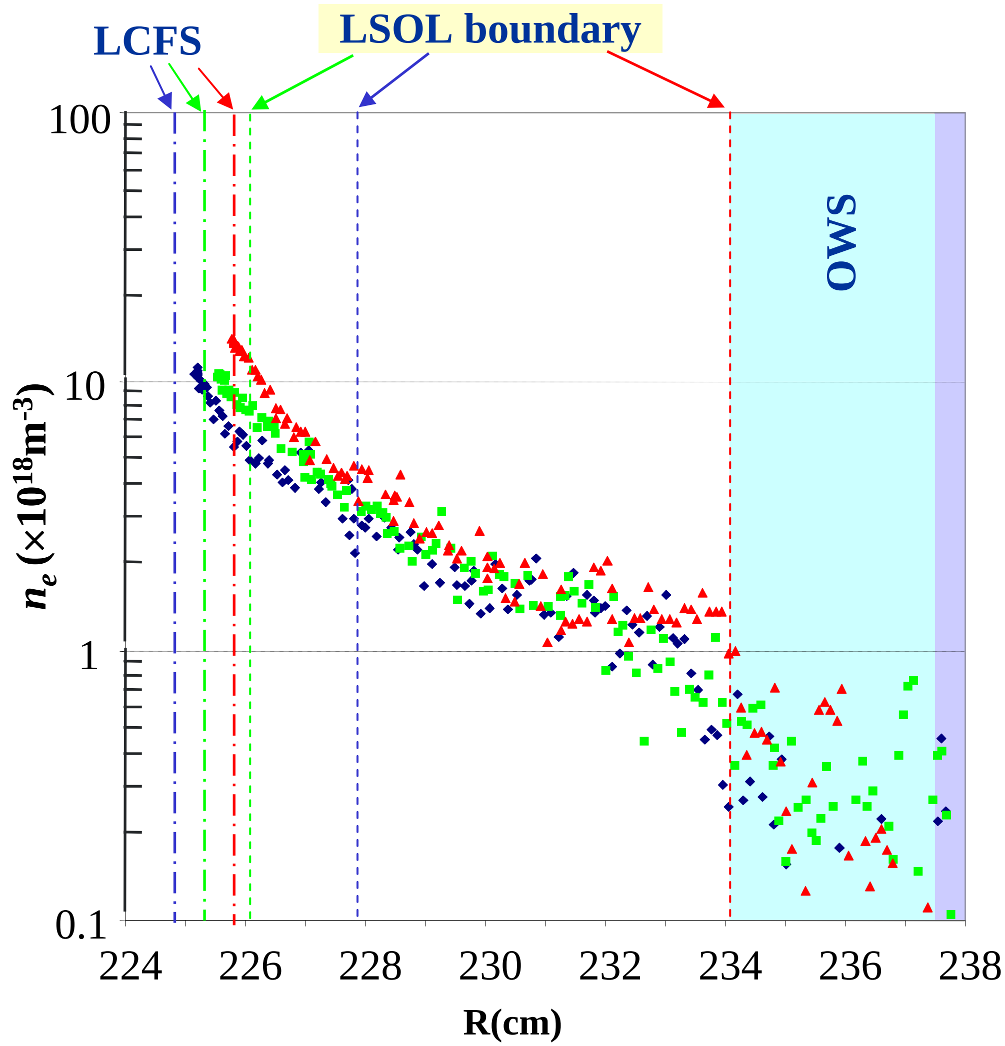
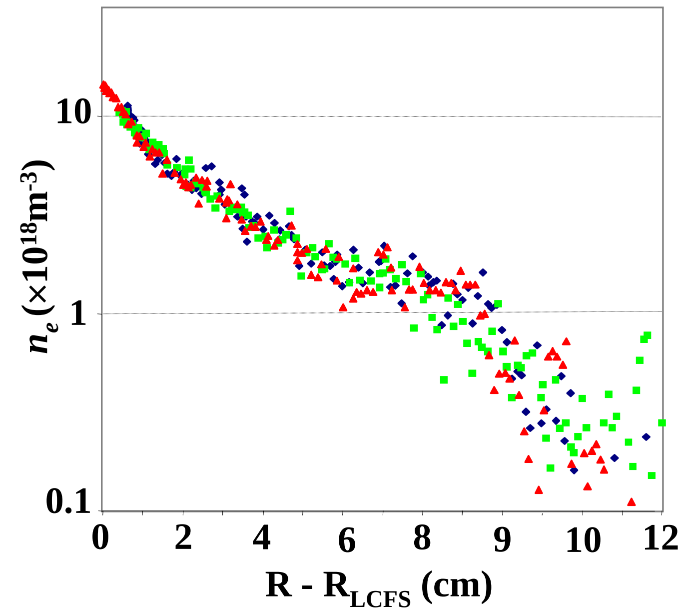
Upper gap scan has little effect on SOL density profiles



All 3 shots f_{Gw}~ 0.3

Upper gap: 23.5 cm
9 cm
2 cm



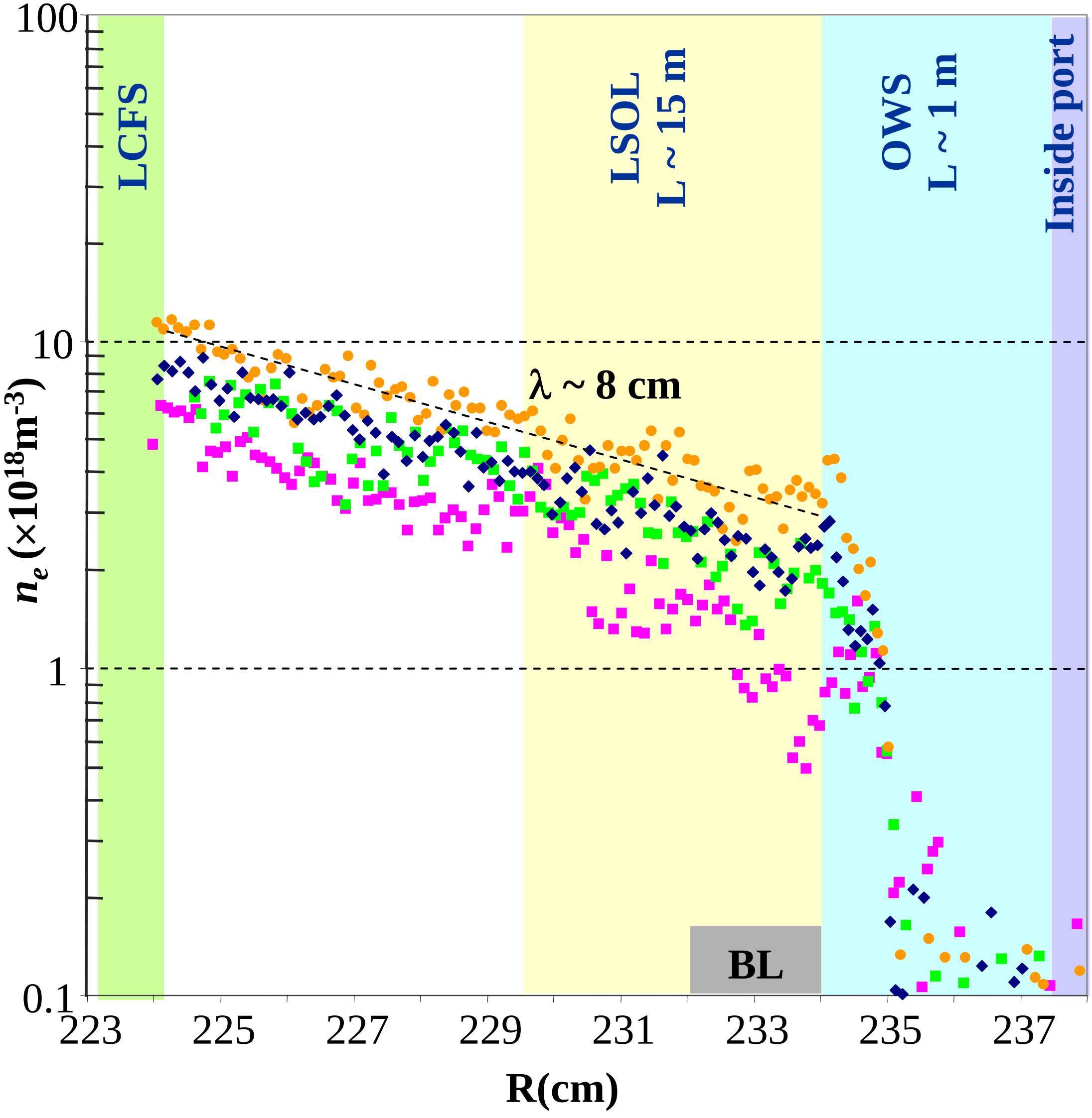
Same data aligned with respect to LCFS

Density near the outer wall changes by less than a factor of 2

The total ion flux to the LFS wall increases with decreasing upper gap

SOL Profiles and Transport in L-mode: Effect of the Plasma Current

At lower I_p density profiles do not show a break at LSOL border and far SOL densities are higher



LSN L-mode

B_T = 2 T, I_p = 0.8 MA

q_{95} ~ 5.3

- **f_{Gw} ~ 0.36**
- **f_{Gw} ~ 0.48**
- **f_{Gw} ~ 0.56**
- **f_{Gw} ~ 0.58**

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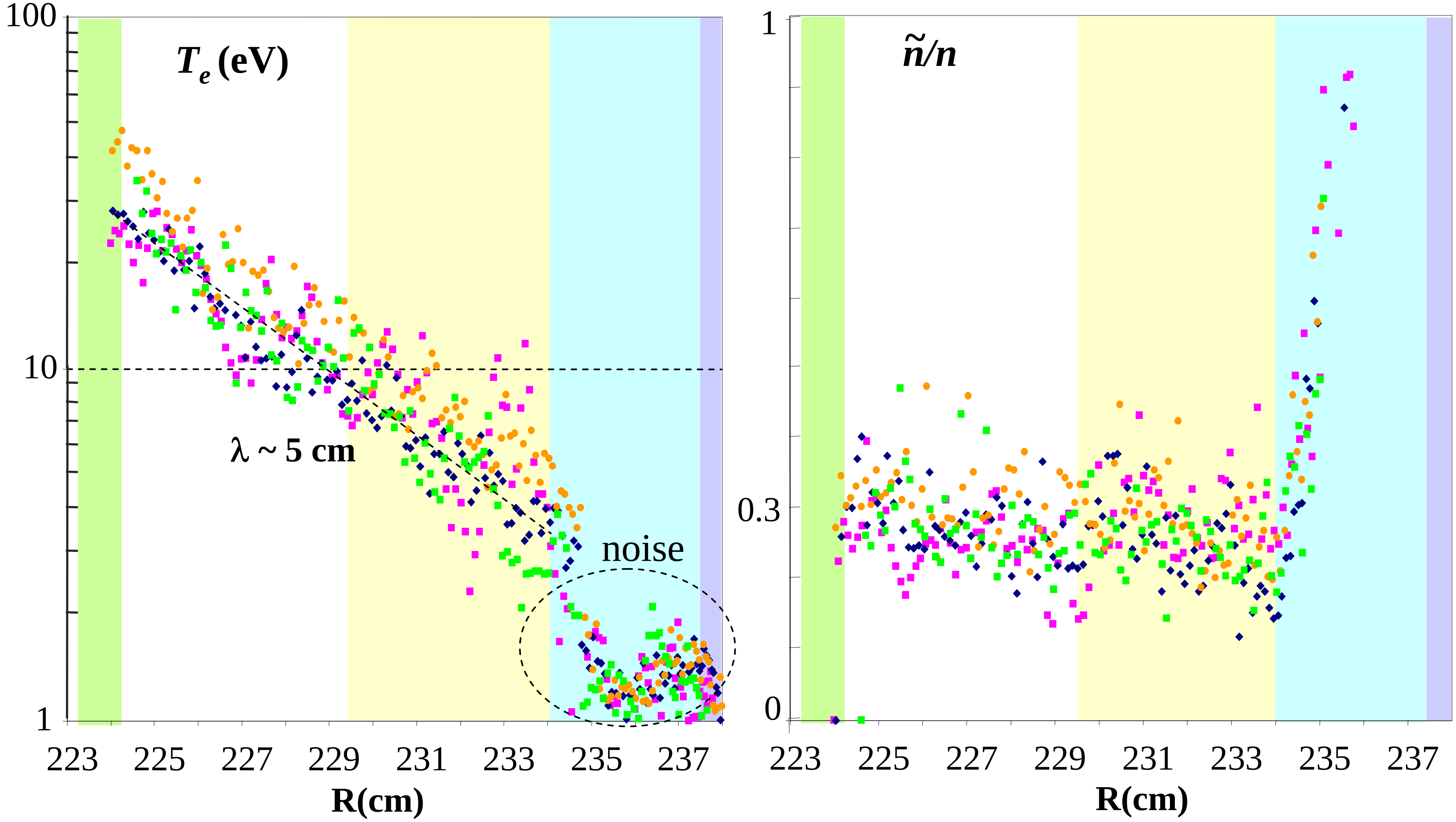
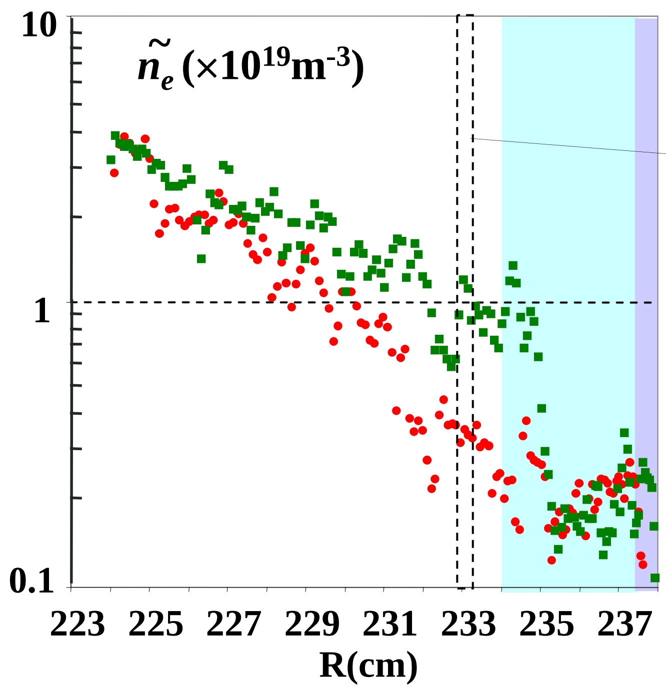
Temperature decay length is longer, relative density fluctuation profiles similar to those at higher I_p



The **absolute** density fluctuation level in far SOL is higher at lower I_p

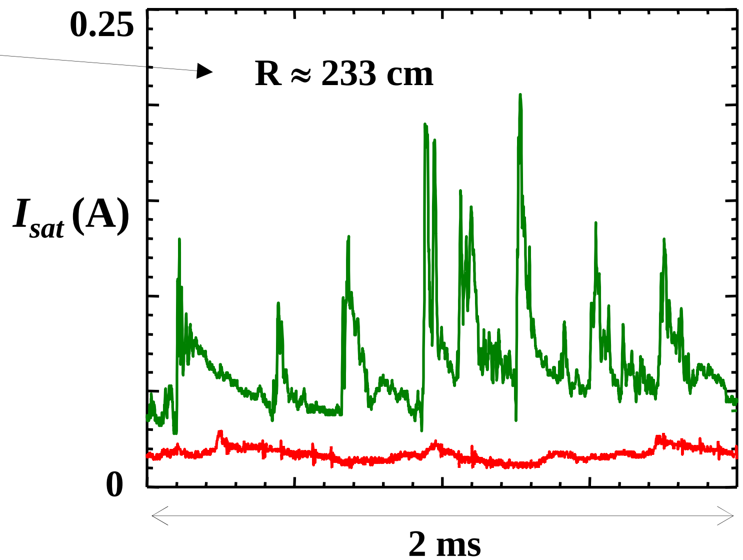
SOL density fluctuations are larger and more bursty at lower I_p

- Connection lengths to the upper and lower baffles are only about 25% longer for the lower I_p shots, not enough to explain such a large difference
- The relative fluctuation levels are similar to those at higher I_p



f_{Gw}~ 0.5, I_p = 1 MA

f_{Gw}~ 0.58, I_p = 0.8 MA



In lower I_p shots absolute fluctuation levels are higher in far SOL

In lower I_p shots far SOL fluctuations exhibit large intermittent bursts

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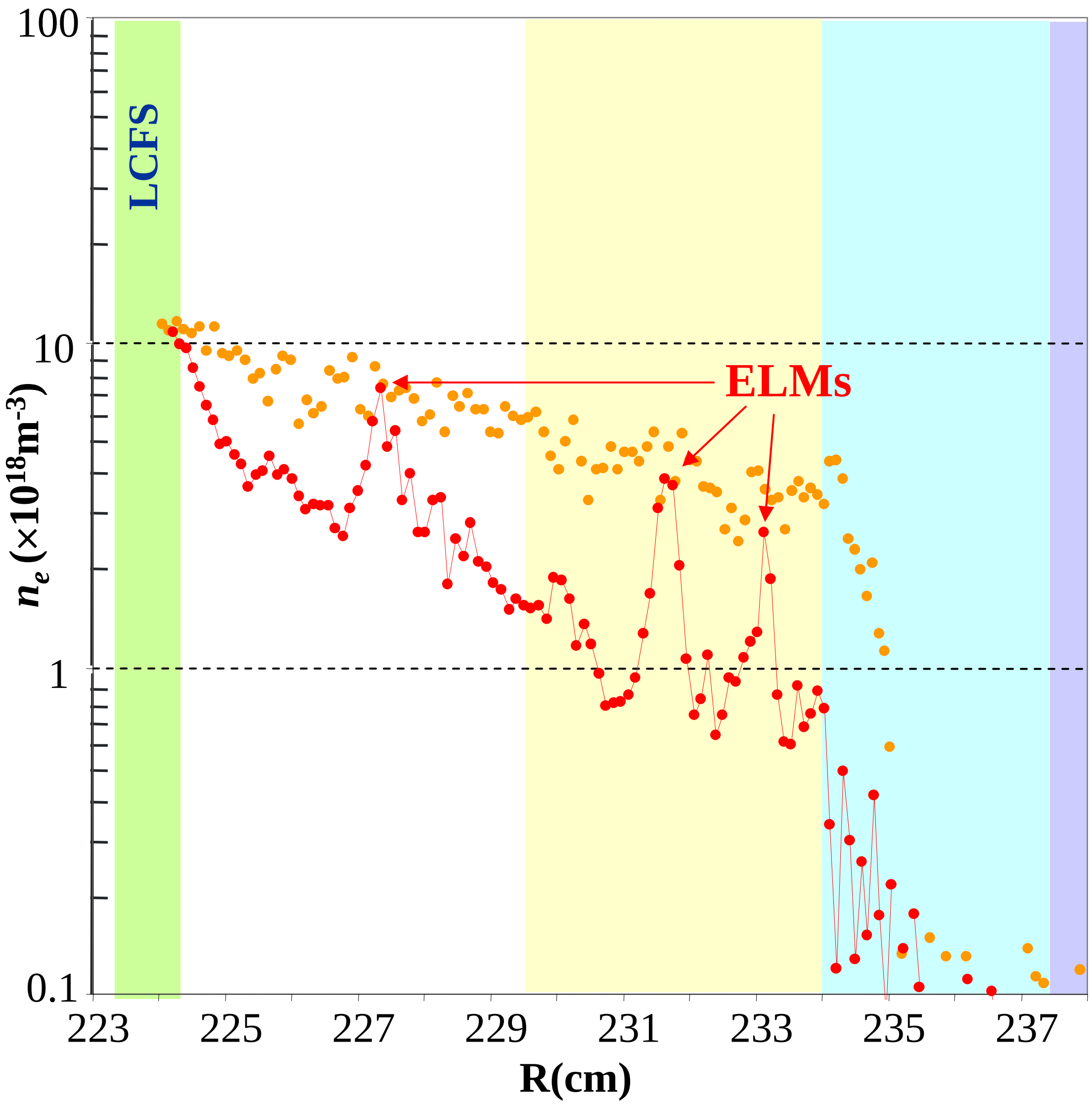
SOL Profiles and Transport: H-mode versus L-mode Comparison

In H-mode between ELMs SOL density is lower than in L-mode



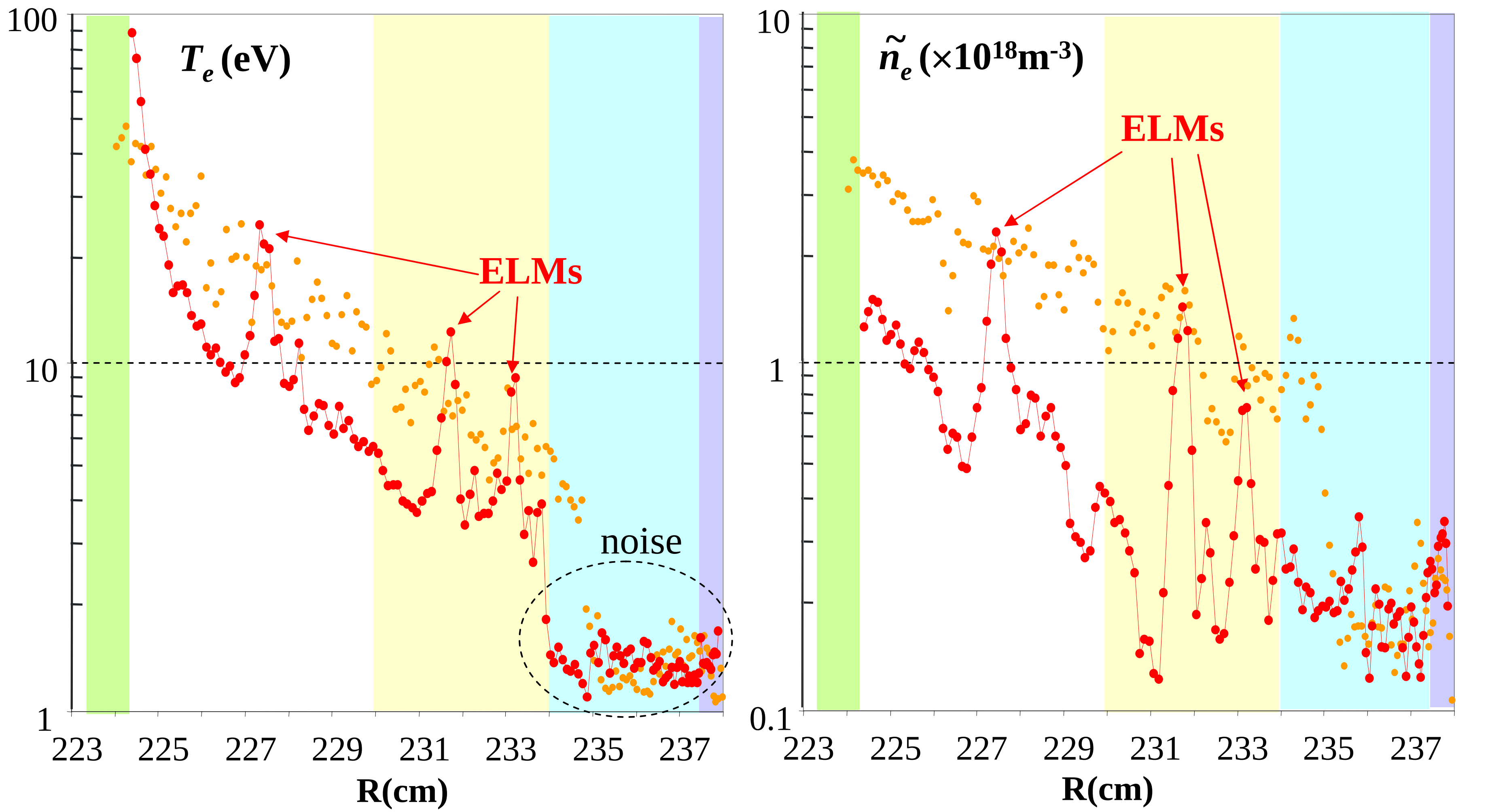
LSN configuration

L-mode
f_{Gw}~ 0.58

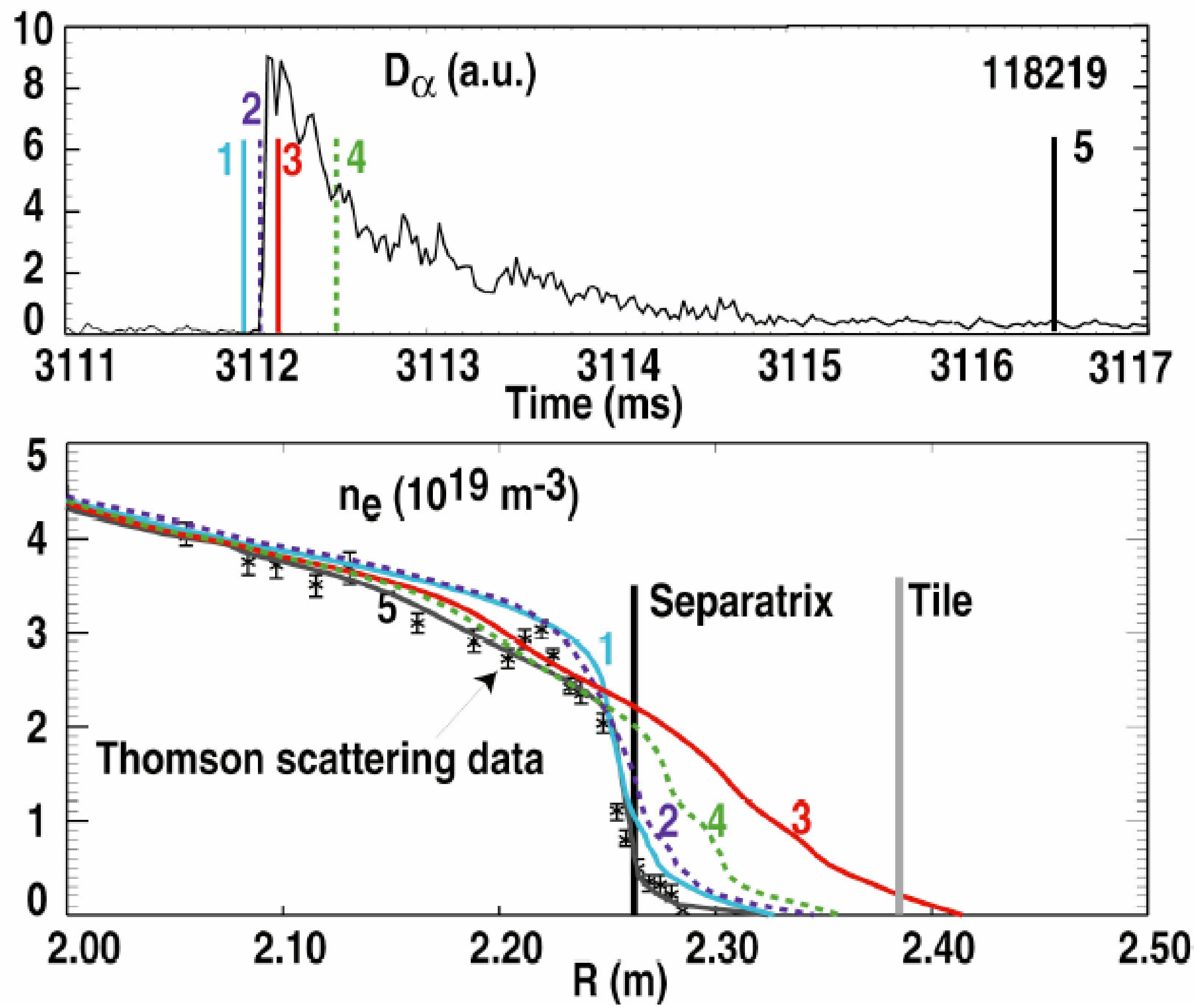
H-mode
f_{Gw}~ 0.65

- Between ELMs SOL density is below L-mode values by a factor of 5 - 8
- During ELMs SOL density reaches L-mode levels

Temperature and fluctuation levels in H-mode are lower between ELMs, comparable to L-mode during ELMs



Profile reflectometer shows outward n_e profile expansion during ELM



- Profile 1, taken just before the ELM onset, shows a typical H-mode steep edge pedestal.
- At the time of the ELM crash, about 100 µs later, Profile 3 has expanded radially outward to the vessel wall, where there is a relatively large density rise of ~ 2×10^{18} m^{-3}.
- Profile 3 exhibits no steep pedestal and is reminiscent of an L-mode profile, consistent with the probe data.

From L. Zeng et al., PSI'04

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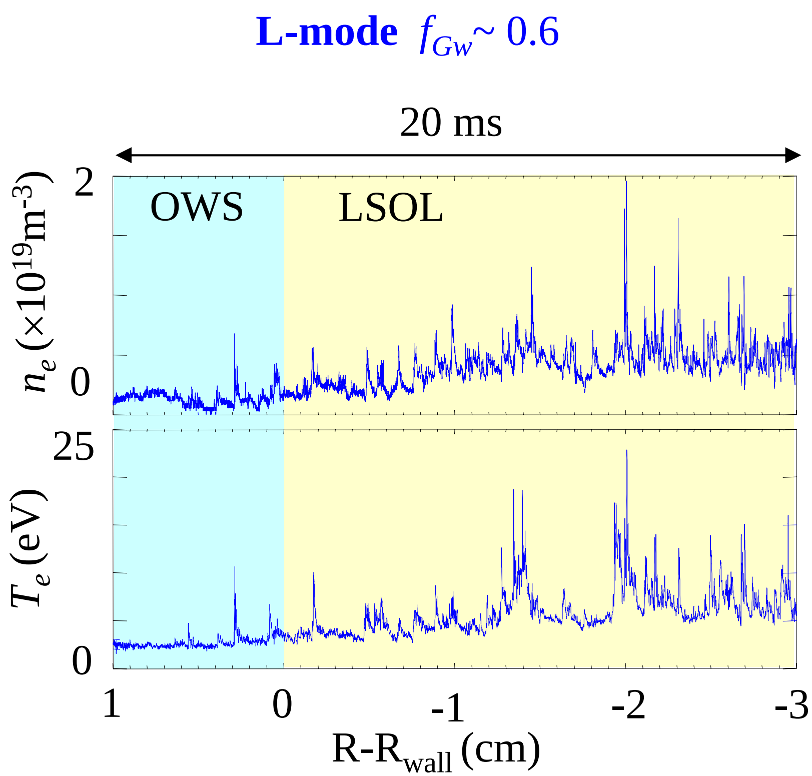
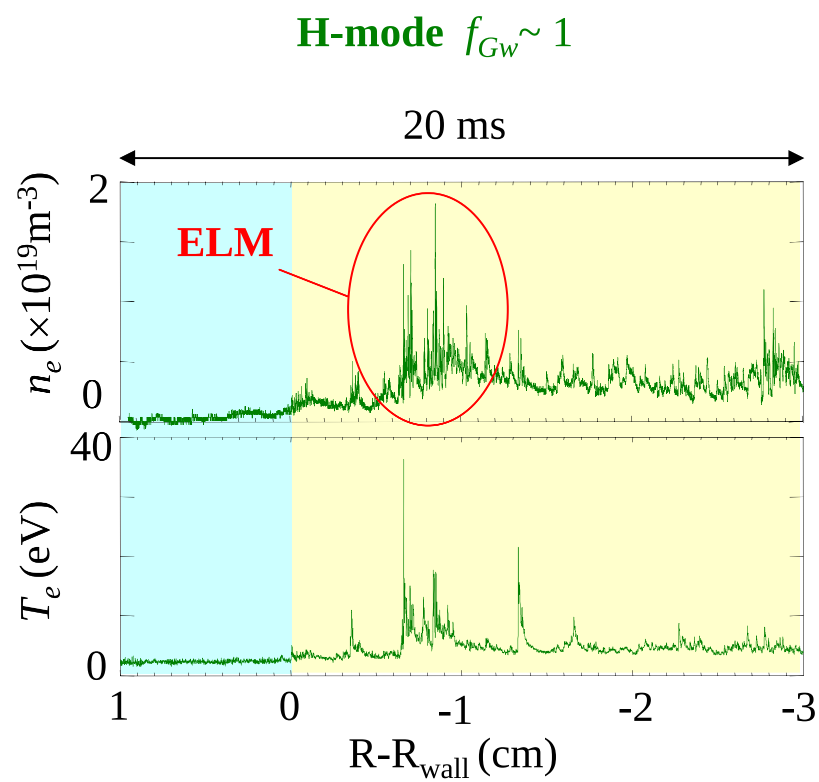
Intermittent bursts of density and temperature during ELMs in high density H-mode look similar to those in L-mode





In high density L-mode and in H-mode during ELMs

blobs of dense plasma get to the outer wall

and may cause erosion

ELMs: Fine Structure and Relative Contribution to the Outer Wall Ion Flux

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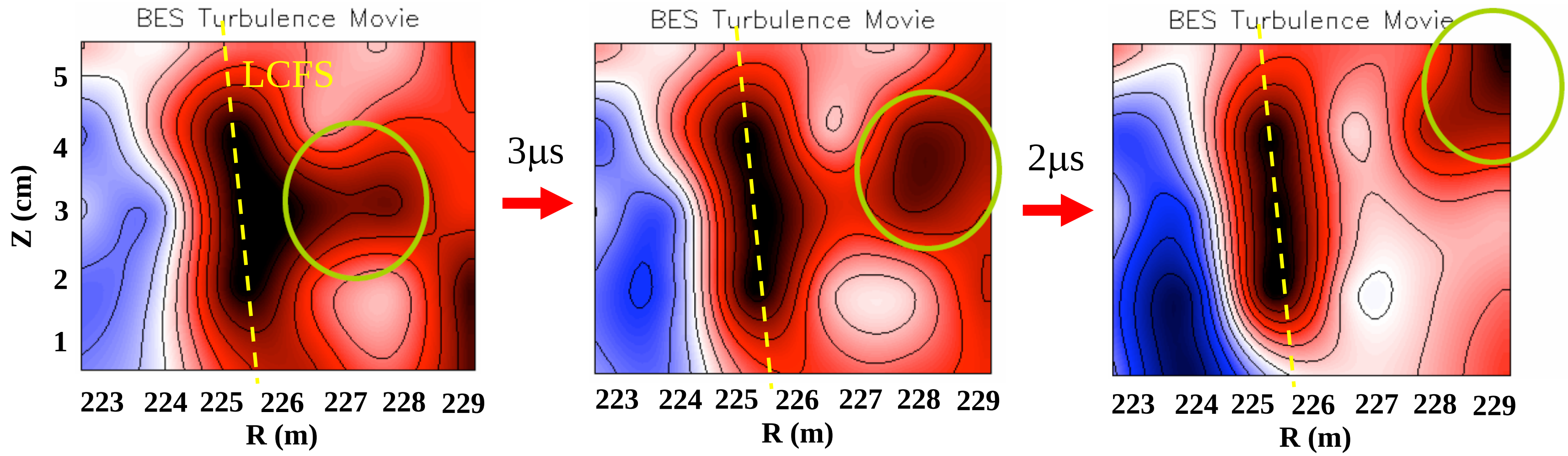
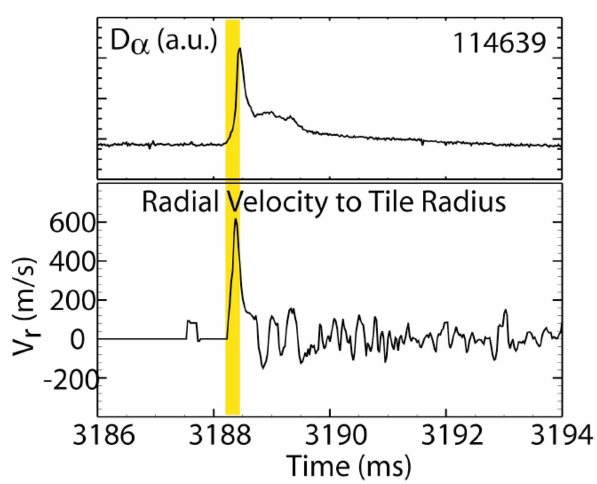
ELMs feature blobs born inside LCFS and propagating towards the wall

BES turbulence images courtesy of G. McKee

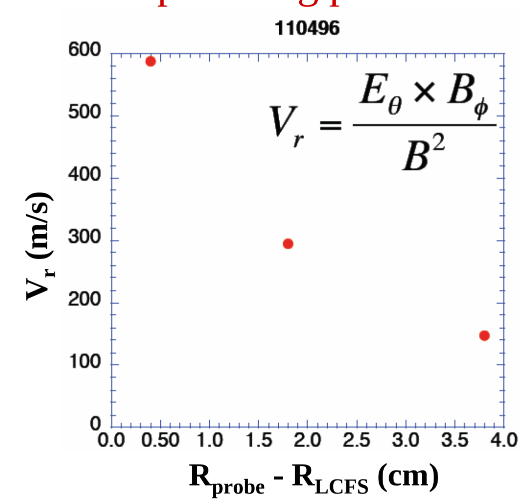


Fast reflectometer data



- ELM blobs originate at or inside LCFS
- Radial propagation velocity of the blobs varies from 5 km/s at LCFS (from BES) to 150-600 m/s in the SOL (from reflectometer and probe)

Reciprocating probe data



BES and probe data from J. Boedo et al., PSI'04
reflectometer data from L. Zeng et al., PSI'04

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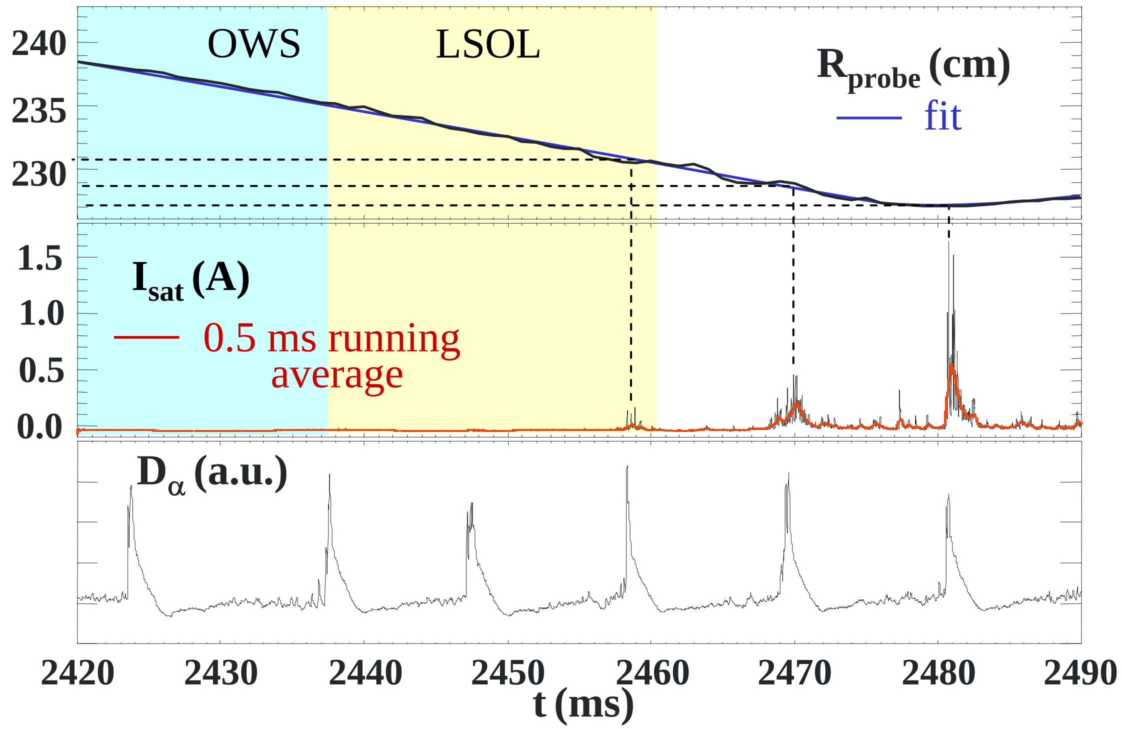
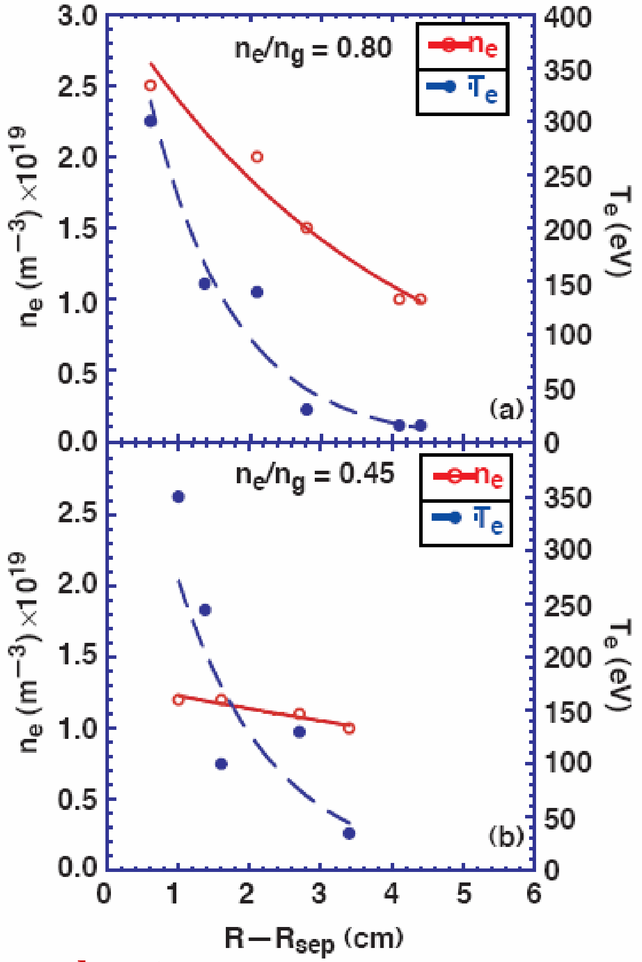
ELM density and temperature decay with radius
Decay length of ELM n_e is longer in lower density H-modes



J. Boedo et al., PSI'04

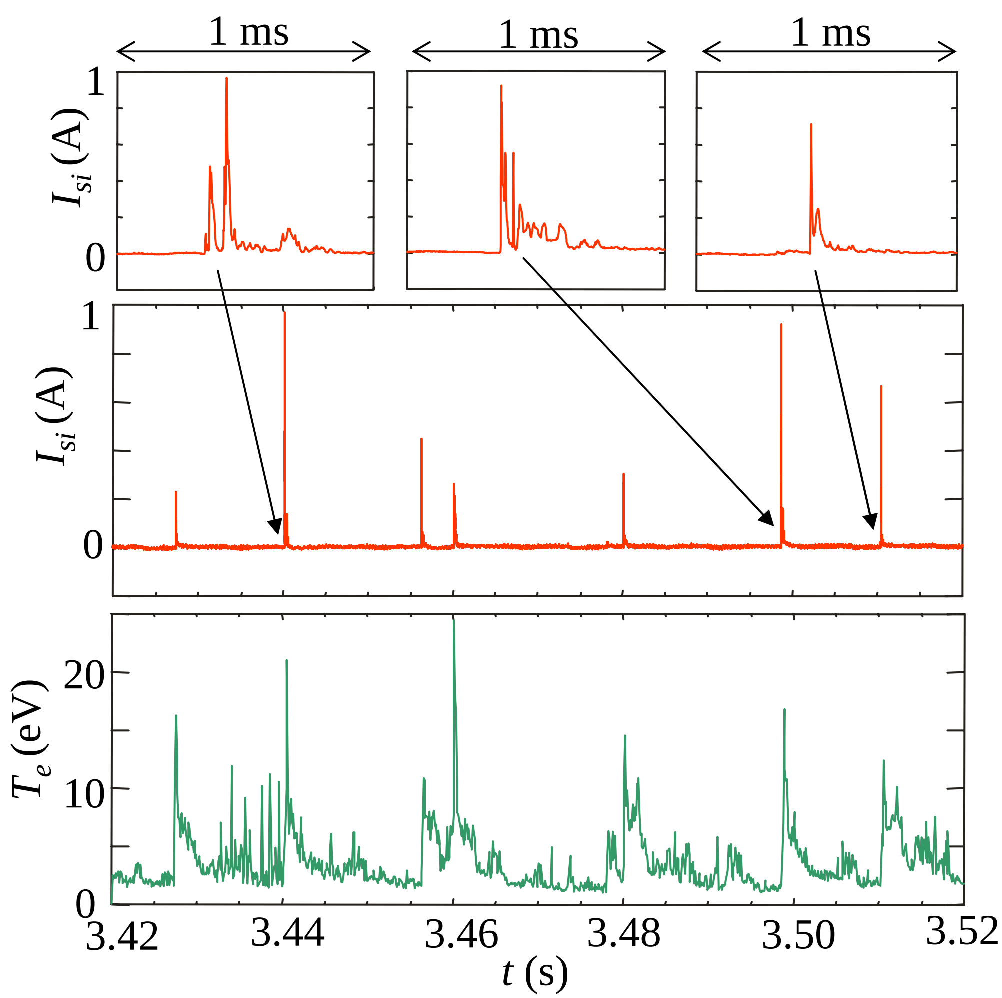


- ELMs in the SOL have fine spatio-temporal structure
- If ELMs are reproducible enough, radial evolution can be derived from the probe data

- ELM temperature decays with radius faster than density
- In lower density H-modes decay length of ELM density is comparable to SOL width

During ELMs blobs of pedestal density can get to the outer wall

I_{si} and T_e measured by midplane reciprocating probe fixed in LSOL about 5 mm inwards of the OWS border



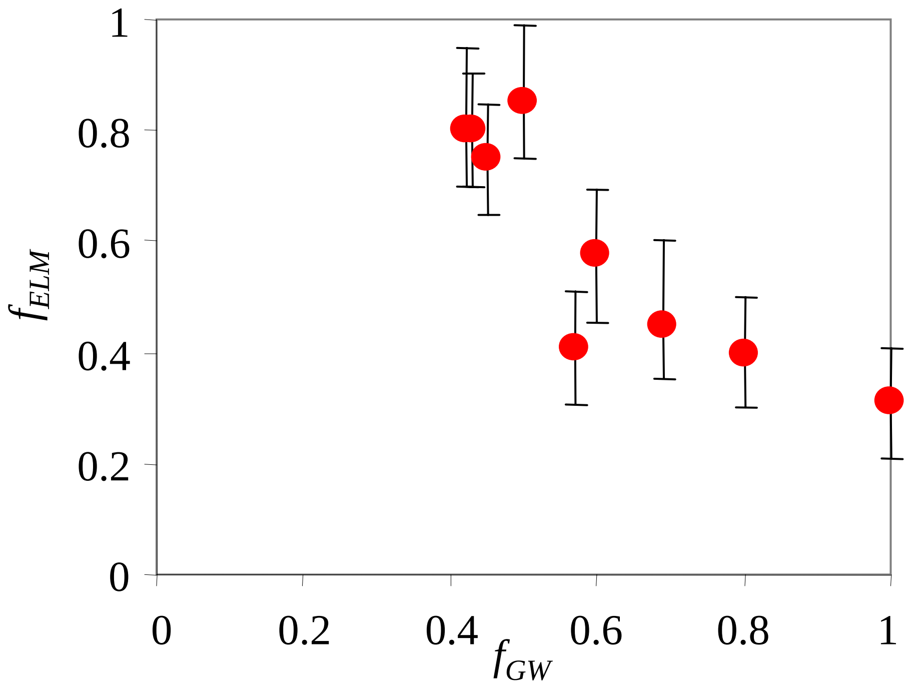
LSN H-mode
B_T = 2 T, I_p = 1.3 MA
P_{NBI} = 6.7 MW, q_{95} ~ 4.0
f_{GW} ~ 5

- ELMs feature large bursts 15-20 μs in duration followed by lower amplitude "tails".
- Some ELMs feature more than one large burst.
- The first burst is not necessarily the largest.
- I_{si} ~ 1 A at T_e ~ 20 eV for the probe area used corresponds to n_e ~ 5×10^{19} m^{-3}, which is the density characteristic of the top of the H-mode pedestal

ELMs are responsible for 30-90% of the ion flux at the LFS wall

- A relative contribution of ELMs to the *local* ion wall flux can be estimated from the ion saturation current to the midplane probe in WSOL.
- If the sheath conditions at the probe are similar to those at the wall, ion flux density collected by the probe should be equal to that at the wall (per projection area perpendicular to the magnetic field).
- We can then estimate the relative contribution of the ELMs to the total ion wall flux as the ratio of the integral of I_{si} taken during a few ELMs to the total integral of I_{si} over the corresponding time interval including inter-ELM periods:

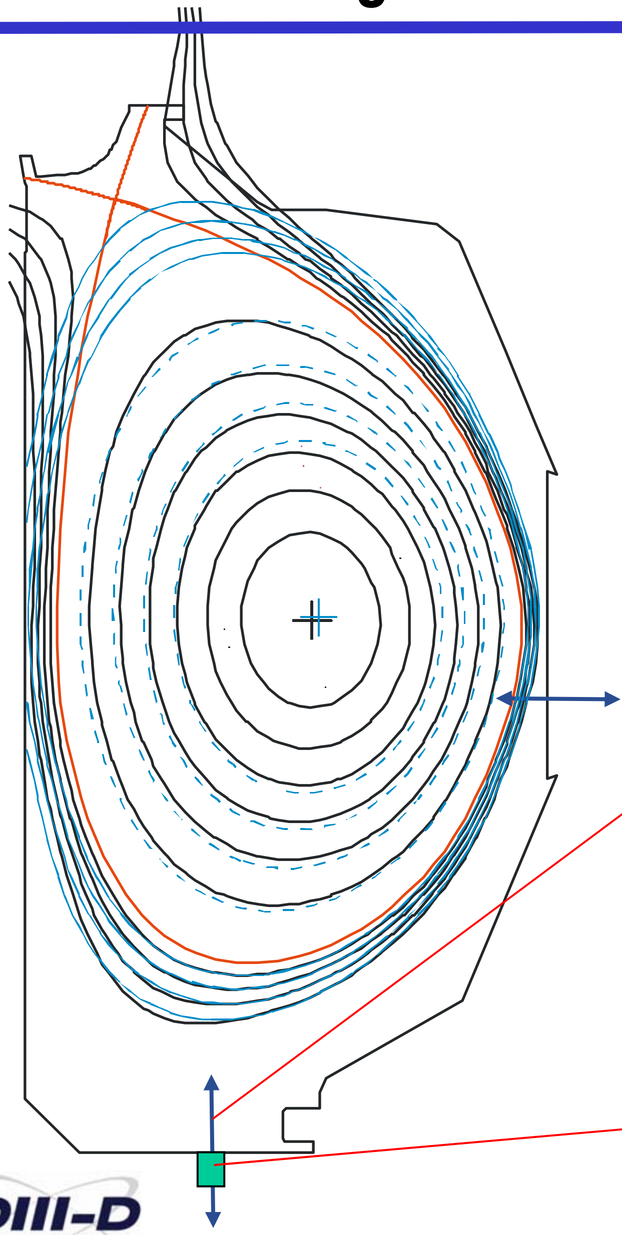
$$f_{\mathrm{ELM}} \equiv \int_{\mathrm{ELM}} I_{\mathrm{si}}\,dt \Big/ \int_{\mathrm{total}} I_{\mathrm{si}}\,dt$$

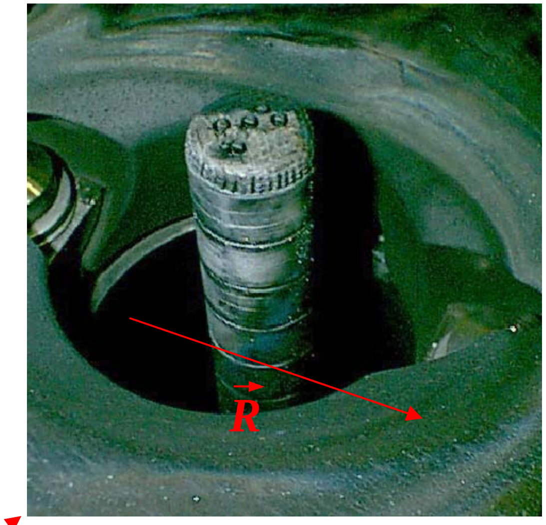


At the highest densities the relative contribution of ELMs to the wall ion flux tends to decrease due to increased plasma-wall contact between ELMs, and reduced ELM amplitude

Main Wall Erosion Studies

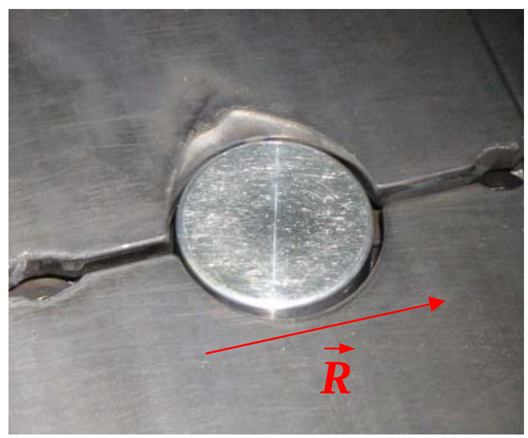
Studying far SOL plasmas near the chamber floor in USN and IWL configurations offers extra diagnostic opportunities





Floor scanning probe array

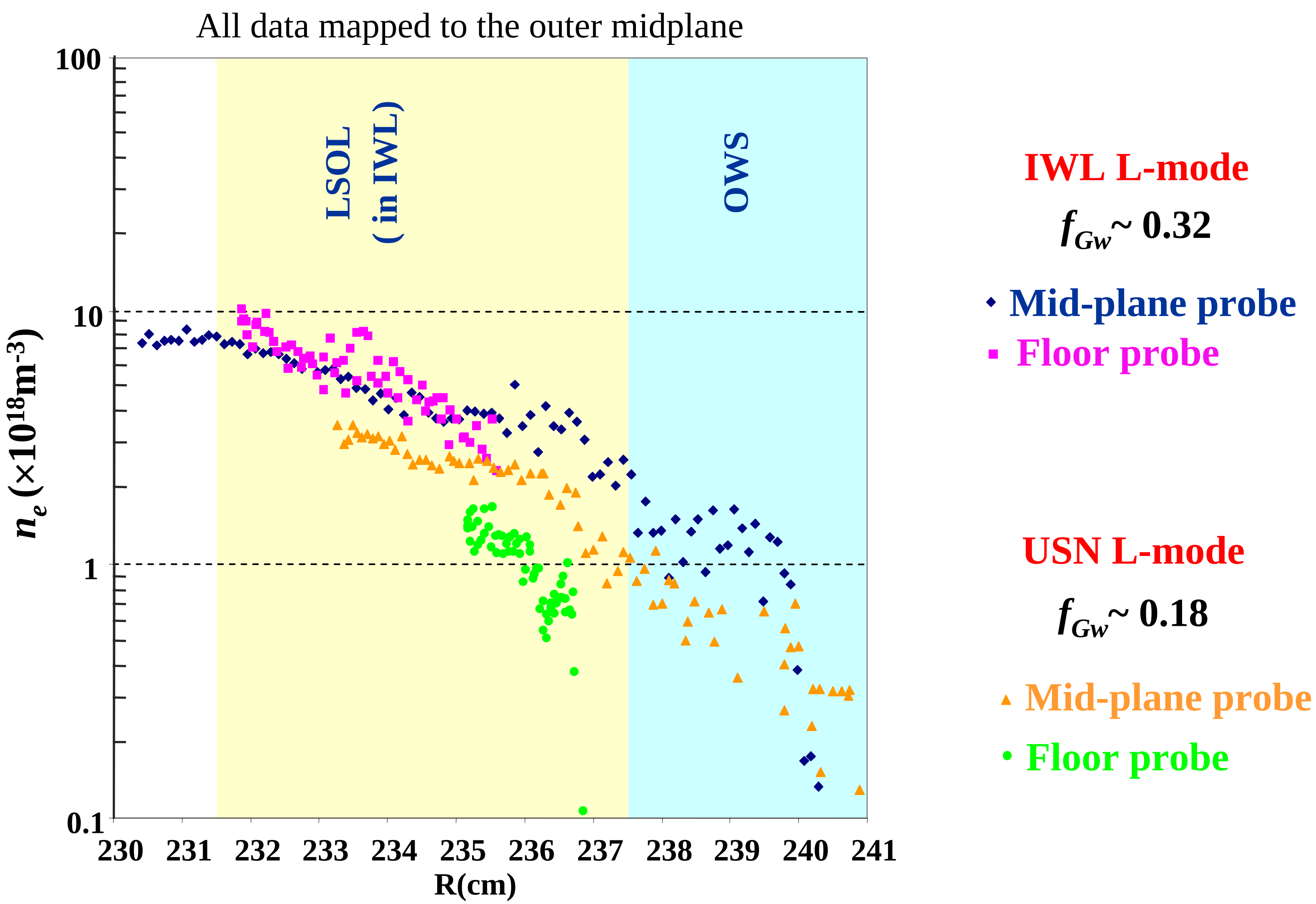
Radial (vertical) profiles of n_e and T_e



Divertor Material Evaluation System (DiMES)

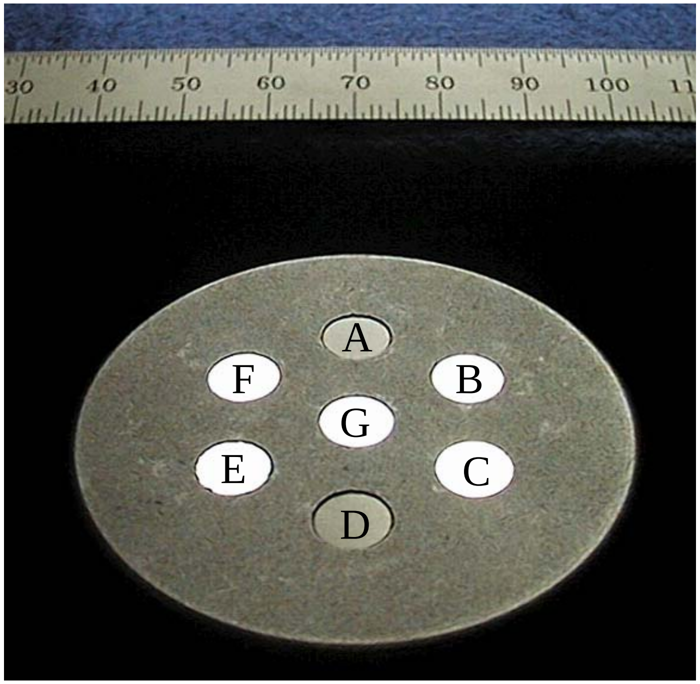
In-situ measurements of erosion/deposition

Plasma conditions near the chamber floor in IWL and USN are comparable to those near the outer wall



Lower density in USN is probably due to the presence of a secondary X-point just above the floor

Future work: We will use DiMES multi-sample probe as a proxy to measure the first wall erosion of ITER-relevant materials



A	53a C Si marker
B	R5C4 Be on Si
C	Witness 74 Be on Si
D	53b C Si marker
E	V on Si
F	W on Si
G	C1 C on Ti/Si

- During the CY 2003 experimental campaign multi-sample probe has been exposed to a series of low-density USN discharges
- Sample has been analyzed by IBA, but the net erosion was too low to measure
- We hope to expose the sample again this year to higher density discharges

SUMMARY

I. L-mode

Far SOL density, fluctuation levels and cross-field transport:

- Increase with average discharge density
- Increase with decreasing outer wall gap
- Increase with decreasing plasma current

II. H-mode

Far SOL density, temperature, and fluctuation levels:

- Between ELMs are a factor of 5-10 lower than in comparable L-mode
- During ELMs are comparable or higher than in L-mode

III. ELMs

- In high density H-modes appear in the SOL as trains of intermittent bursts similar to those observed in L-mode
- In lower density H-modes feature blobs of pedestal density propagating all the way to the outer wall
- Are responsible for 30-90% of the ion flux at the outer wall

IV. Main wall erosion

- In DIII-D can be studied by proxy using DiMES in the lower divertor in USN or IWL discharges