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Transport and deposition of ^{13}C from methane injection into partially detached divertor H-mode plasmas in DIII-D

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W.R. Wampler[1], A.G. McLean[2], S.L. Allen[3], N.H. Brooks[4], M.E. Fenstermacher[3], J.D. Elder[2], M. Groth[3], P.C. Stangeby[2], J.G. Watkins[1], W.P. West[4], and D.G. Whyte[5]

[1]Sandia National Laboratories

[2]University of Toronto Institute for Aerospace Studies

[3]Lawrence Livermore National Laboratory

[4]General Atomics

[5]University of Wisconsin

DIII-D NATIONAL FUSION FACILITY

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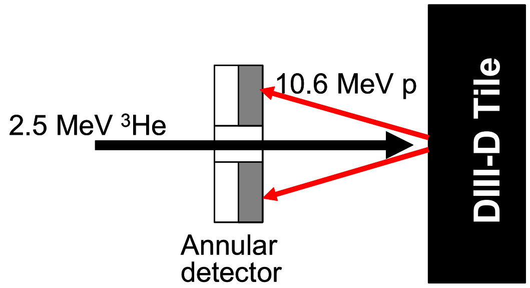
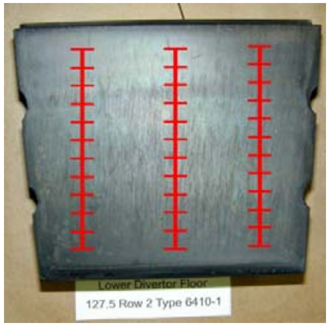
Introduction

- Plasma-wall interactions with carbon PFCs produce hydrocarbons in the main plasma chamber, which dissociate in the SOL and deposit back onto plasma facing surfaces along with DT.
- Controlling carbon erosion and redeposition is critical for managing tritium inventory in tritium fueled devices with carbon PFCs.
- Experiments in DIII-D show where this carbon is deposited with PDD H-mode and L-mode plasmas.

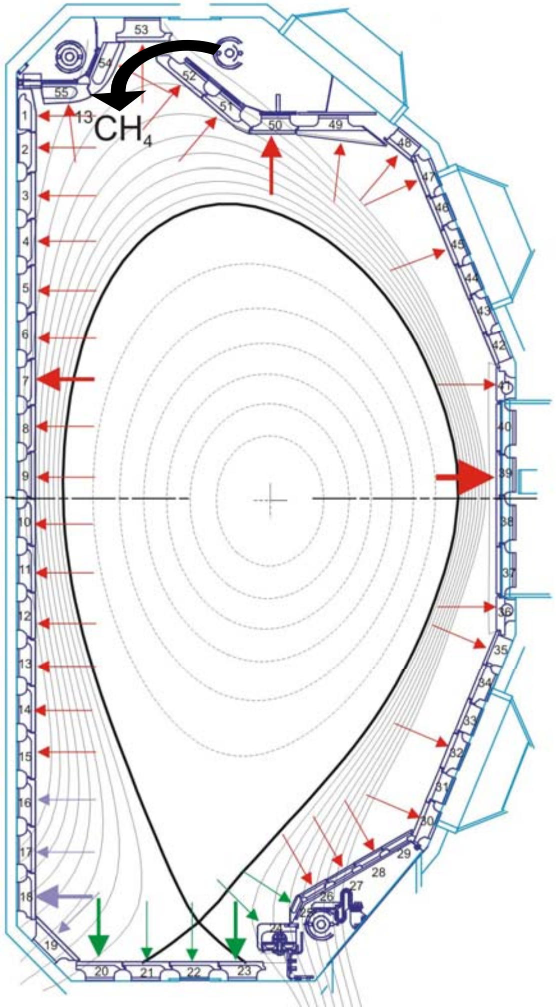
Experimental Approach

- $^{13}CH_4$ was injected from the upper divertor pump plenum into lower single null plasmas at a rate that did not significantly perturb plasma conditions. (giving toroidally symmetric injection).
- This plasma geometry, and location of injection far from the divertor, were chosen to simulate methane originating from plasma interactions with carbon on the main chamber wall.
- Tiles were then removed for nuclear reaction analysis of ^{13}C deposition.
  $^{13}C(^3He,p)^{15}N$ Sandia National Laboratories
  $^{13}C(p,\gamma)^{14}N$ University of Wisconsin





$^{13}CH_4$ injected into the top of LSN plasmas



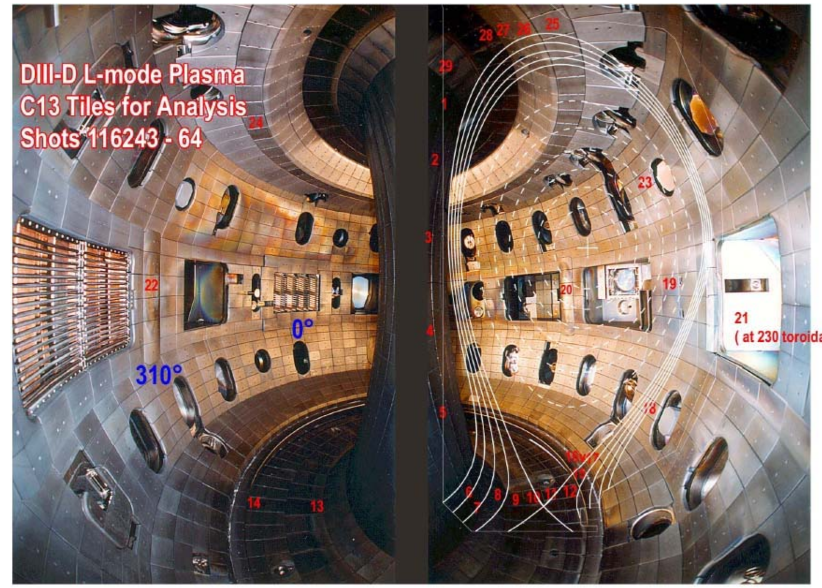
Arrows indicate tiles removed for analysis

$^{13}CH_4$ Injected into L-mode & H-mode plasmas

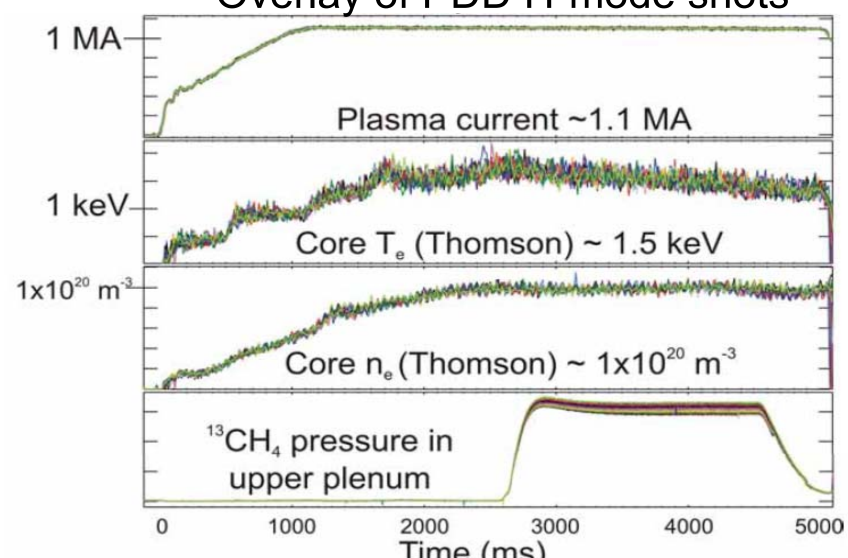
Year	2003	2005
Plasma	SAPP L-Mode	PDD ELMy H-mode
Repeat shots	22	17
Line average n_e (10^{19} m^{-3})	3	8
NB Power (MW)	0.17	6.6
^{13}C injection * (10^{22} atoms)	1.0	2.3
Tiles removed	29	64

Divertor & SOL plasmas were characterized by Langmuir probes, Thomson scattering, emission spectroscopy.

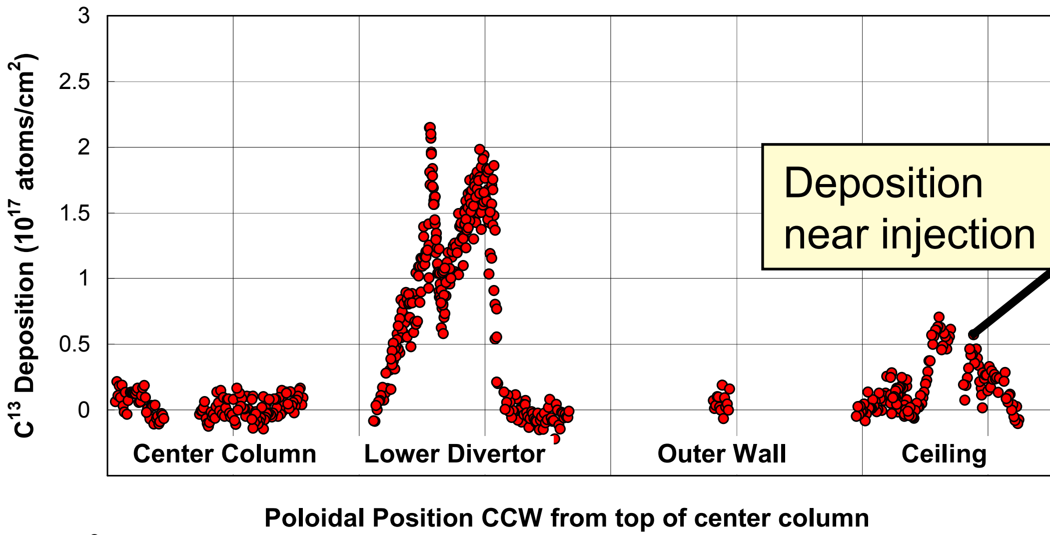
* 10^{22} carbon atoms deposited uniformly in DIII-D is about 10^{16} atoms/cm^2 or 1nm of carbon.

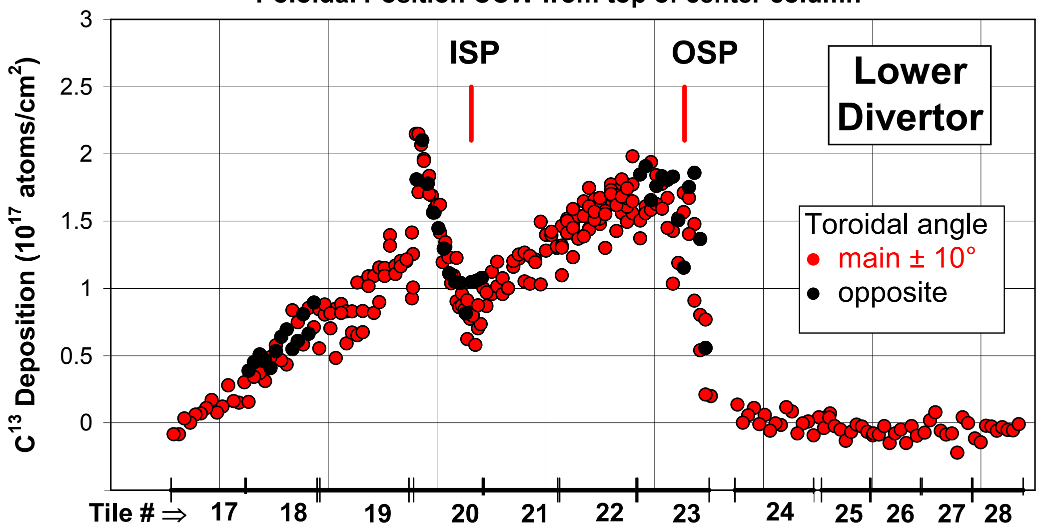


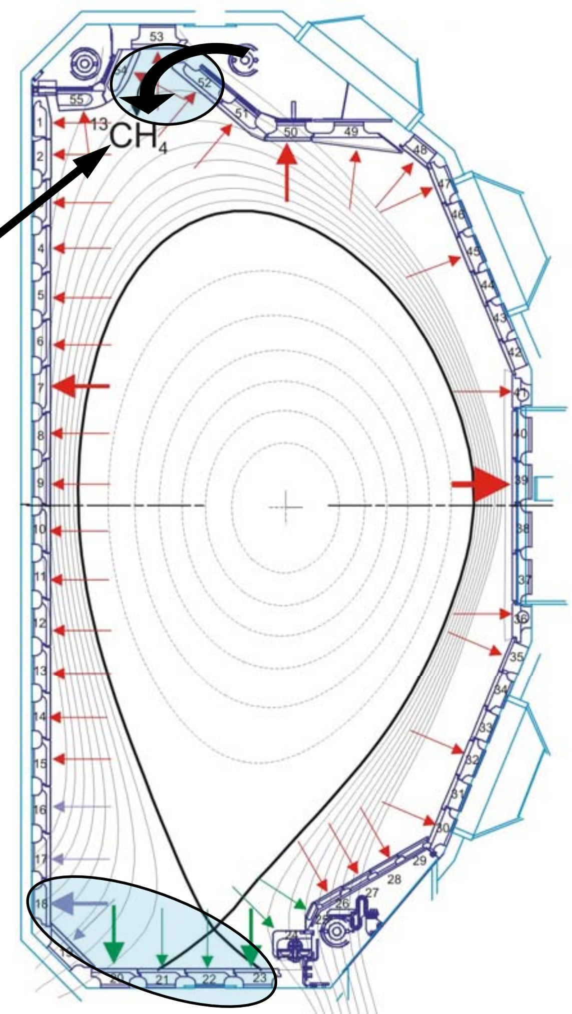
Overlay of PDD H-mode shots



^{13}C deposition from PDD H-Mode





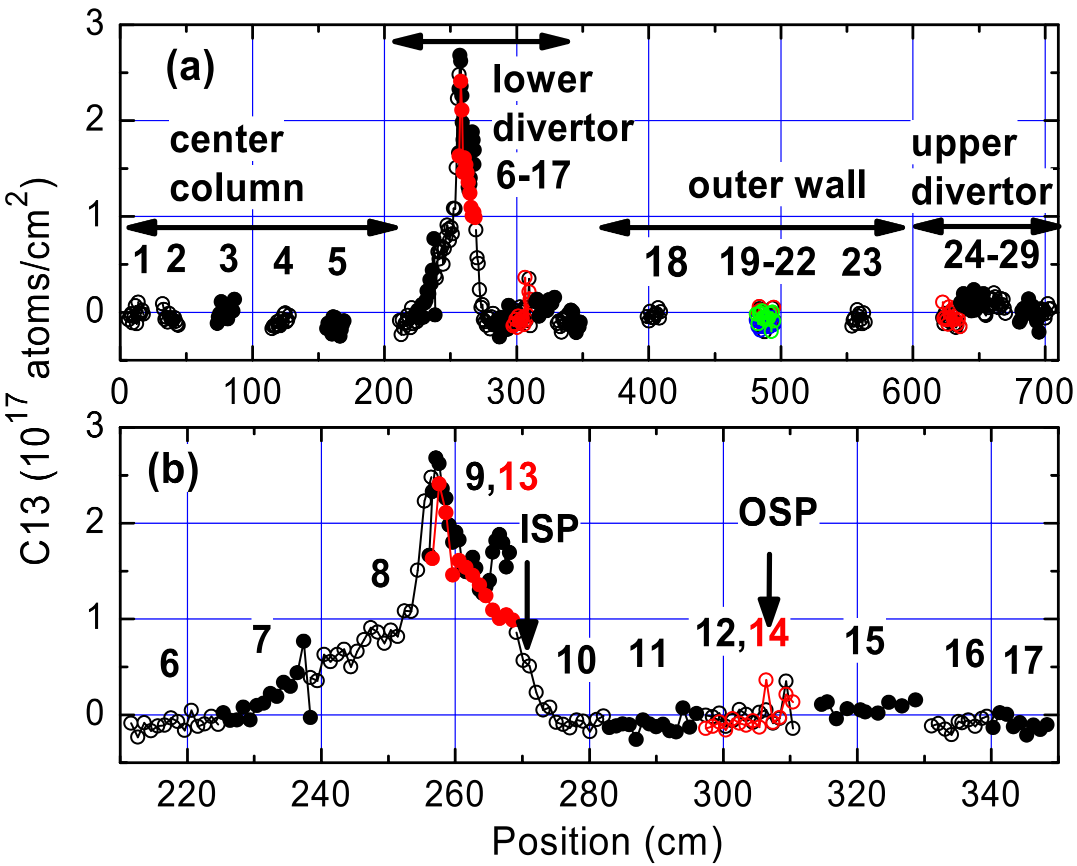


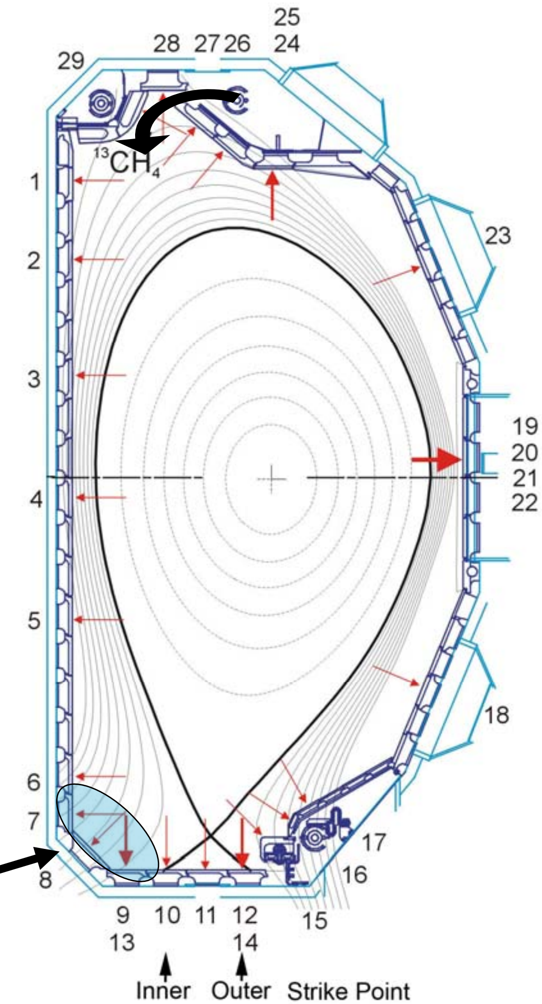
Deposition is toroidally symmetric

Heaviest deposition on inner divertor and PFZ

Detection limit ~$2x10^{16}$ atoms/cm^2 due to 1% natural abundance.

^{13}C deposition from L-Mode



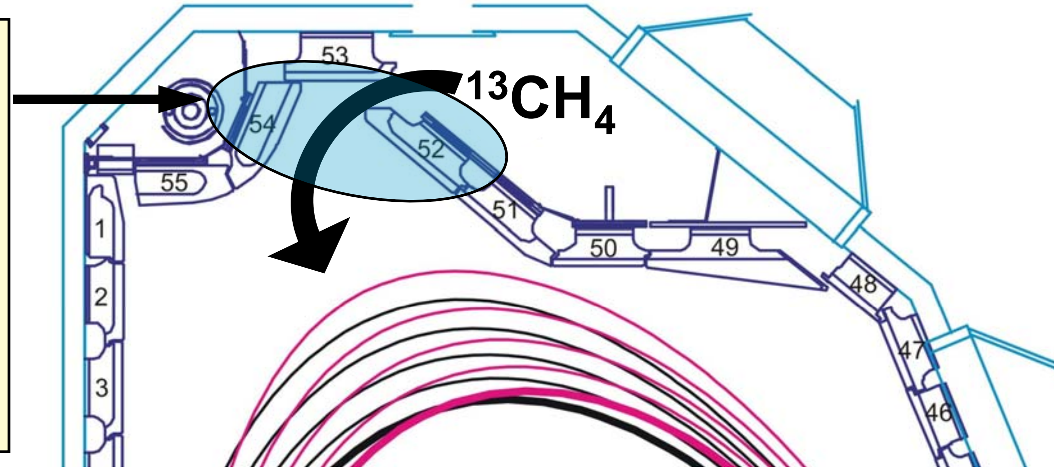


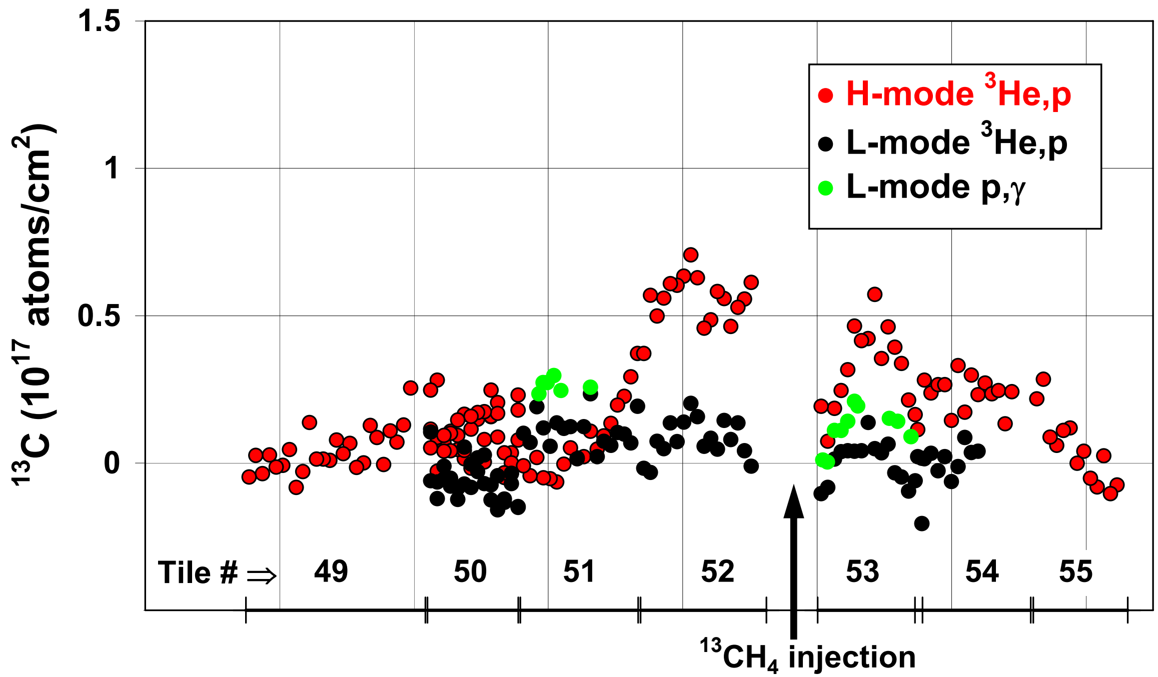
^{13}C deposition heaviest near inner divertor

H-mode vs L-mode : Ceiling

H-mode
^{13}C deposition observed near region of injection (~8% of injected quantity), dissociation begins far out in the SOL.

L-mode
p,γ RNRA gives 1-3x$10^{16}/cm^2$, ~10% of injected quantity.

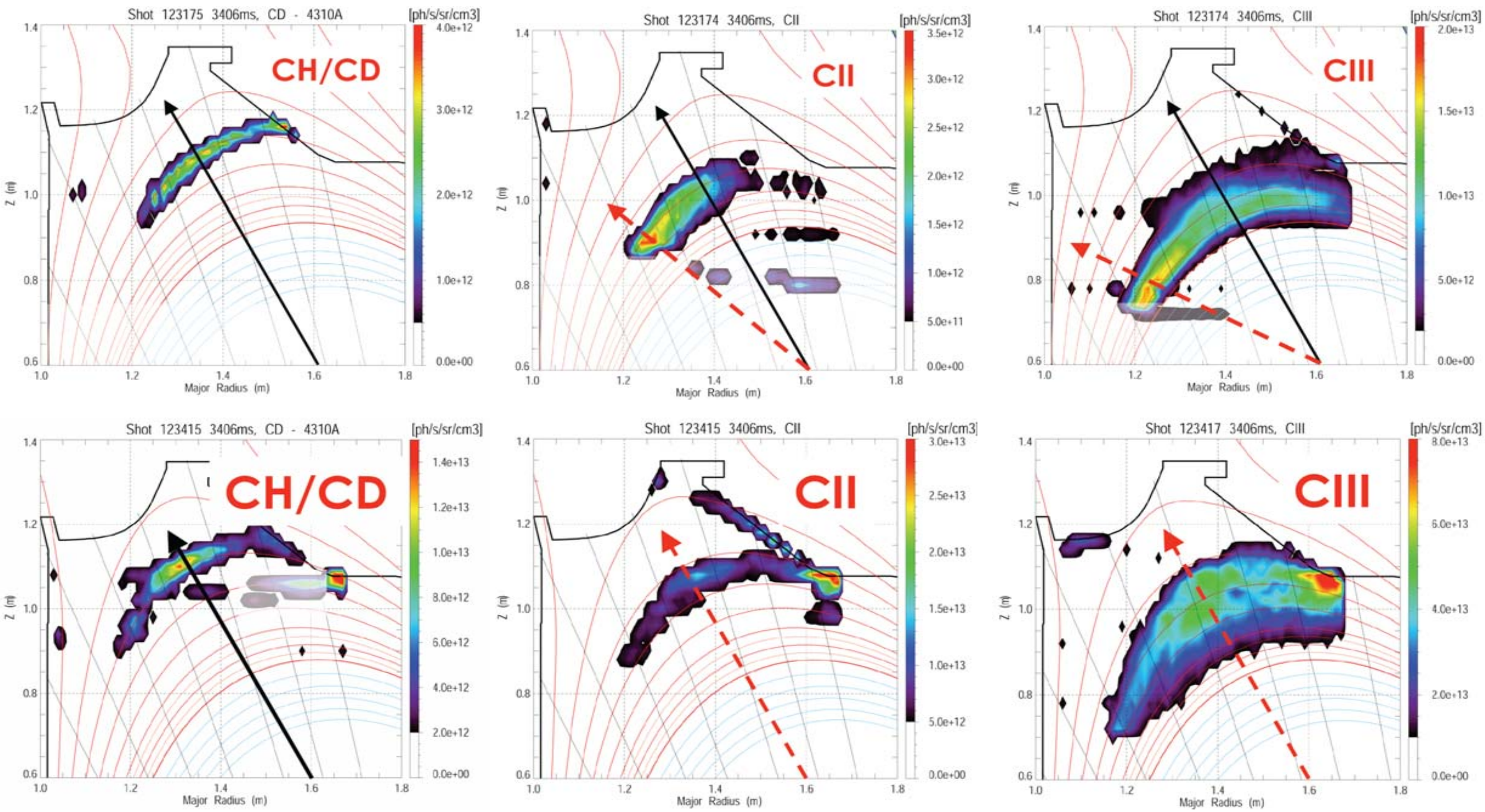




Carbon emission spectroscopy near injection

L-mode

H-mode

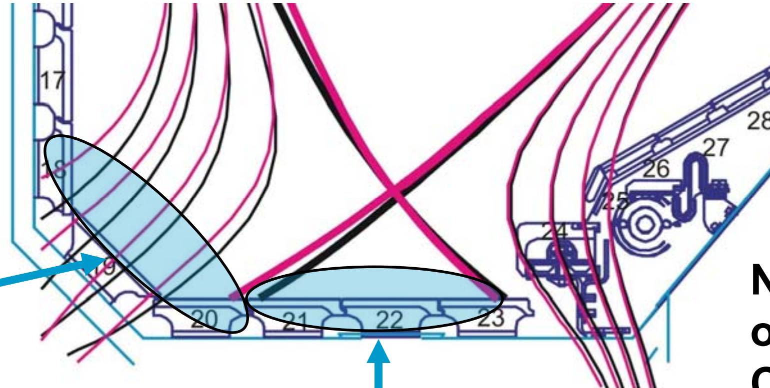


- ➢ Emission occurs farther out in SOL in H-mode than in L-mode.
- ➢ In L-mode, CII and CIII emission are shifted wrt. CH, indicating net poloidal flow of plasma toward inner divertor. (OEDGE, McLean PSI16)
- ➢ In H-mode, smaller shift in the CII and CIII emission.

M. Groth

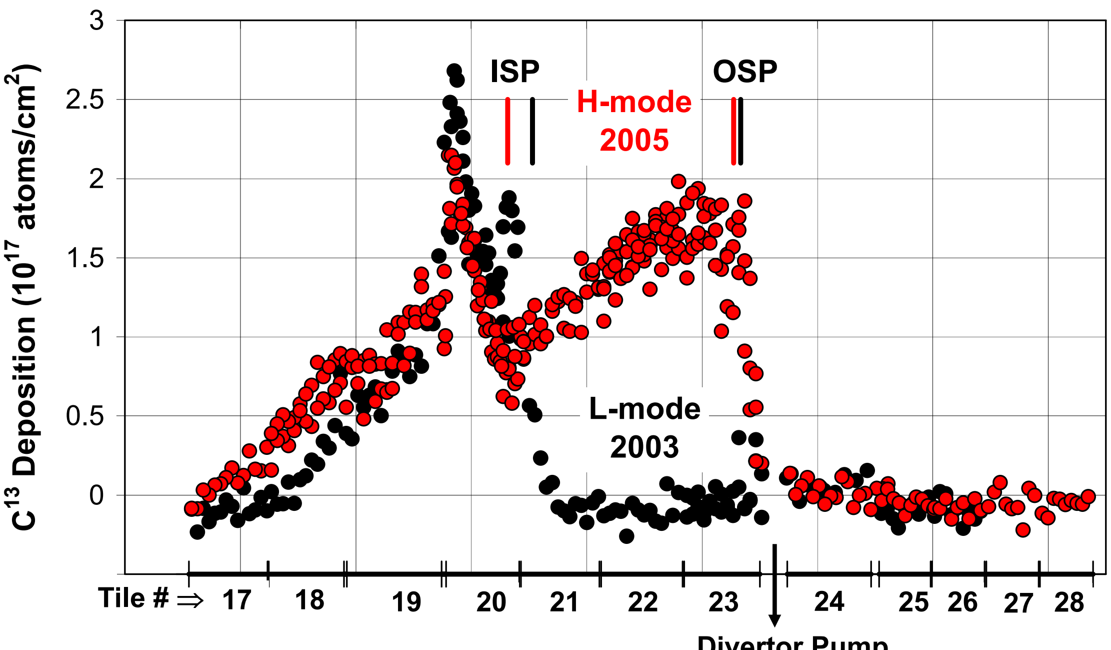
H-mode vs L-mode : Lower Divertor

Deposition at inner leg from L-mode (30%) and H-mode (13%)



No deposition observed at outer leg from L or H-mode. Confirmed by p,γ RNRA .

Deposition in the PFZ from H-mode (24%)



Asymmetric deposition indicates carbon flows into the divertor mainly from the inboard side.

DiMES experiments show carbon deposition in the divertor from ELMy H-mode plasmas

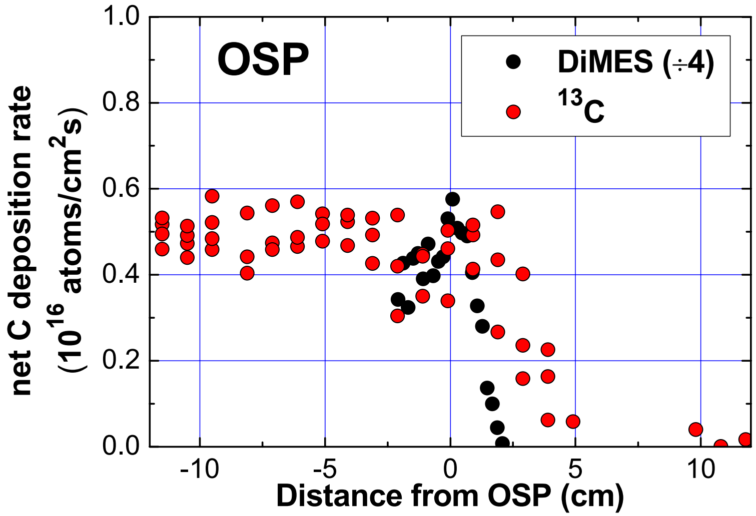
Previous studies of erosion/deposition using the Divertor Materials Evaluation System (DiMES) during PDD ELMy H-mode plasmas [1] show:

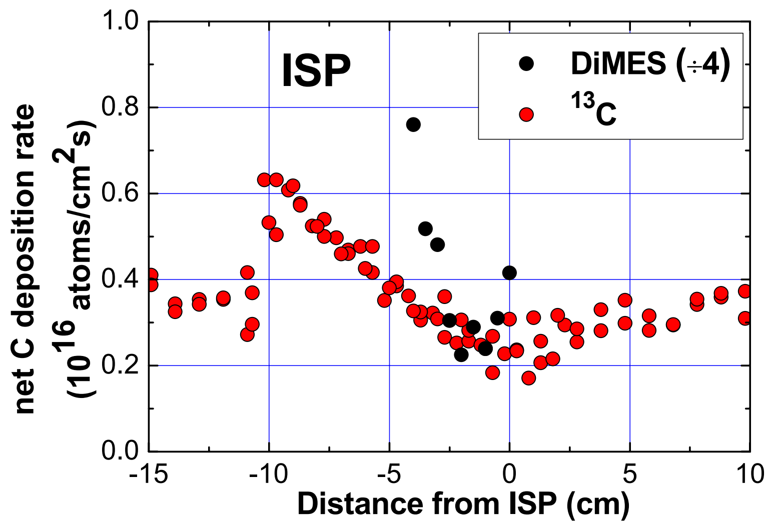
- Net rate of carbon deposition near ISP and OSP is ~4x rate of ^{13}C deposition observed here,
- C deposition drops abruptly outboard of the OSP
- D/C~1 in deposited film

Indicates total carbon flux into plasma from the main chamber during PDD H-mode is ~4x rate of ^{13}C injection or 3×10^{21} atoms/second (0.06 gram/sec).

Rate of D codeposition should be similar.

Erosion at edges of flat center-post tiles is a likely source of carbon (M. Groth P1-12).

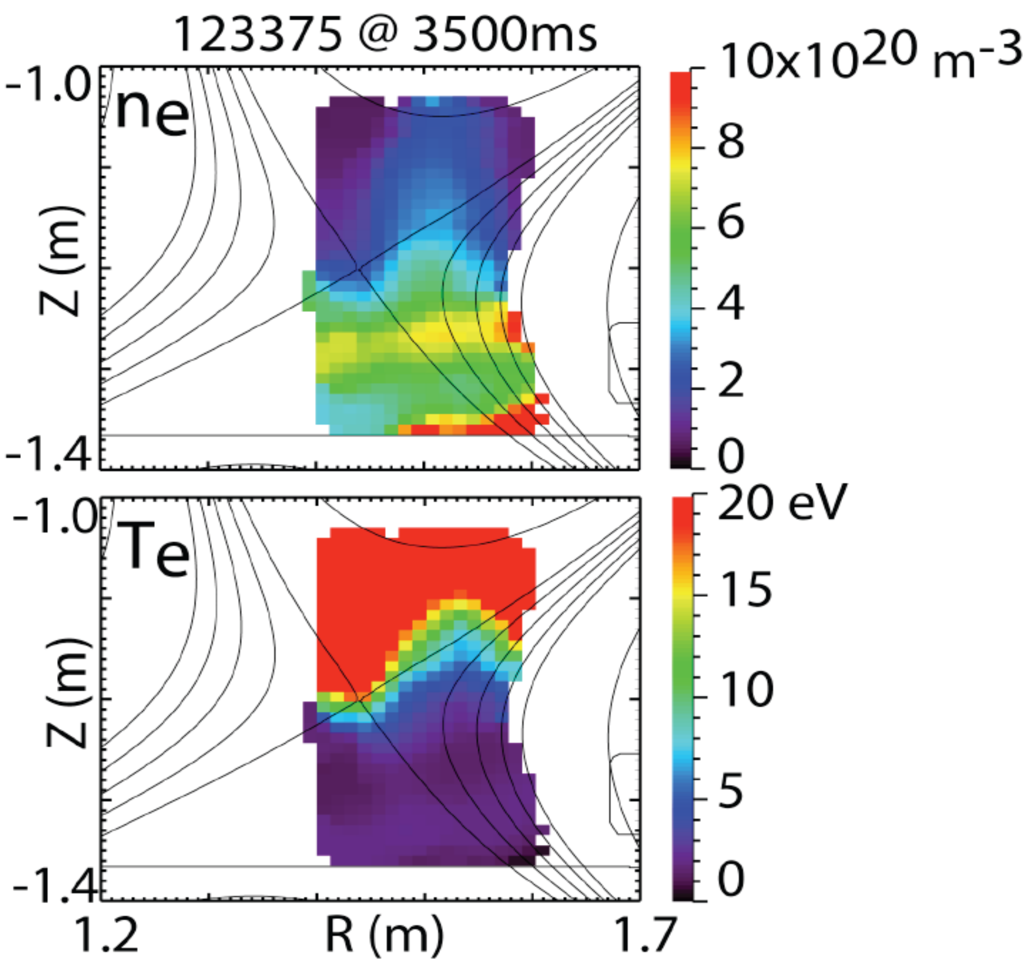




[1] Wampler et.al. PSI14 (2000)

Divertor Thomson Scattering PDD H-mode

- Outboard divertor plasma (ELM averaged) is cold and dense.
- From just below the X-point to the floor the plasma is 2.5 eV or less and the density is mid 10^{20} /m^3.
- No significant gradients in density or temperature across the outer separatrix in the divertor.
- Volume recombination and transport of neutral carbon is likely to influence deposition from PDD H-mode.



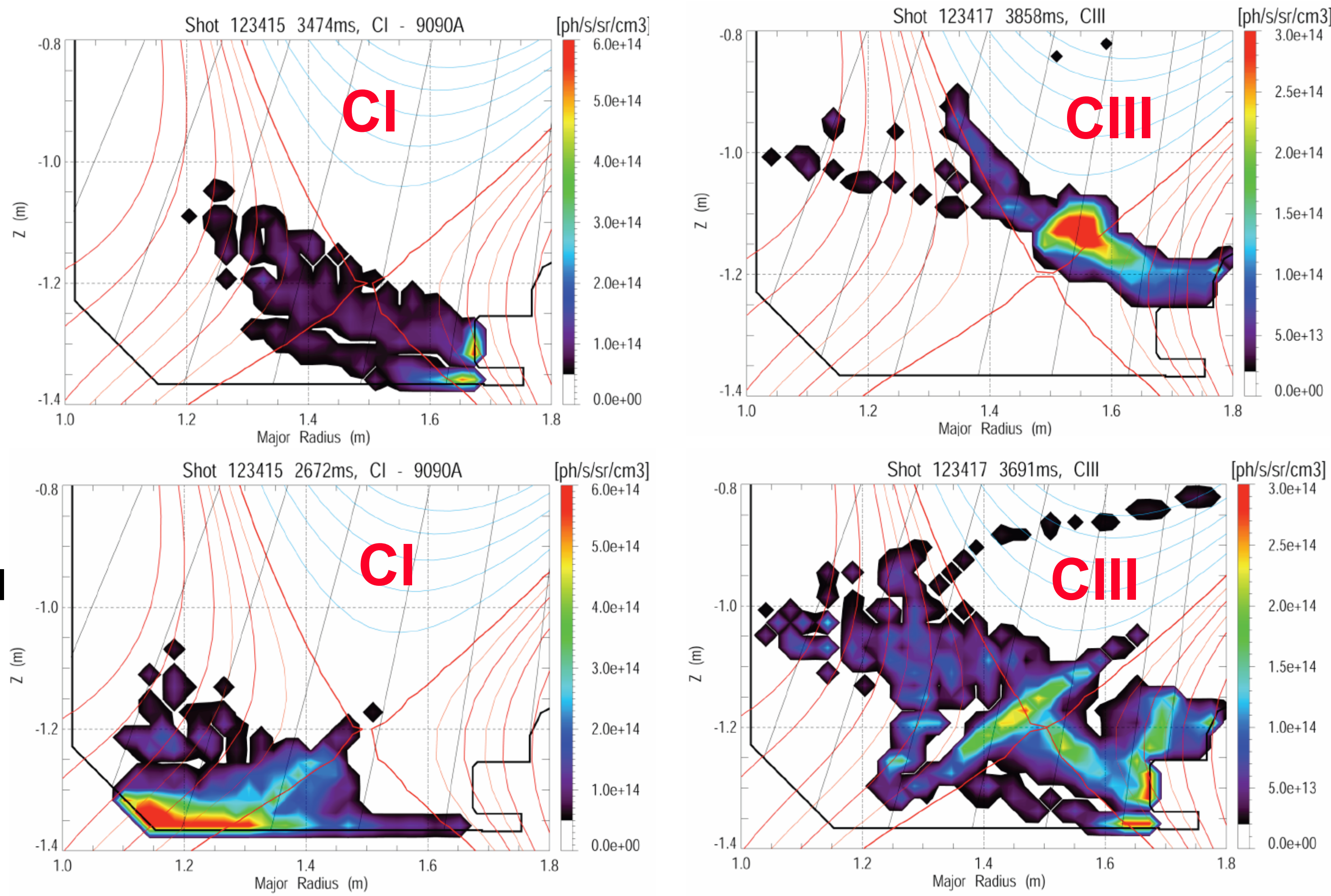
A.W. Leonard

Emission spectroscopy in the divertor (H-mode)

- ELMs (200Hz) modulate emission from carbon and deuterium.
- ELMs may influence ^{13}C deposition, but mechanisms are not yet understood.

Between ELM

At peak of ELM



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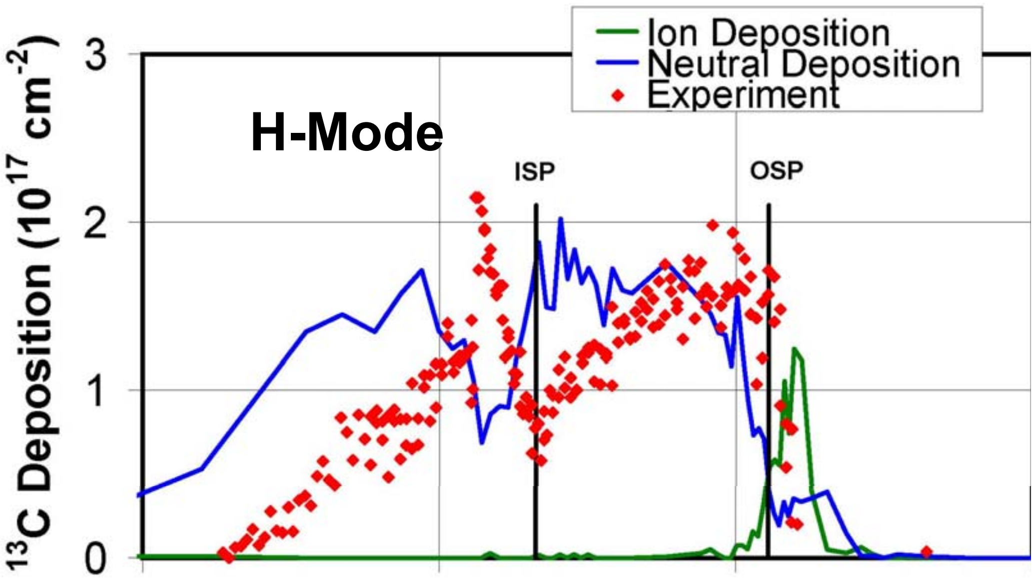
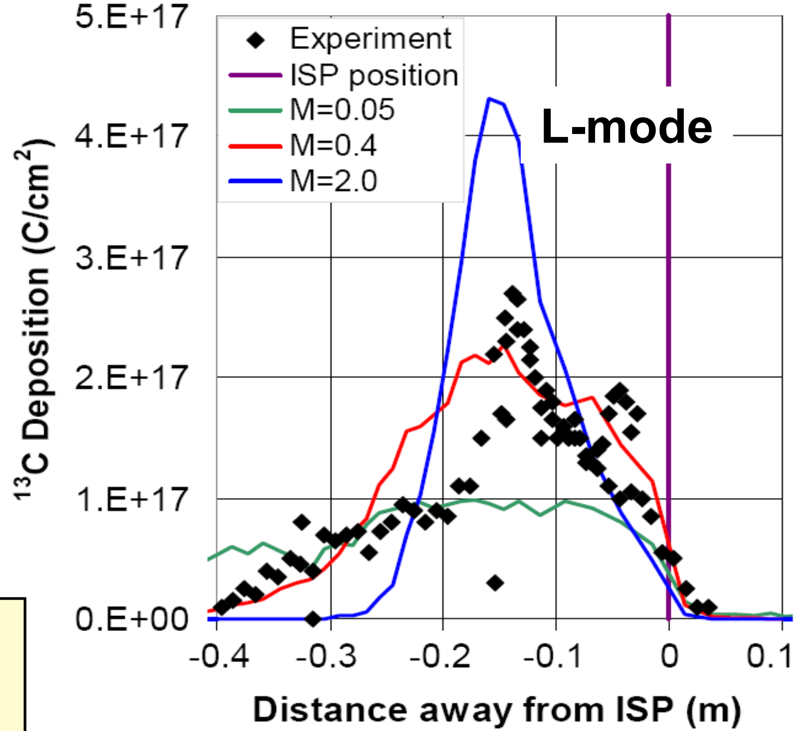
OEDGE Modeling





Parallel flow in SOL $M_{//}$ =0.3 towards inner divertor and radial pinch 10 m/s.

Cold plasma extends farther from divertor allowing neutral C to reach private flux region. (Elder P1-9).

ELMs may also influence transport & deposition.

Parallel flow in SOL $M_{//}$ =0.4 towards inner divertor. Elder PSI16

Main Conclusions

- Some local ^{13}C deposition occurs during initial breakup of injected $^{13}CH_4$ but most is ionized in the SOL.
- Asymmetry between ^{13}C deposition at inner and outer divertor indicates carbon flows into the divertor mainly from the inboard side.
- Time resolved emission spectroscopy shows divertor plasma conditions are modulated by ELMS in PDD H-mode. ELMs may influence deposition in the divertor.
- In PDD H-mode, divertor plasma is denser, colder & extends farther than in L-mode. Volume recombination and transport of neutral carbon likely influences deposition.
- OEDGE modeling reproduces observed ^{13}C deposition with
  - Fast parallel flow in SOL towards inner divertor for L-mode,
  - Fast parallel flow and radial pinch for H-mode.