Transport and Deposition of ^{13}C from Methane Injection Into L- and H-mode Plasmas in DIII–D

by
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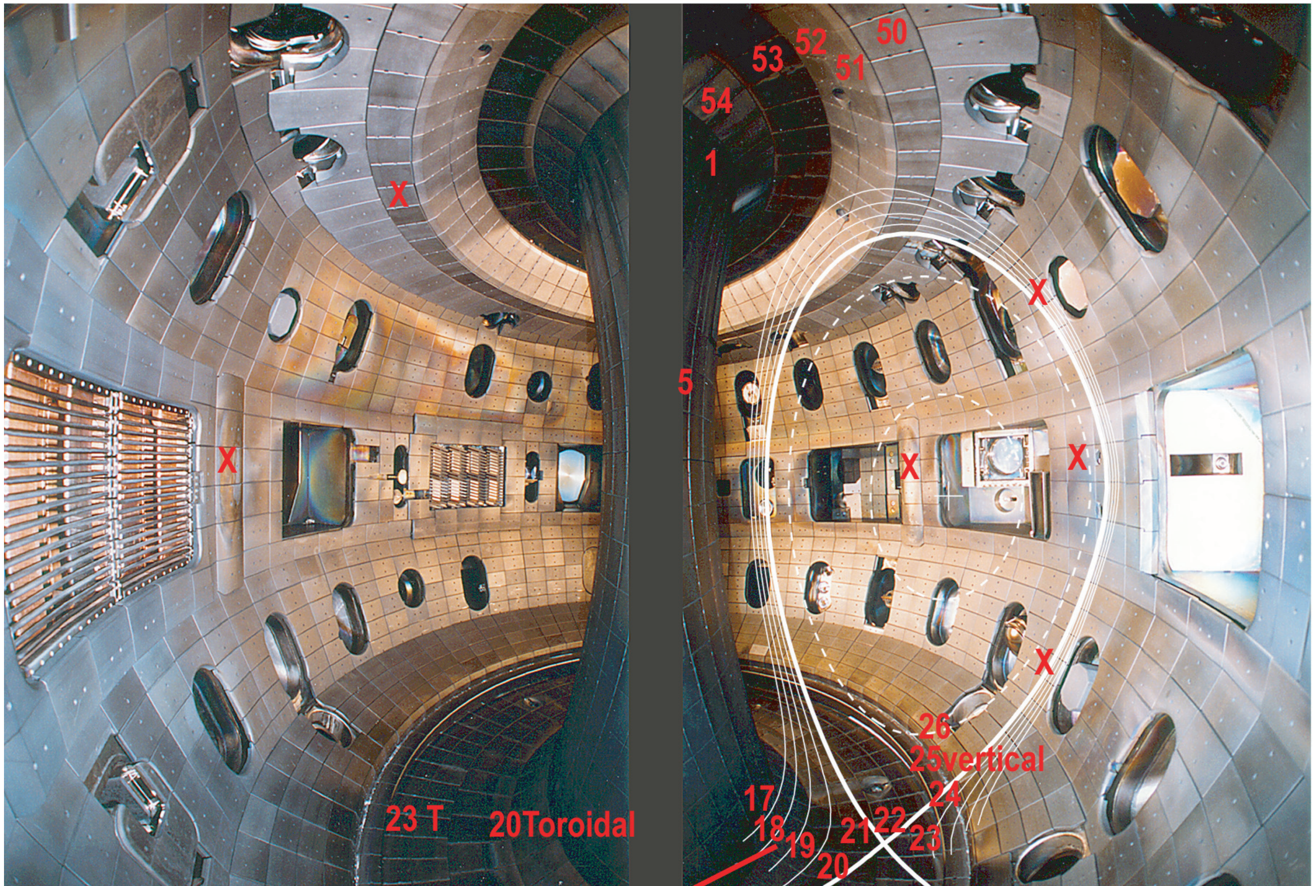
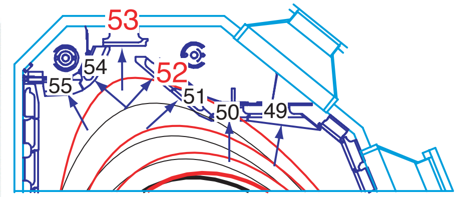
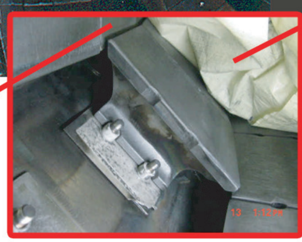
DIII–D
NATIONAL FUSION FACILITY
SAN DIEGO

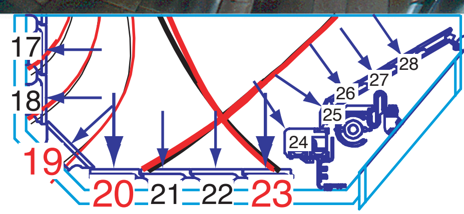
Carbon deposition studies on the DIII-D Tokamak



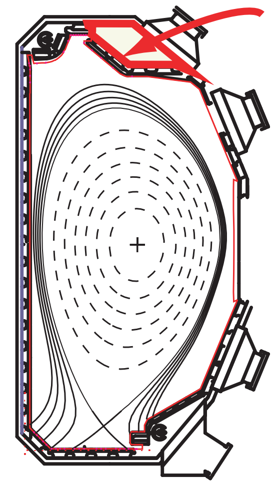


Tritium on bottom of
Tile : only tile with gap

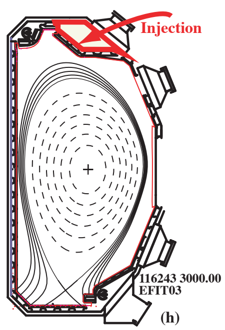




Toroidally Symmetric $^{13}CH_4$ inection



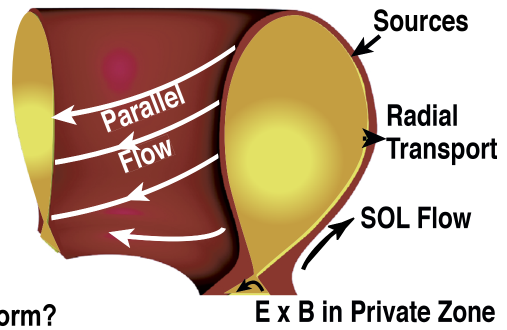
- Both L- and H-mode plasmas
- Tiles removed at end of run and analyzed with two different NRA analysis techniques



Experimental Method

Carbon Transport in All-Carbon DIII-D

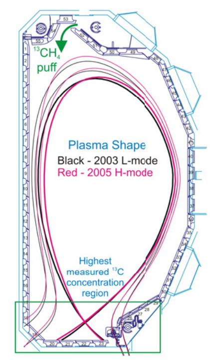
- Carbon Source (divertor or main walls)
- Physical or chemical sputtering
- SOL and divertor transport
- Where is the carbon re-deposited, and what is it's form? (C13 tracer experiments)

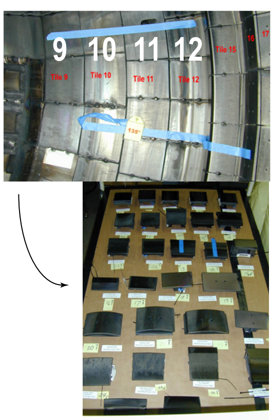


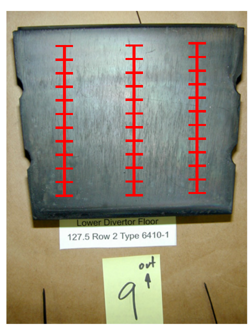
Divertor:
Deposition & Erosion - Sources

Relevant to ITER because the largest tritium inventory could be co- deposited with carbon layers that have large surface area.

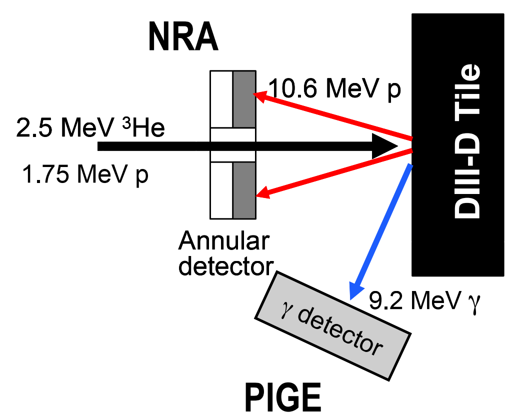
- $^{13}CH_4$ was injected from the upper divertor pump plenum into lower single null plasmas at a rate that did not significantly perturb plasma conditions. (toroidally symmetric injection & deposition).
- This plasma geometry, and location of injection far from the divertor, were chosen to simulate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

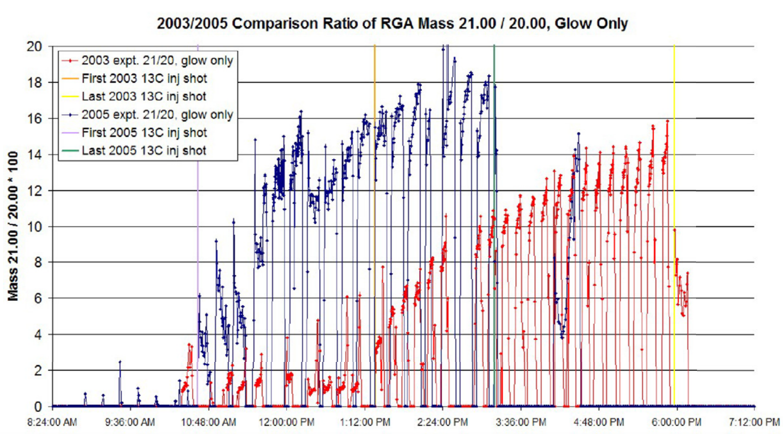






- 3 rows of analysis on each tile at ~1 cm intervals (shown schematically)
- 1255 data points on 29 tiles

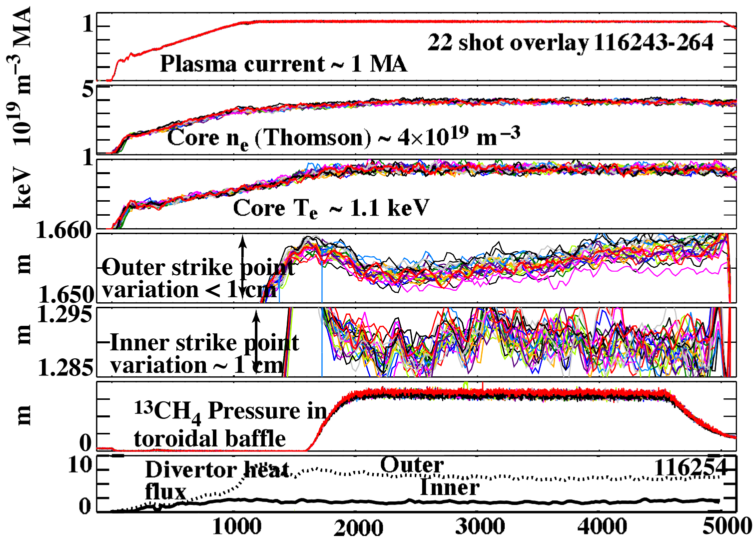


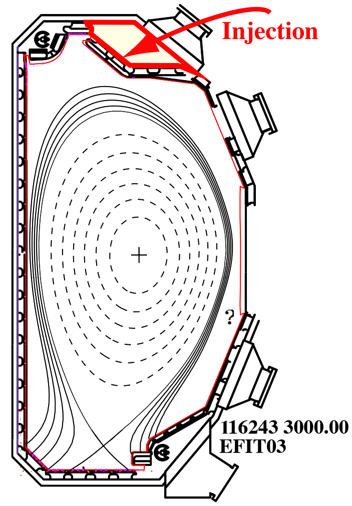


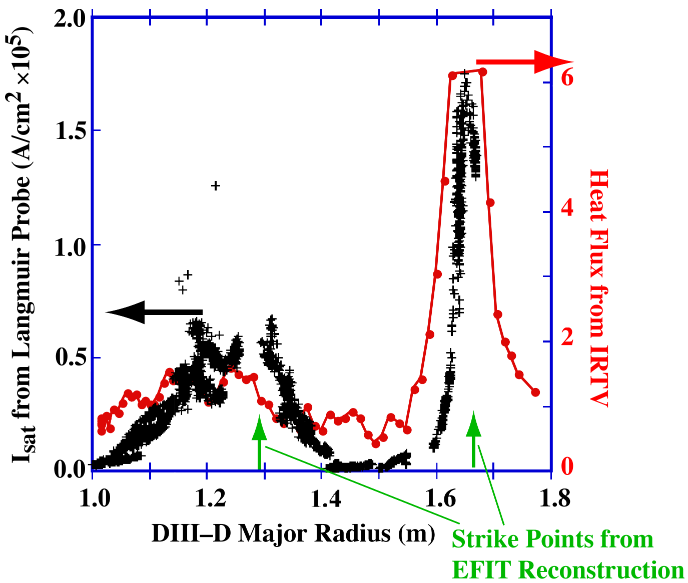
He Glow Between Shots

5 min glow between shots did not remove carbon deposits, as shown in RGA scans. Over 99% of injected methane remained.

L-mode Results

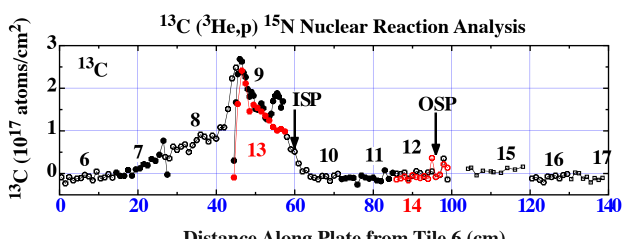


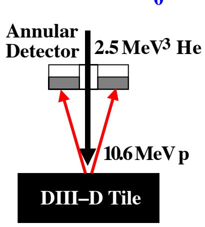


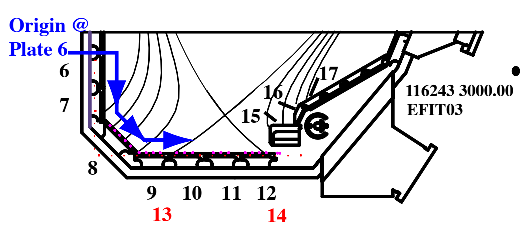


Plasma Conditions

- L-mode with beam “blips” for diagnostics
- Attached outer strike point, detached inner strike point
- Methane puff did not perturb plasma
- 22 reproducible shots



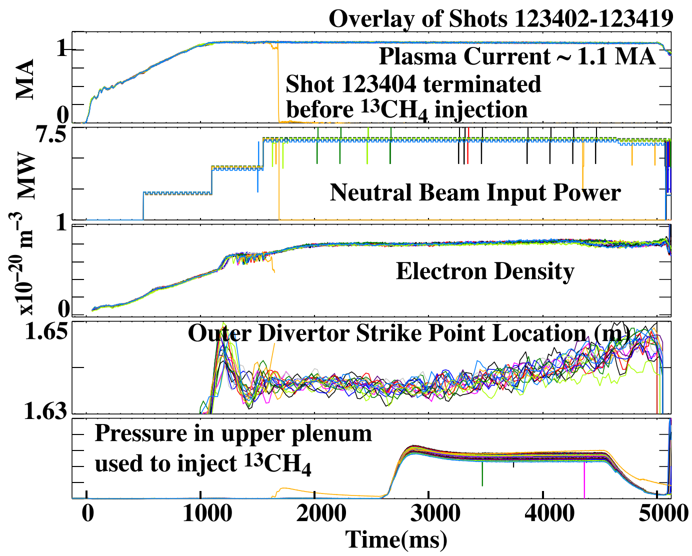




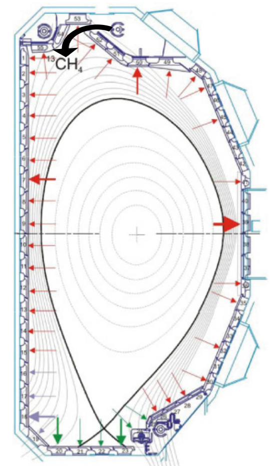
Deposition Results

- Highest concentration of deposition near inner strike point
- This zone is also close to “corner” or divertor
- Surprising amount of toroidal symmetry

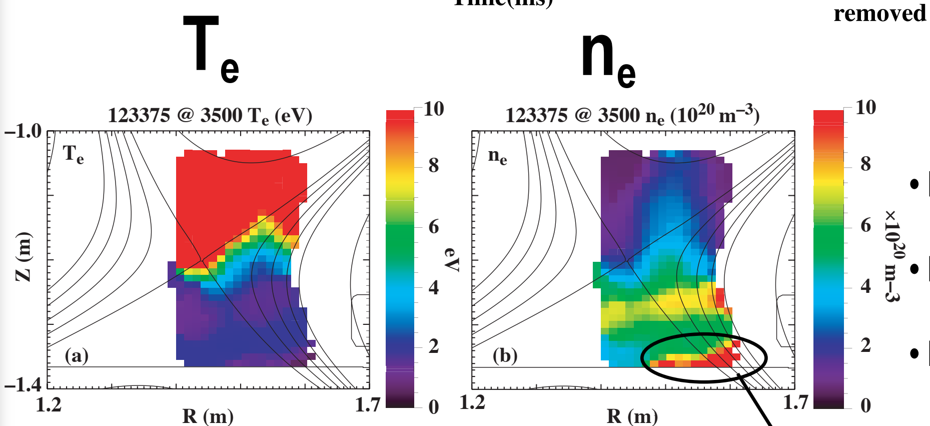
H-mode Plasmas



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



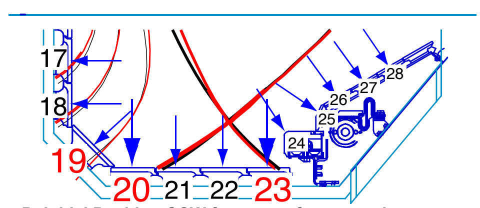
Arrows indicate tiles removed for analysis

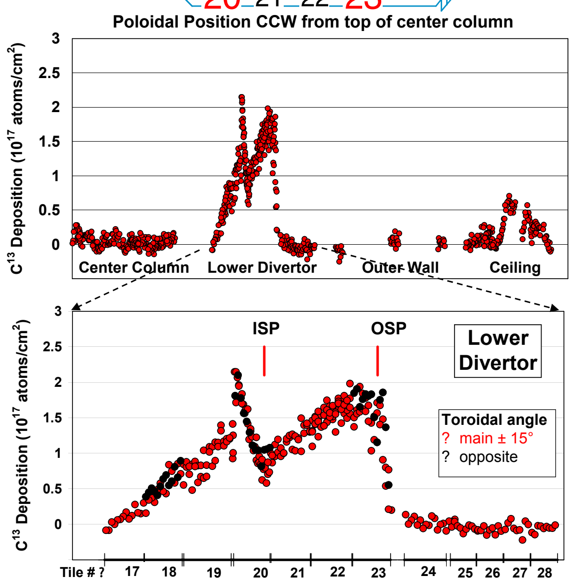


There may be instrumental problems with stray divertor light very close to the divertor plate

Plasma Conditions

- High density detached H-mode
- Plasma in the private flux region
- ELMs ~ 200Hz

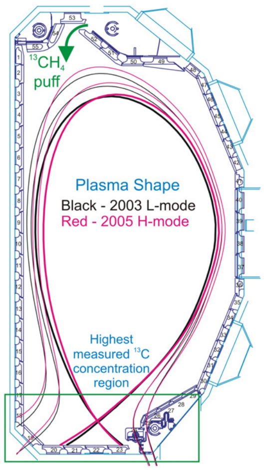




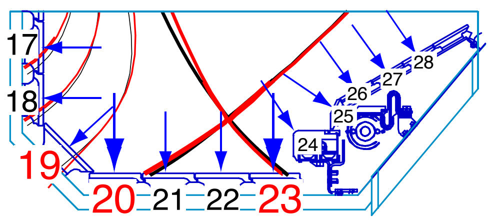
Deposition Results

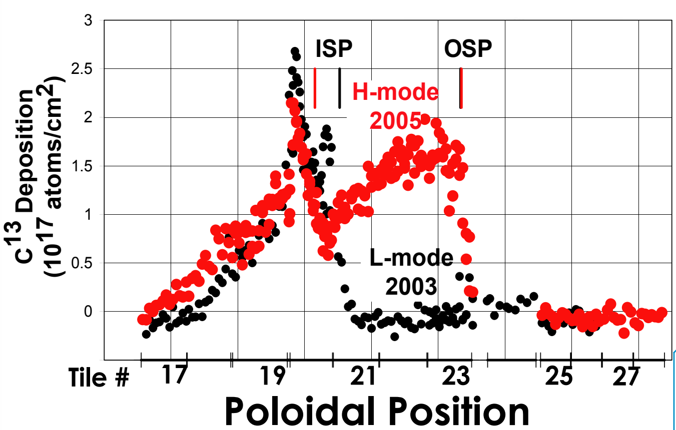
- Highest concentration of deposition near inner strike point
- Deposition in the private flux region
- Suprising amount of toroidal symmetry

Comparison of L- and H- Mode



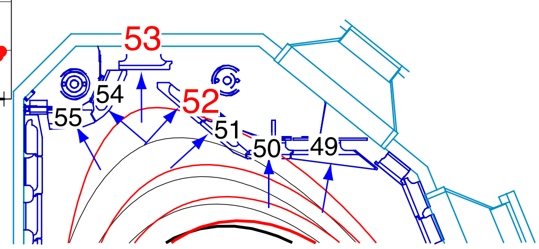
Year	2003	2005
Plasma	SAPP L-Mode	ELMy H-mode
Inner divertor	detached	detached
Outer divertor	attached	detached
Repeat shots	22	17
Line average n_e (10^{19} m^{-3})	3	8
NB Power (MW)	0.17	6.6
^{13}C injection (10^{22} atoms)	1.0	2.3
Tiles removed	29	64





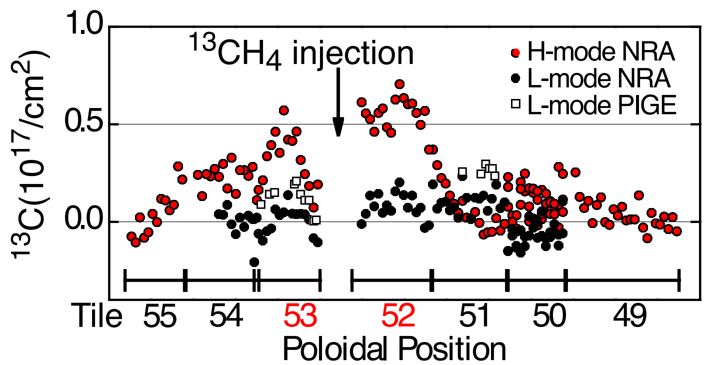
Divertor Deposition Results

- Highest concentration of deposition near inner strike point
- Deposition in the private flux region for H-mode
- Both NRA and PIGE show low concentration at outer strike point
- About 35% deposited in divertor

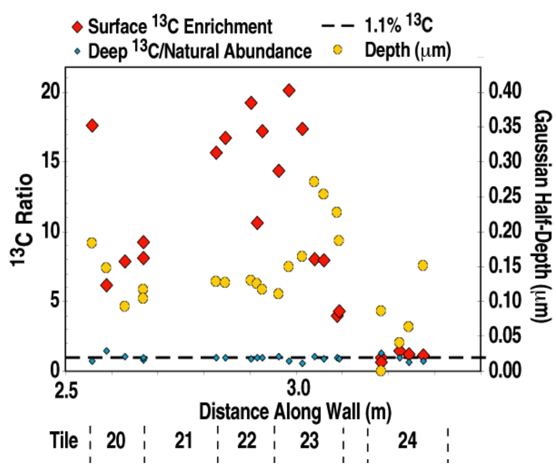


Near Injection Zone

- About 10% deposited close to gas injection plenum
- Recall about twice as much methane injected in H-mode



Carbon Surface Physics on DIII-D



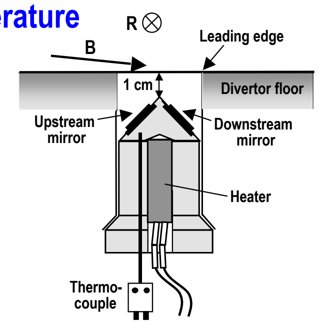
$^{13}C/^{12}C$ ratio

- Average ratio is 5 - 10
- Naturally occurring ^{13}C is 1.1%
- 10 x 1% ~ 10-20% of ^{13}C
- Still have 80% ^{12}C - so even on the surface scale, this was a "trace" experiment

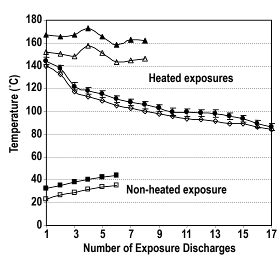
Depth Scale of ^{13}C

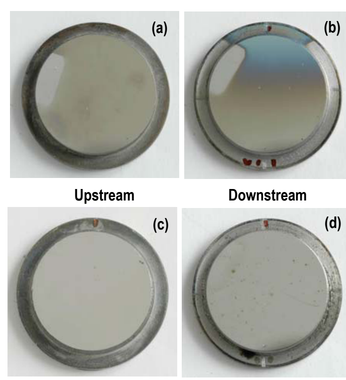
- Typical depth scale is 0.1-0.2 microns
- Deposition rate is 1-4nm/s (50-100s)
- ~200 grams of Carbon/hr of DIII-D

DiMES Experiments at Elevated Temperature



- Samples compared at two temperatures
  a) & b) 40° (unheated)
  c) & d) > 100° (heated)
- No appreciable deposition at the elevated temperature

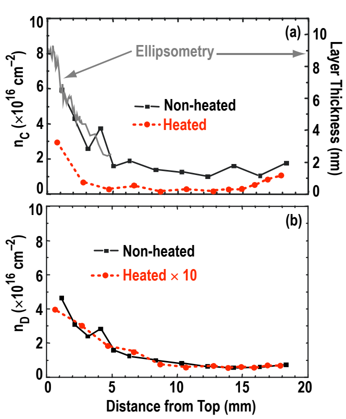


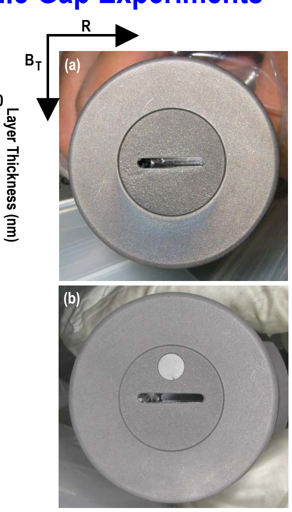


WARM

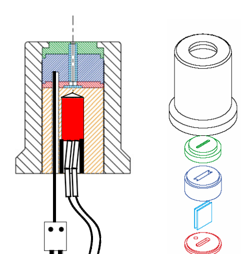
HOT

Tile Gap Experiments



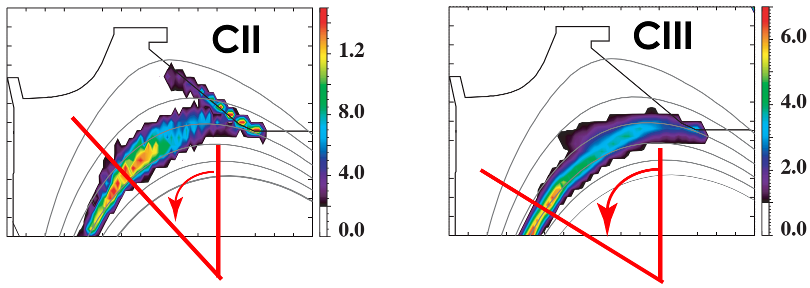


- Heated sample has 4x less carbon and 10x less deposition than non-heated sample.

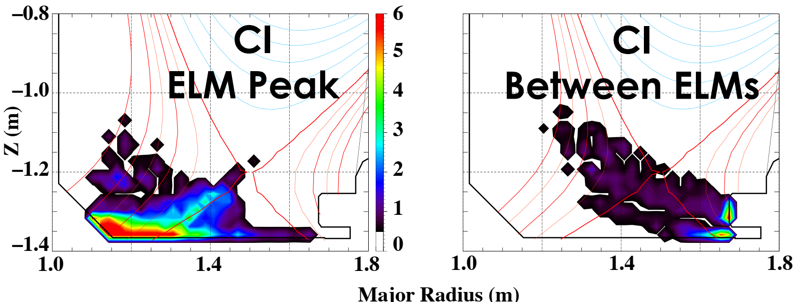


Built in heater and thermocouple for *in situ* temperature control

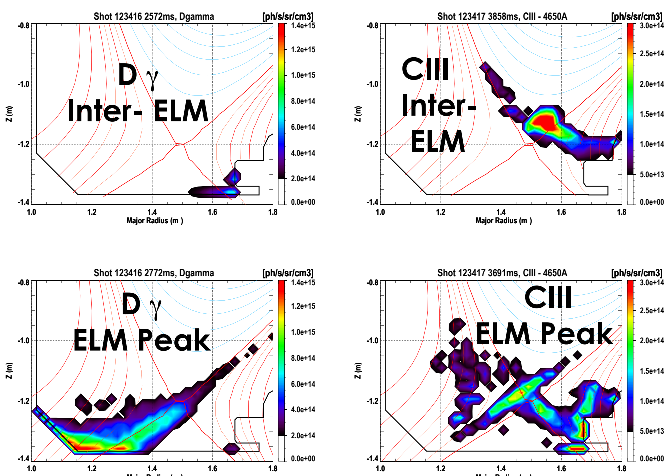
Physics of Carbon Transport in DIII-D



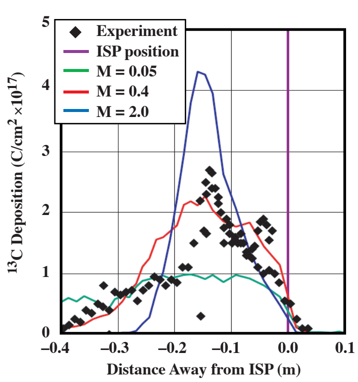
2-D tomographic reconstructions show SOL carbon flow of ~ 20 km/s



Neutral carbon emission shows changes during the ELM cycle - private flux deposition?



- Inner plate emission can be ionization and/or recombination
- CIII emission moves from near x-point (detached) to the outer strike point during the ELM
- Jsat increases near outer strike point at the ELM peak

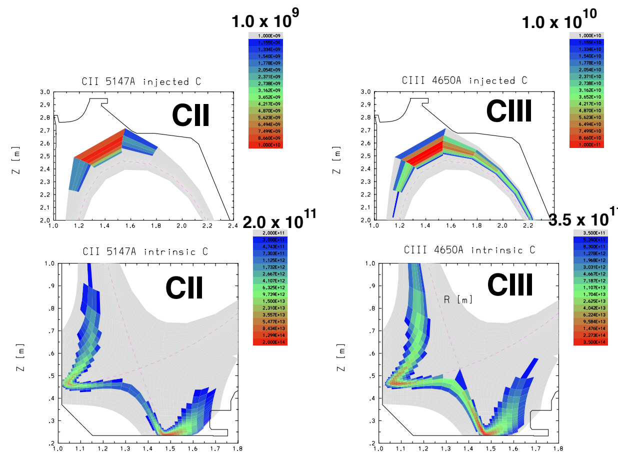


OEDGE Modeling follows carbon breakup:

- Methane breakup into fixed background plasma
- Inward radial shift required to match plate profile
- Uses ad-hoc carbon SOL flow towards inner divertor

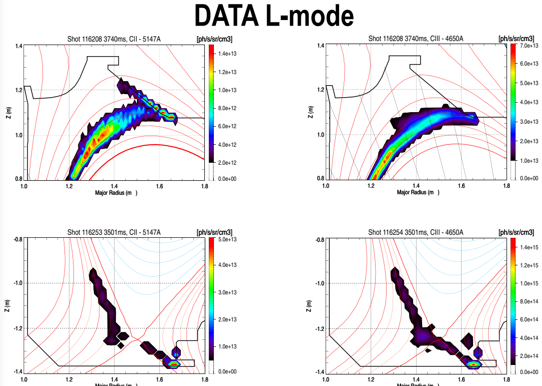
UEDGE Modeling Compared to Data

UEDGE with Drifts
L-mode



MGa04g003inj1 - drifts

DATA L-mode



Drift Case

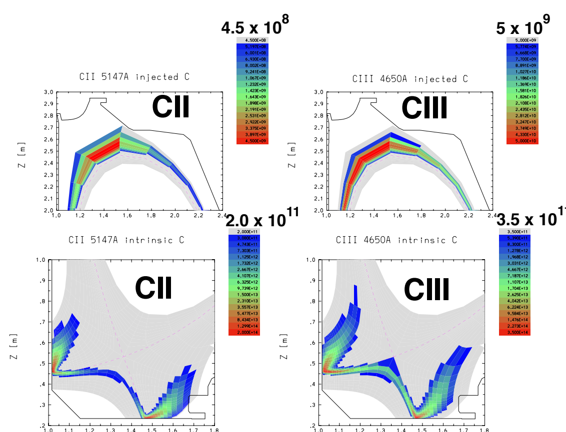
- Emission in crown is tilted towards the OUTER divertor in model
- Emission in divertor is more similar to data

UEDGE shows carbon transport follows deuterium flow.

No-Drift Case

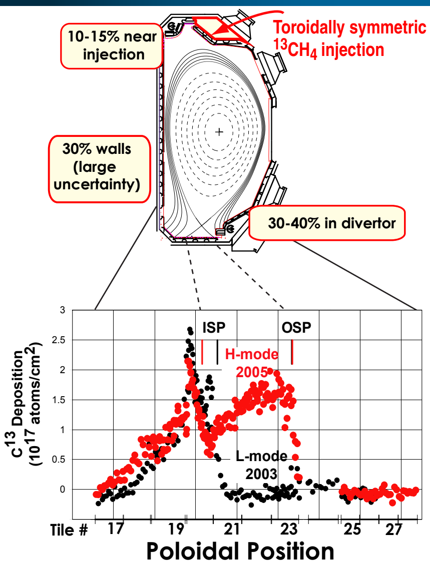
- Emission in crown is tilted towards the inner divertor in both model and data
- No drift case - ISP attached in model, detached in data

UEDGE No Drifts
L-mode



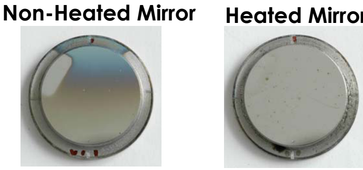
MGa04g043inj1 - no drifts

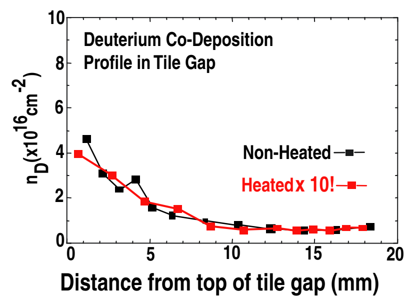
Recent Experiments Suggests Tritium Uptake in Carbon Facing Surfaces May be Controllable



- DiMES experiments show large reduction in C and D deposition on heated materials

Non-Heated Mirror   Heated Mirror





Conclusions

- These experiments simulate transport of carbon entering the SOL in the main chamber
- Highest concentration of carbon deposition is in the divertor, localized near the inner strike point
- Carbon transport from upper crown to inner divertor by SOL flows of 20 km/s
- We can account for ~30-40% of the injected carbon in the divertor, about 10% at the injection region, and measurements of a few tiles in the main chamber suggest the remaining may be in a low-level deposit.
- Hydrocarbon breakup does not result in sufficient radial penetration to explain the profile at the plate - radial shift needed. Ad hoc flow of M~0.4 imposed in OEDGE modeling.
- Removal: Oxygen bake experiments are in progress, if promising, these could be carried out in DIII-D at the end of the next campaign.