Investigation of main-chamber and divertor recycling in DIII-D using tangentially viewing CID cameras

M. Groth,[a] T.W. Petrie,[b] G.D. Porter,[a] M.E. Fenstermacher,[a] N.H. Brooks[b]

[a] Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
[b] General Atomics, San Diego, CA 92186, USA

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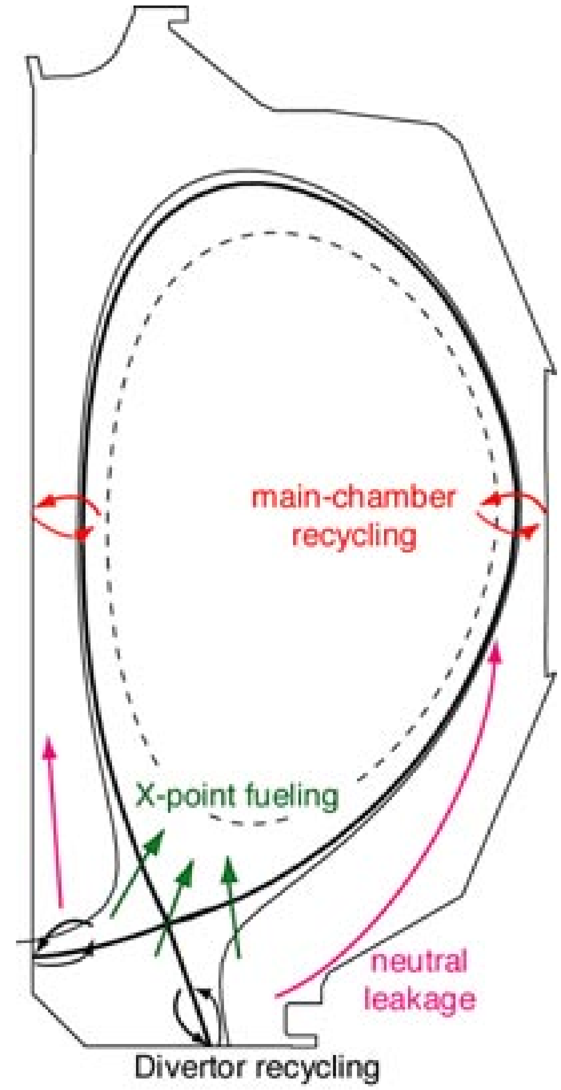
Objective: How significant is main-chamber recycling to core plasma fueling and impurity content?

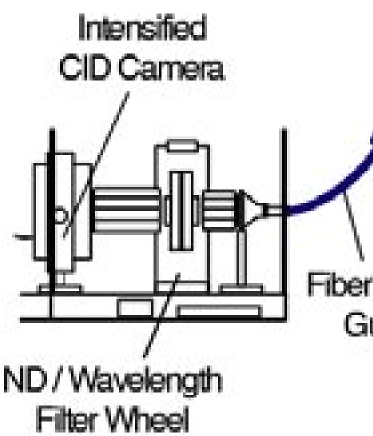
- Undesired impurity source “main chamber”
- Alcator C-Mod [1] and experiments in DIII-D reported significant contribution of main-chamber recycling (MCR) to core plasma fueling and impurity content
    - » Under which plasma conditions is main-chamber recycling significant?
    - » Toroidal and poloidal distribution of wall fluxes?
- Spatially limited diagnostic coverage of main-chamber wall in DIIID, view outer wall SOL at / around tokamak midplane
- Introduction of tangentially viewing midplane camera to better benchmark numerical models

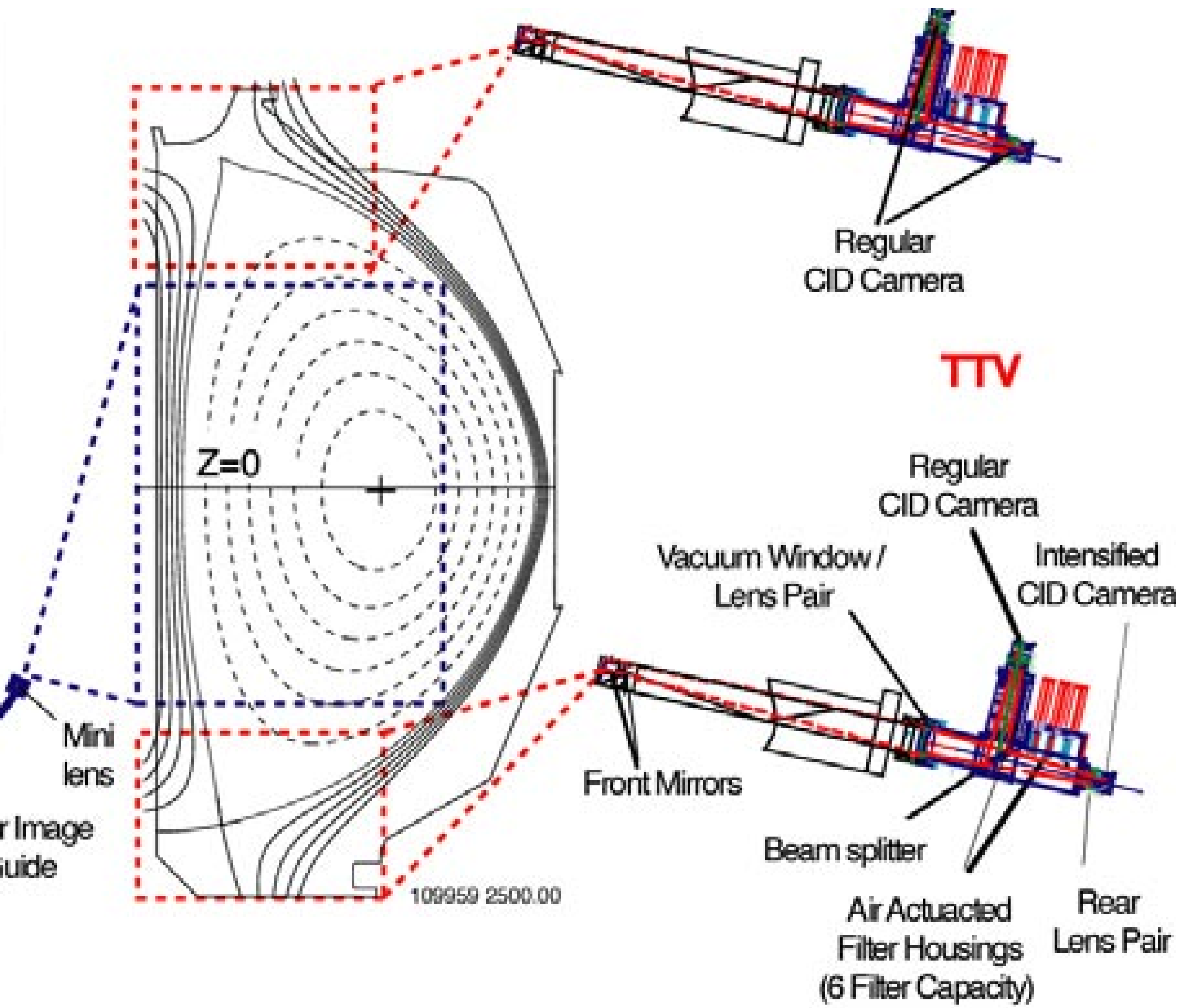
⇒ Use codes to evaluate significance of MCR



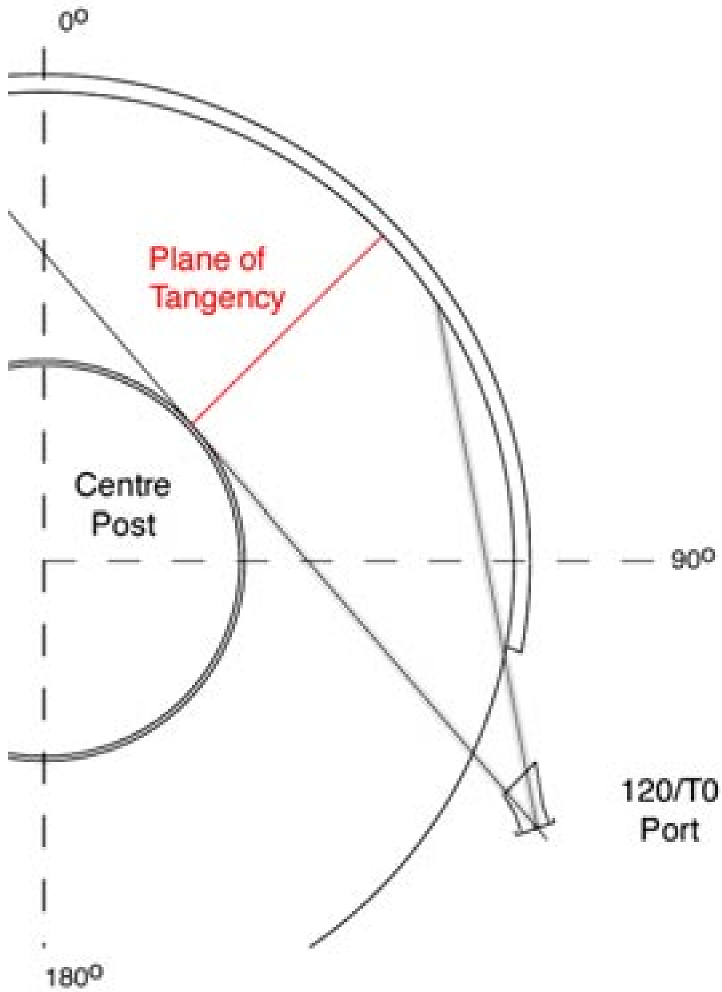
Assess recycling using tangentially viewing CID cameras (upper and lower divertor + inner SOL)

Midplane view

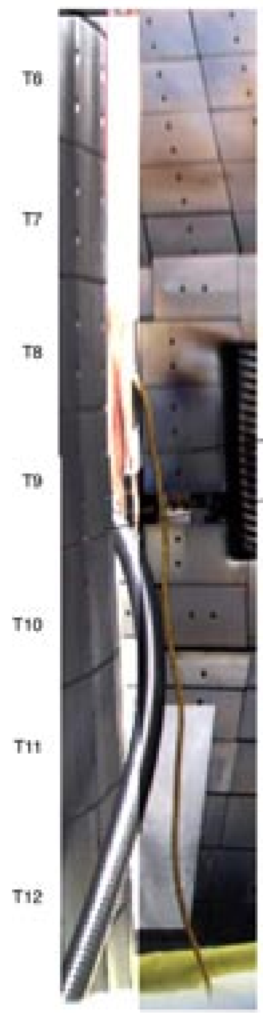




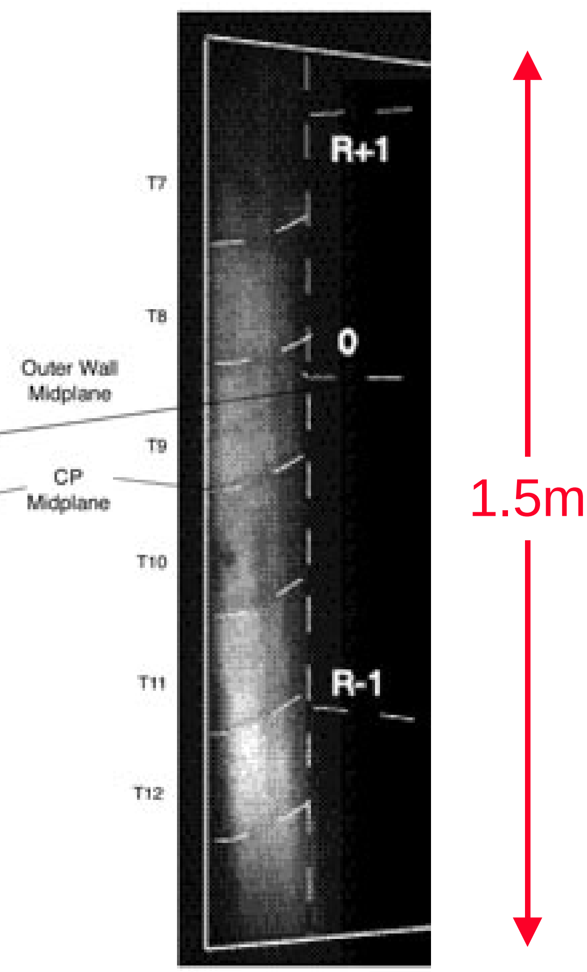
Viewing geometry I: Tangent at inner wall ~ 45º toroidally, 0.75m above and below midplane



Standard camera

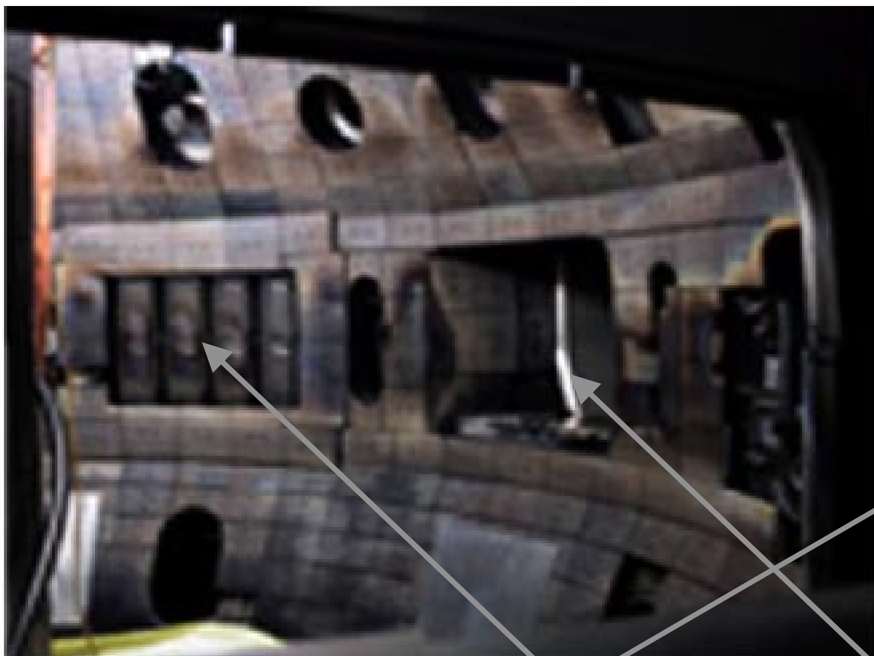


CID

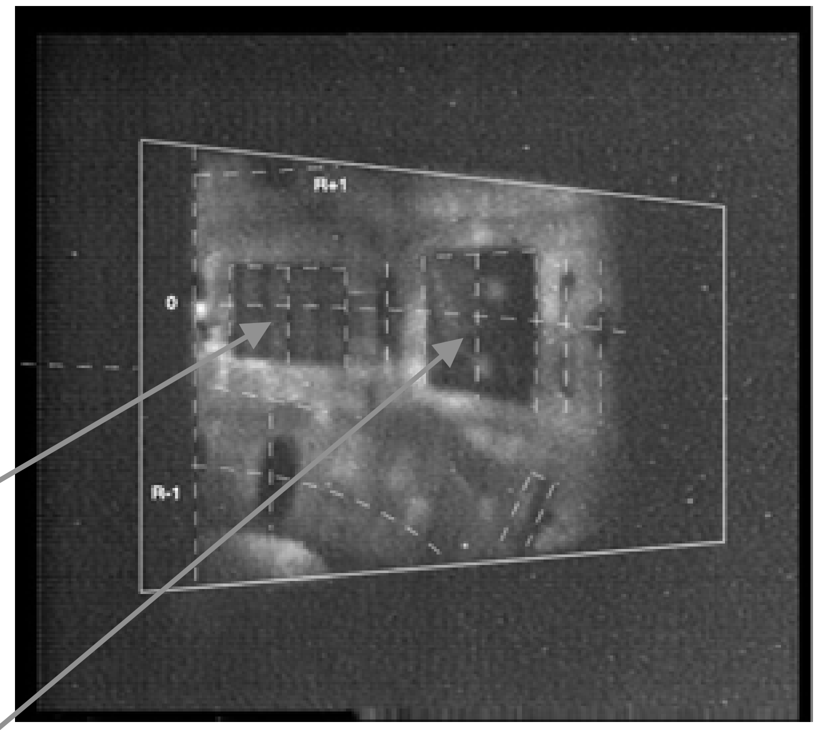


Viewing geometry II: Outer wall coverage ~ 60°, ~ R-1 → R+1 ports at plane of tangency

Standard camera



CID camera through image guide

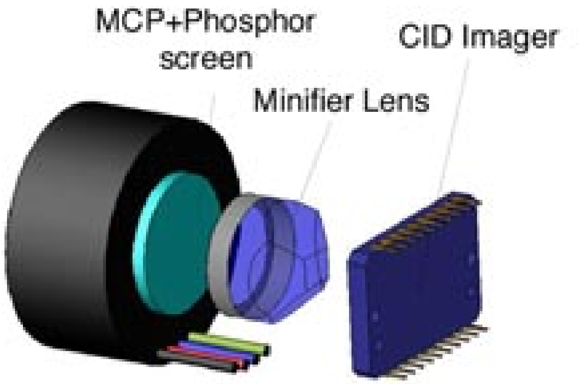


0° ICRF Antenna

30° NBI duct

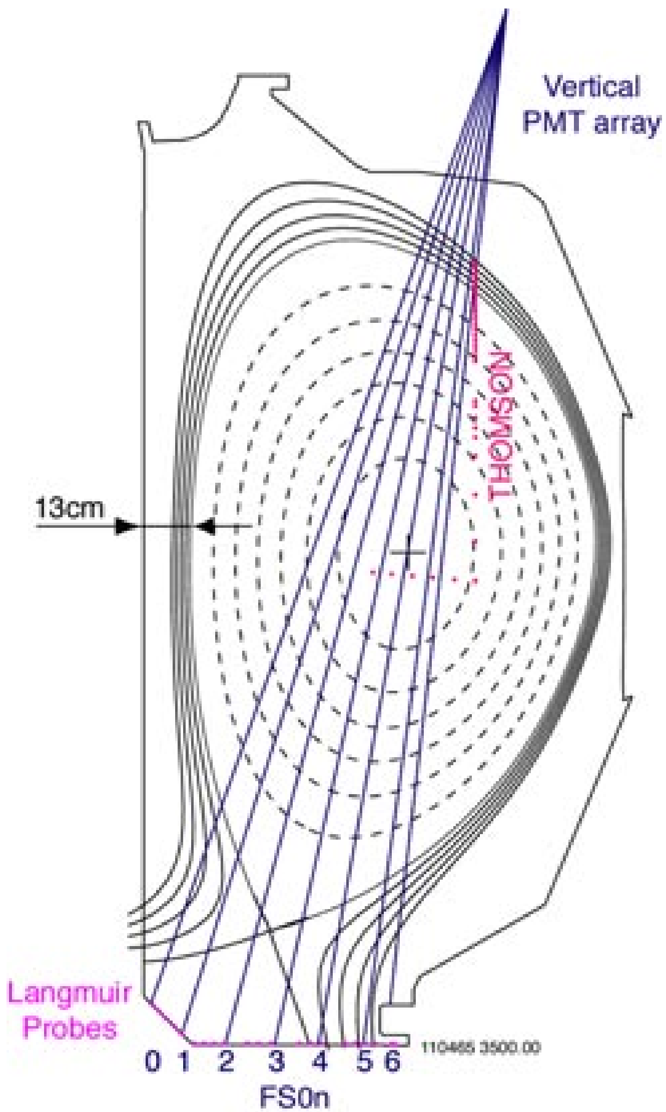
Image data from CID cameras, poloidal emission profiles using tomographic reconstruction [2,3]

- Imager = radiation hardened charge-injected device (CID) camera, 8bit dynamic range



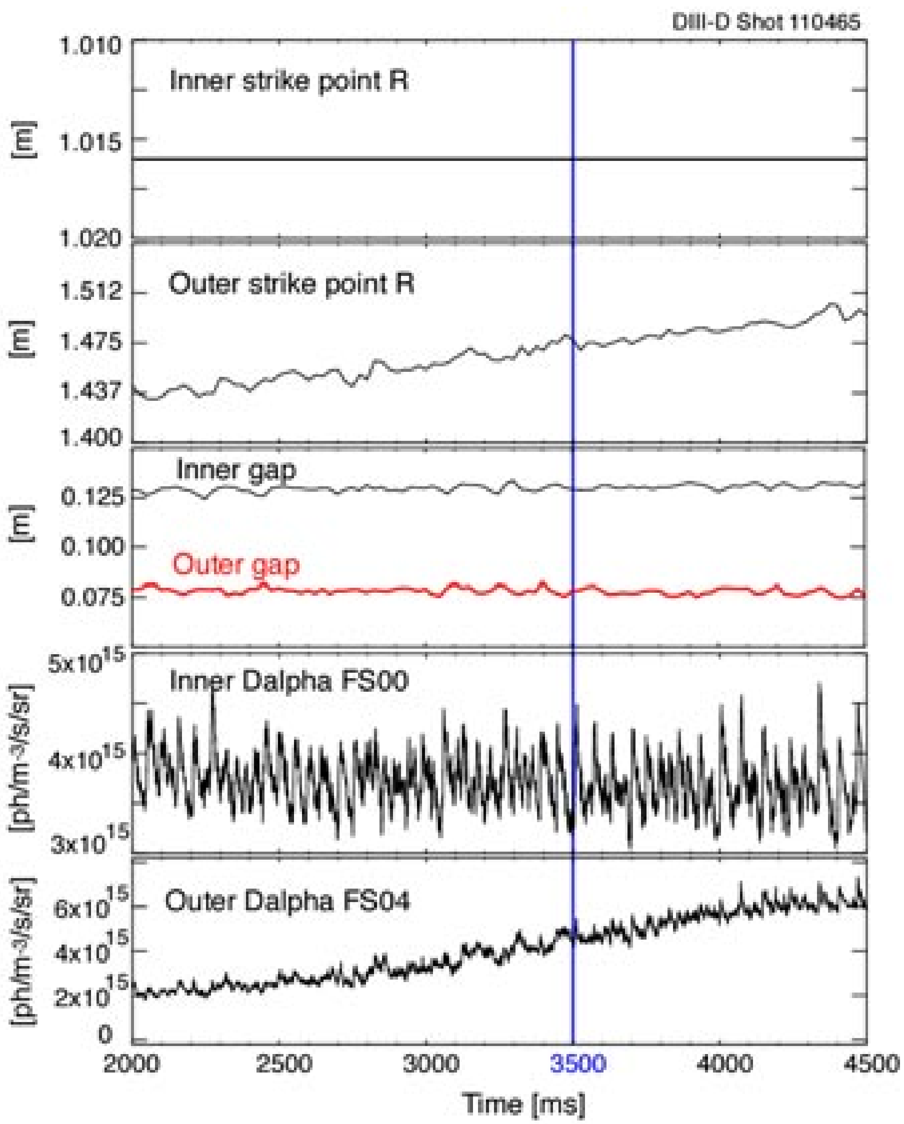
- DEP GEN II intensifier
  - » Adjustable gain, max. ~ 10000, gating down to microseconds
- Measurement of line emission profiles using interference filters
- Midplane camera latest addition to TTV system (2002):
  - » Intensified CID camera
  - » SCHOTT glass fiber image guide (**400x400 pixel elements**) connecting port optics with filter/ camera assembly
  - » Field-of-view: **1m x 1.5m of the inner SOL**, outer SOL 1m x 0.8m optional
  - » Reconstruction of 2D profiles using Abel inversion and tomographic reconstruction technique

Main-chamber recycling (MCR) in low-density L-mode plasmas (SAPP)



- Simple-As-Possible-Plasmas (SAPP) [4] = quiescent L-mode plasmas, i.e no ELMs
- Lower single null configuration; optimized for diagnosis of outer divertor leg
  - » Inner strike point on the center post
  - » Sweep outer strike point for profile data
  - » Inner gap 13cm
- Repeat of identical discharges for diagnostic purposes
- Low core density: n/n_{GW} ~0.2, low beam heating power ~0.5MW, quiescent - no core MHD mode
- Well-attached outer leg divertor plasma, $T_{e,\ plate}$ ~ 25-30eV

Slow sweep of outer strike point for divertor density and temperature measurement

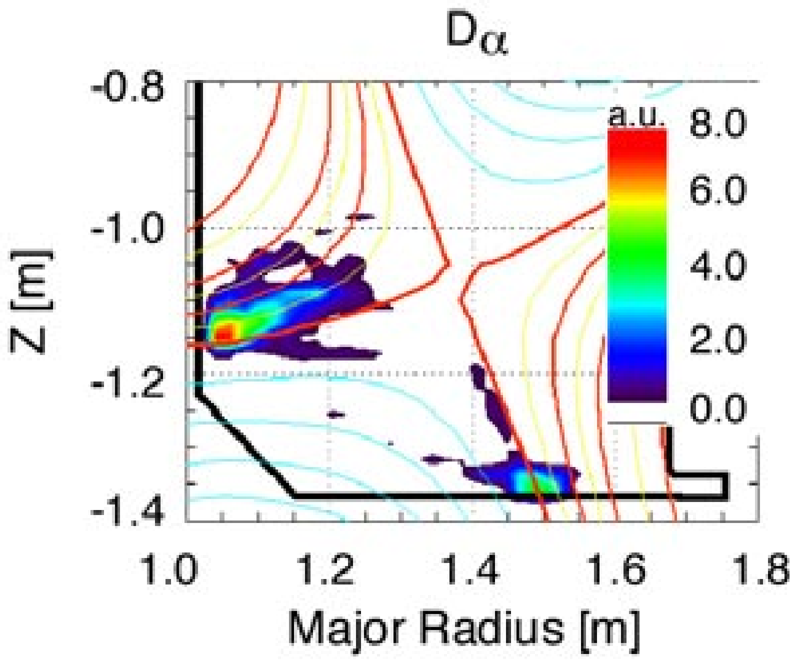


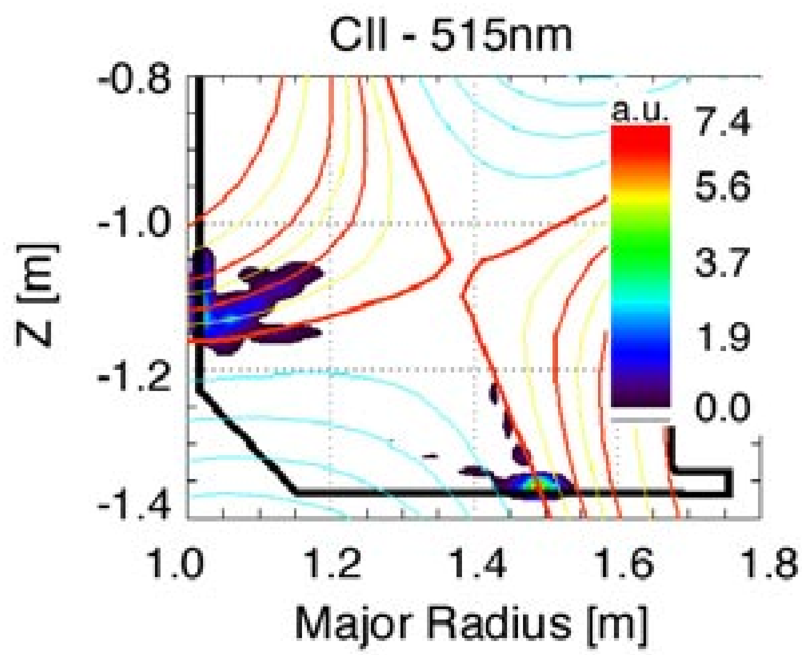
- Slow sweep of outer strike point to scan divertor plasma over Divertor Thompson scattering view cords $\rightarrow$ 2D $n_{e,div}$ and $T_{e,div}$,
- LPs: density and temperature profiles at target plates
- Inner strike point fixed, but inner gap slightly increasing
- As plasma swept over PMT array line-of-sights, outer D_α (and CIII) increase; inner fixed

$\rightarrow$ Combination of data over sweep to obtain emission profile with better radial resolution

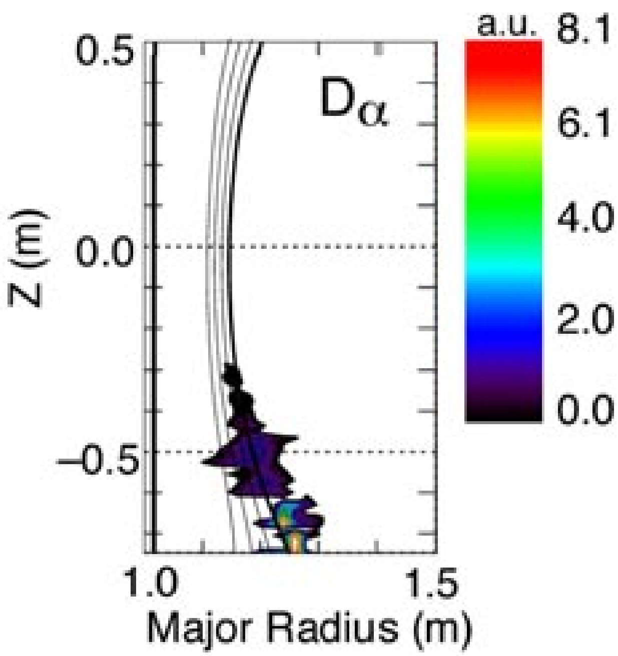
Asymmetric D_α and CII divertor emission profiles, partially detached inner divertor plasma

- Extended D_α emission profile along inner divertor leg, emission twice as high at inner strike zone as compared to outer strike zone
- CII emission highly localized at inner and outer strike zones, ~three times higher at the outer than at the inner strike zone

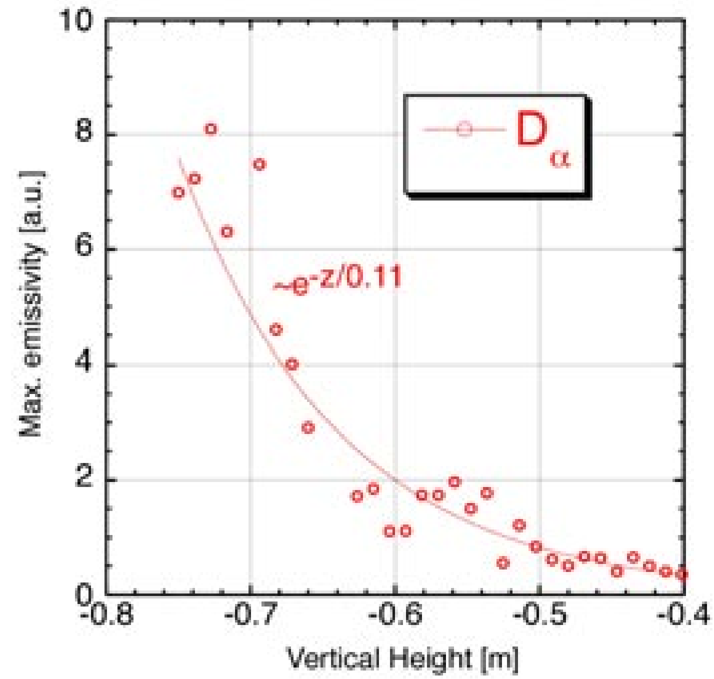




Max. D_α emission inside core plasma near x-point $\rightarrow$ divertor is powerful fueling source



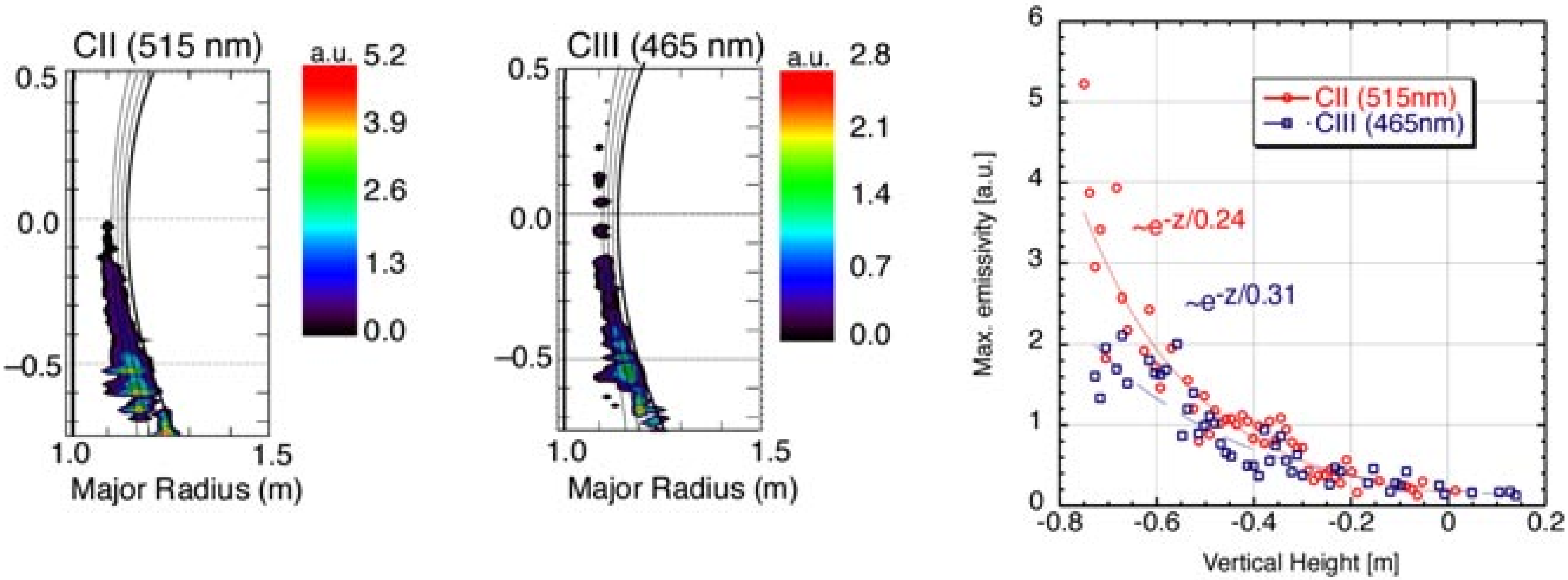
Poloidal decay of D_α emission



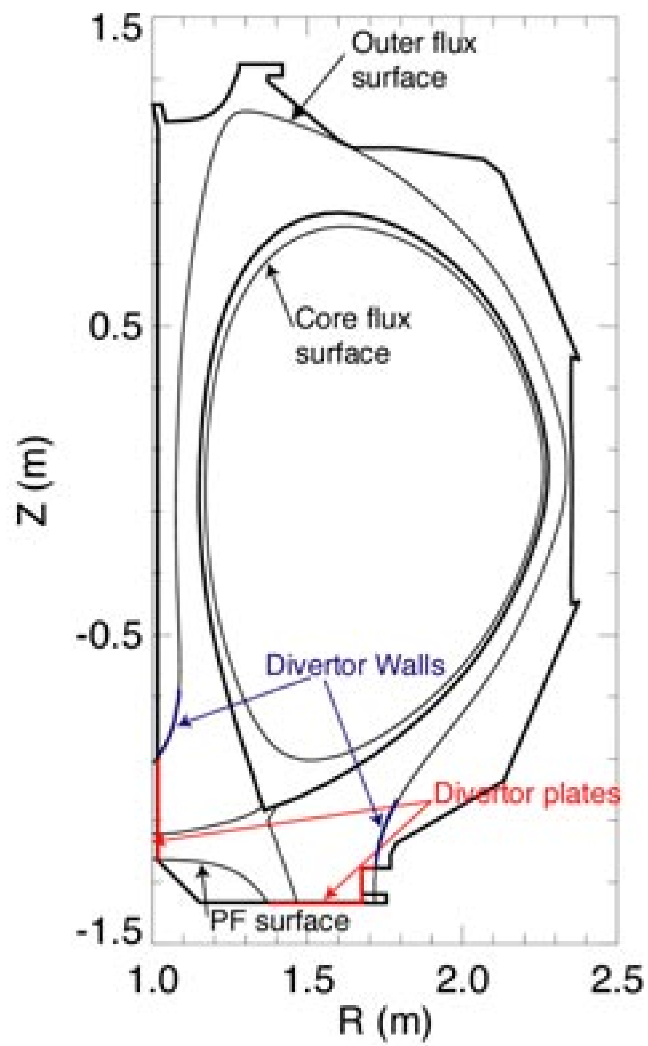
- Tomographic reconstruction performed for entire image, negligible emission from outer wall
- D_α emission dominant in region adjacent to lower x-point, decays poloidally toward midplane: tenfold within 0.5m poloidally

Poloidally asymmetric CII and CIII midplane profiles, strongly weighted toward lower divertor

- CII and CIII emission found in SOL only (T_e<10eV), CIII emission more poloidally extended, closer to separatrix
- Ratio of peak divertor to midplane emission: 10^3 - 10^4
- Various routes for carbon to enter camera view conceivable, higher degree of poloidal symmetry expected if main walls were the primary source



UEDGE modeling: SOL, diffusive radial transport, carbon from divertor plates and walls

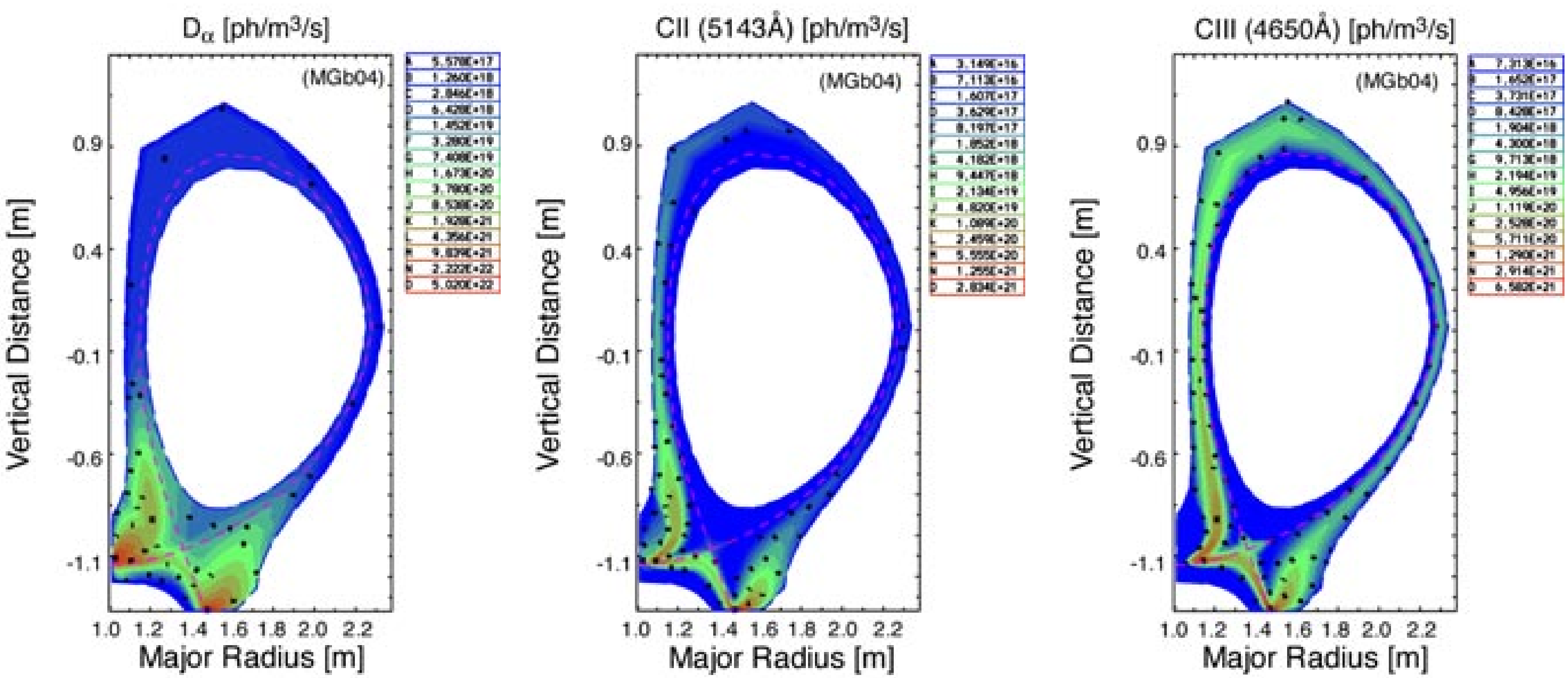


- UEDGE [5]: Classical parallel transport, w/drifts
- Diffusive radial transport, spatially constant diffusivities, obtained by matching exp. SOL n_e and T_e profiles:
  - » $D_\perp = 0.2\text{m}^2/\text{s}$, $\chi_e = \chi_i = 0.8\text{m}^2/\text{s}$
- Carbon origin:
  - » Physical and chemical sputtering at plates using published data [6,7]
  - » Chemical sputtering at outer boundary
  - » No recycling of carbon
- Carbon transport:
  - » Force balance model for carbon impurities in parallel B-field direction [8]:

$$F_Z = -\frac{1}{n_Z}\frac{dp_Z}{ds} + m_Z\frac{(v_i - v_Z)}{\tau_S} + ZeE + \alpha_e\frac{d(kT_e)}{ds} + \beta_i\frac{d(kT_i)}{ds}$$

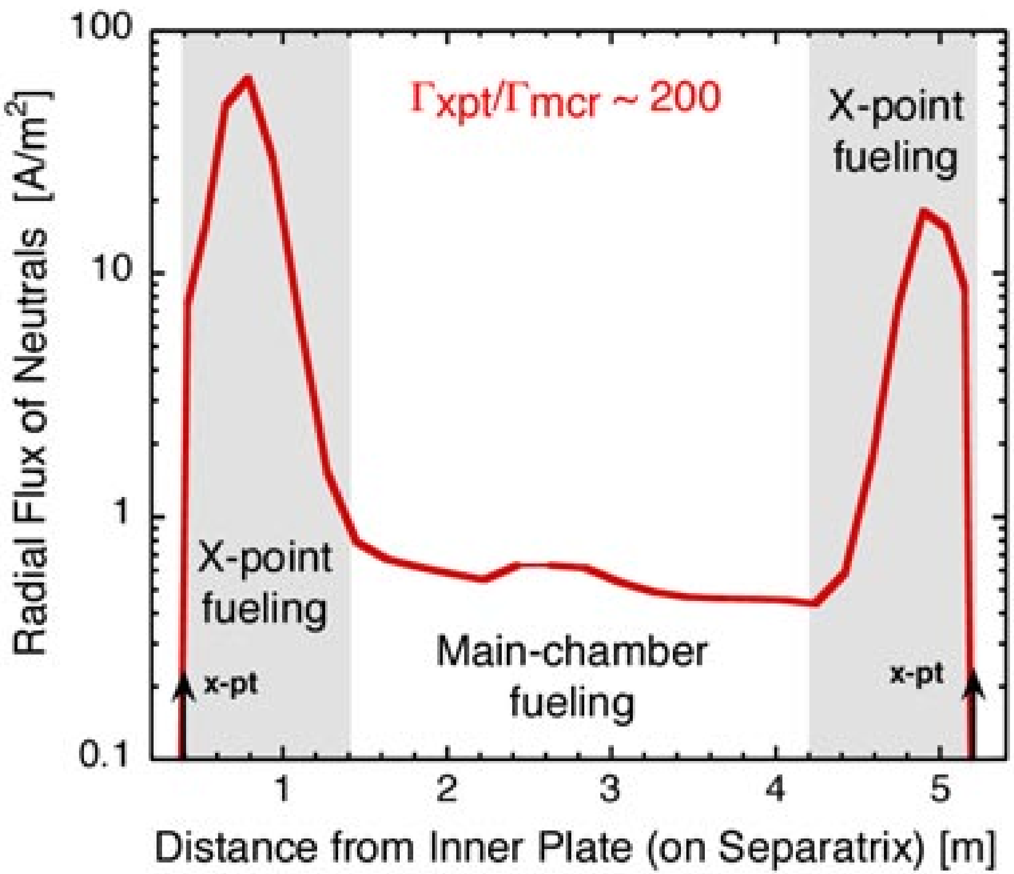
UEDGE captures most of emission profile features → significant D_α emiss. around x-point

- CII / CIII emission outside separatrix only, CIII emission well off inner plate → partially detached inner divertor plasma
- CIII more poloidally symmetric than CII → consistent with experimental data
- Reduced emission in view of midplane camera by 10^3 to 10^4 (consistent w/exp.)



Dominant fueling source from x-point region calculated by UEDGE

Poloidal D^0 flux into core plasma

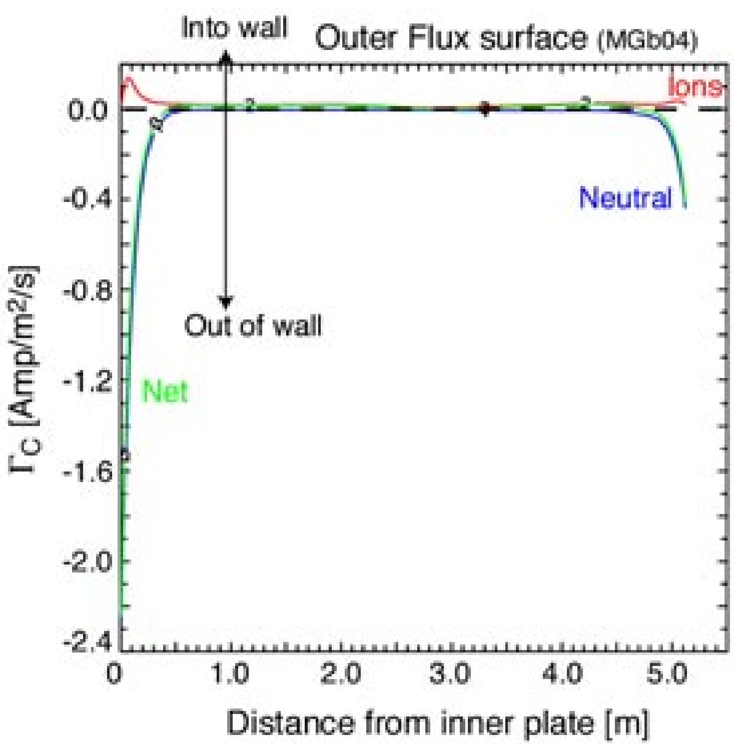


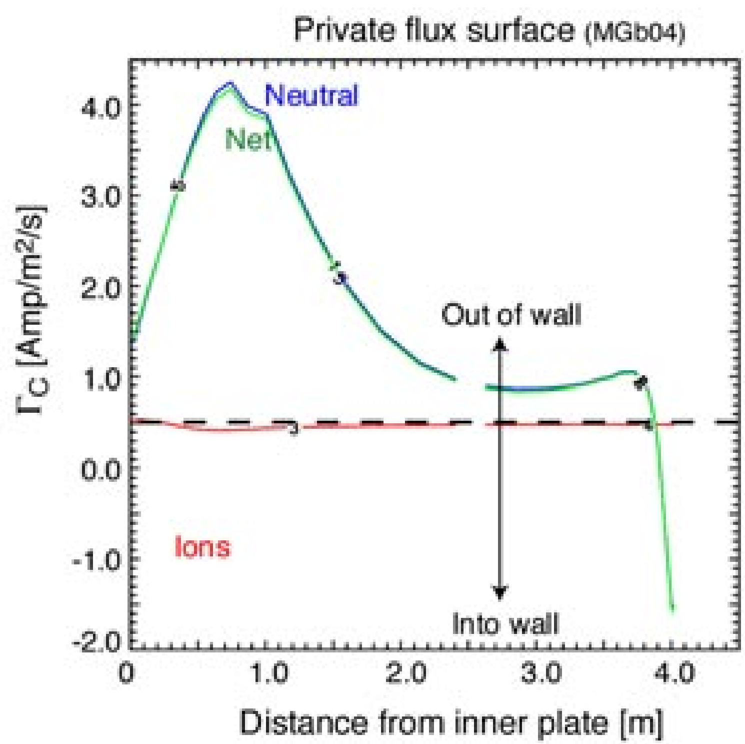
- Integrate D^0 fluxes into core around x-point (shaded area) and main-chamber region
- Ratio of D^0 influxes from x-point region to main chamber ~200

⇒ Low-density L-mode plasma very likely to be dominated by x-point fueling

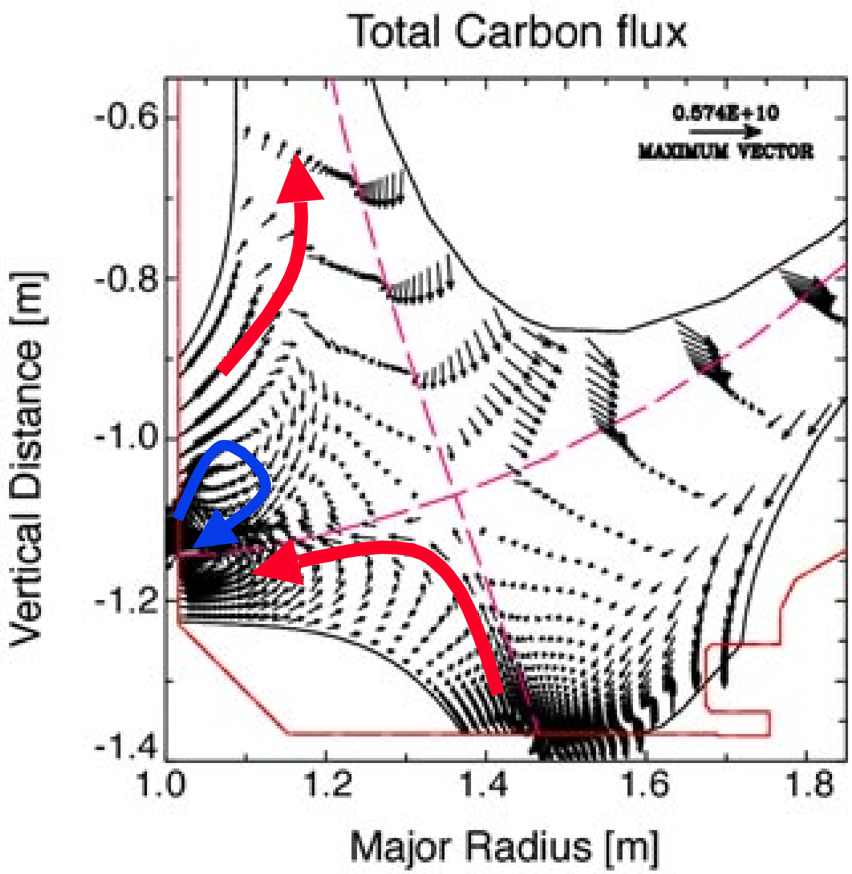
Transfer of chemically sputtered carbon from divertor walls to target plates

- P-C sputtered material from target plates mostly redeposited onto plates
- Neutral carbon away from plates arises from chemical sputtering at divertor walls (where n_o is high)
- Divertor wall source localized within 50 cm away from plate





Main SOL (and core) carbon combination of sputtering and complex ion transport



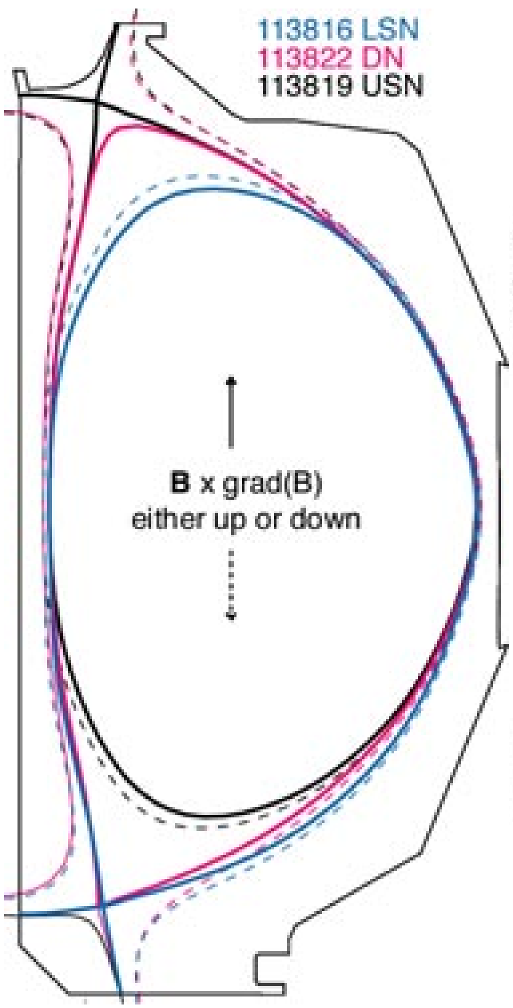
- Carbon from PF swept to inner plate by **E**×**B** associated with large E_r near separatrix
- Circulation of carbon around strike zones: sputtering and redeposition
- Chemical sputtering at divertor walls up to 0.5m above the plate

⇒ (Net)transfer of carbon from divertor walls to target plates

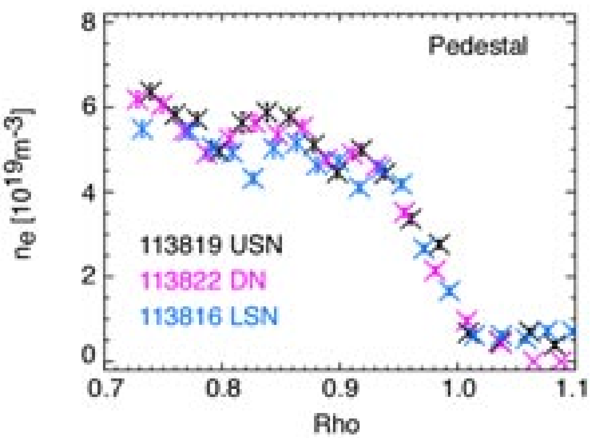
- Above Z>-0.8m, ion temp. gradient force exceeds friction with background ions

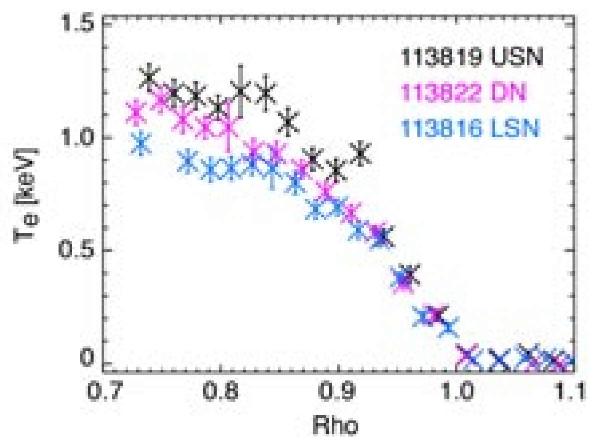
⇒ Carbon ions transported upstream along inner main SOL

MCR in low and medium density ELMy H-mode in balanced and unbalanced double-null config.



B x∇B up, n/n_{GW} ~ 0.4

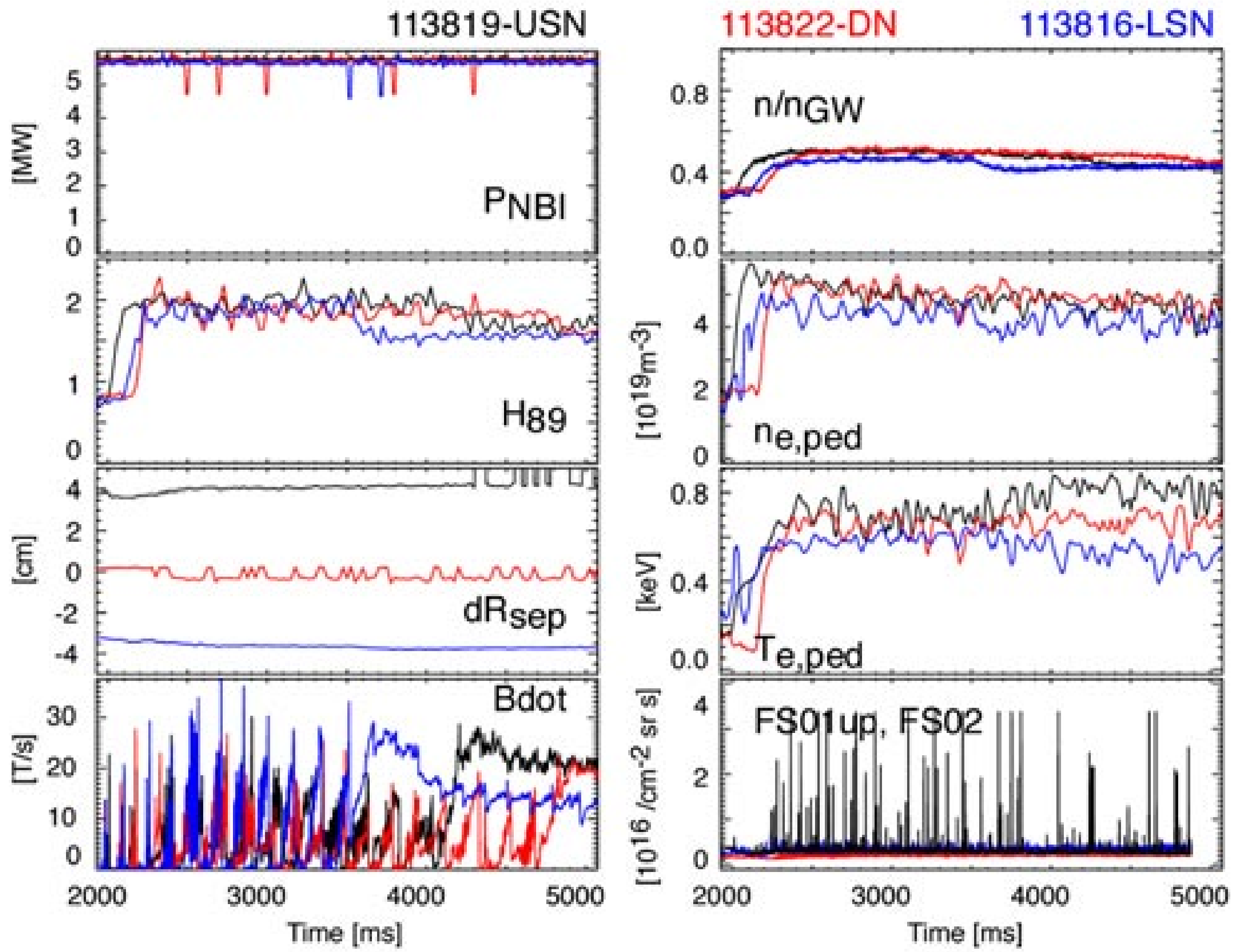




- ELMy H-mode:
  - » H_{89} ~ [1.8, 2.2]
  - » I_P=1.3MA , B_T=2.0T
  - » P_{NBI} =5.5MW
- Vary magnetic balance for effect of divertor geometry (dRsep=0,±4cm)
- Vary B_T direction for effect of **B**x∇B and **E**x**B** drifts
- n/n_{GW} ~ [0.4, 0.6], well-matched $n_{e,ped}$

⇒ $T_{e,ped}$ varies significantly with configuration (up to 40%)

Similar $n_{e,ped}$, but variations in $T_{e,ped}$ for otherwise similar plasmas in USN, DN and LSN

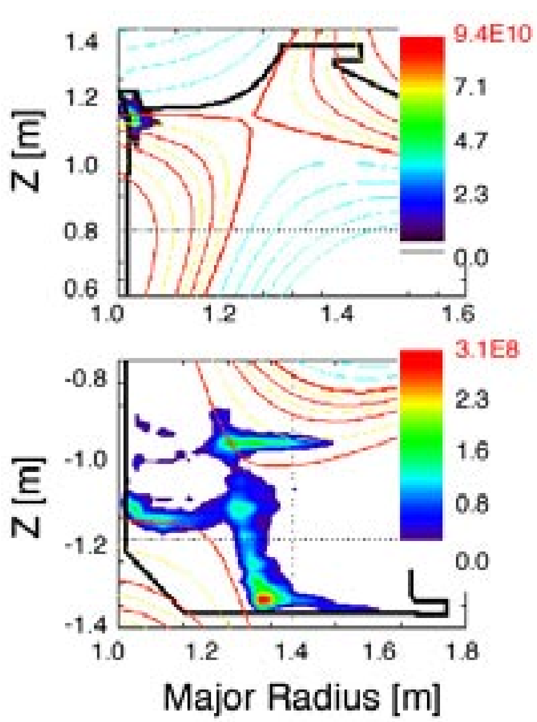


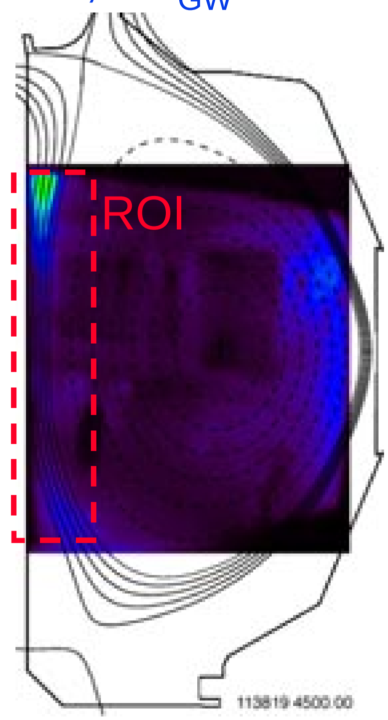
- H_{89} ~ 1.8-2.2
- Reduced $\langle n_e \rangle$ due to core MHD
- n/n_{GW} ~ 0.42
- $T_{e,ped}$ [USN] > $T_{e,ped}$ [DN] > $T_{e,ped}$ [LSN]
- ELM amplitude larger in the upper divertor in USN than in lower divertor in LSN

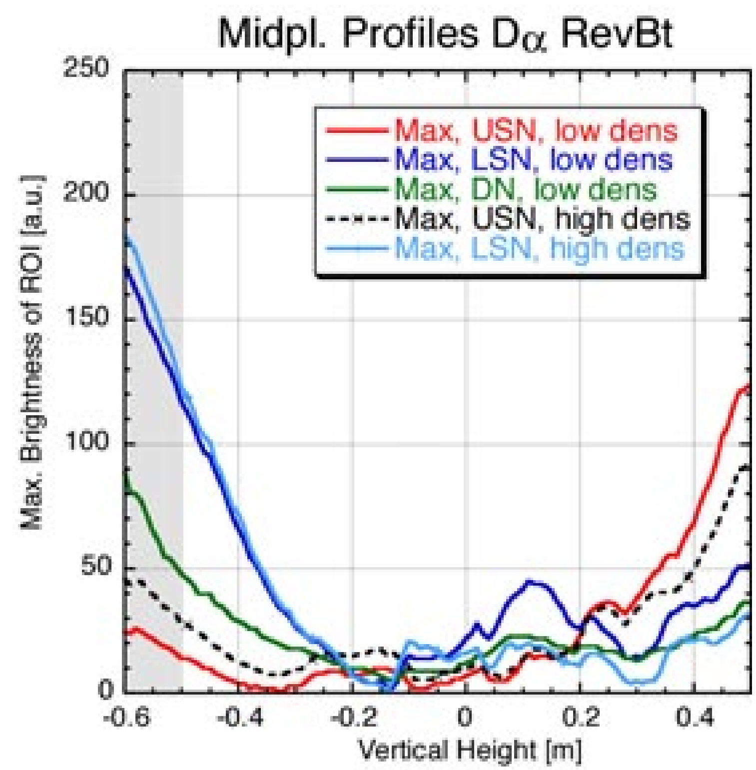
Poloidally asymmetric D_α emission profile, weighted toward primary divertor(s)

- In USN: D_α peaks at inner strike zone in upper div. (consistent with **E**x**B** drift), in lower divertor maps “extended” div. legs
- Difference in emission between the two divertors: ~ two orders of magnitude
- In LSN and DN, D_α dominant at outer strike points in upper and lower divertor

Div. and Midpl. D_α, USN, n/n_{GW}~0.4



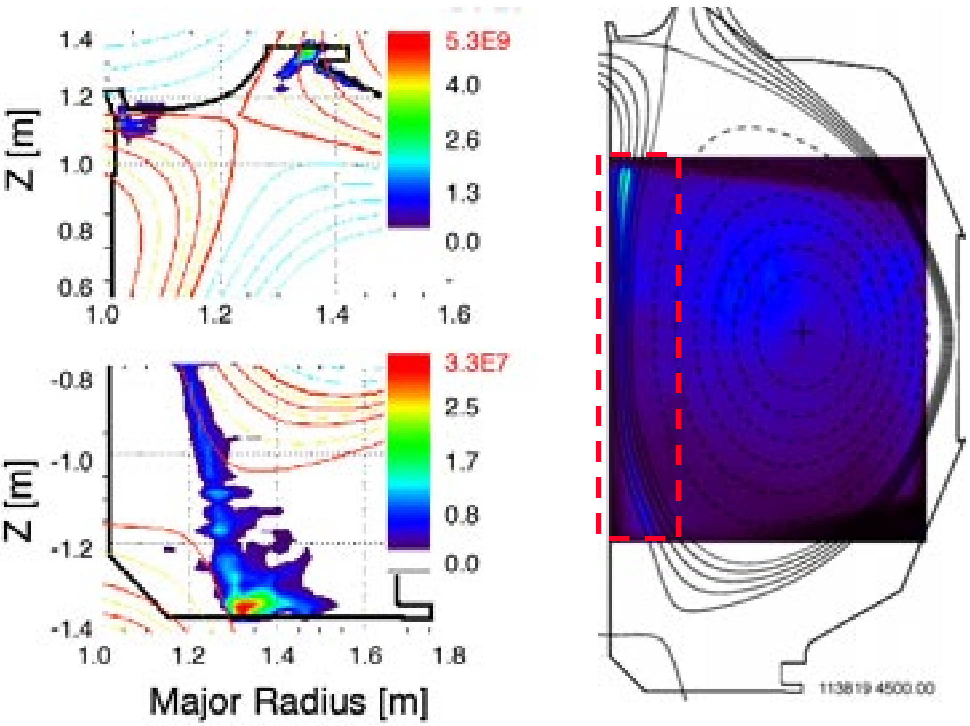


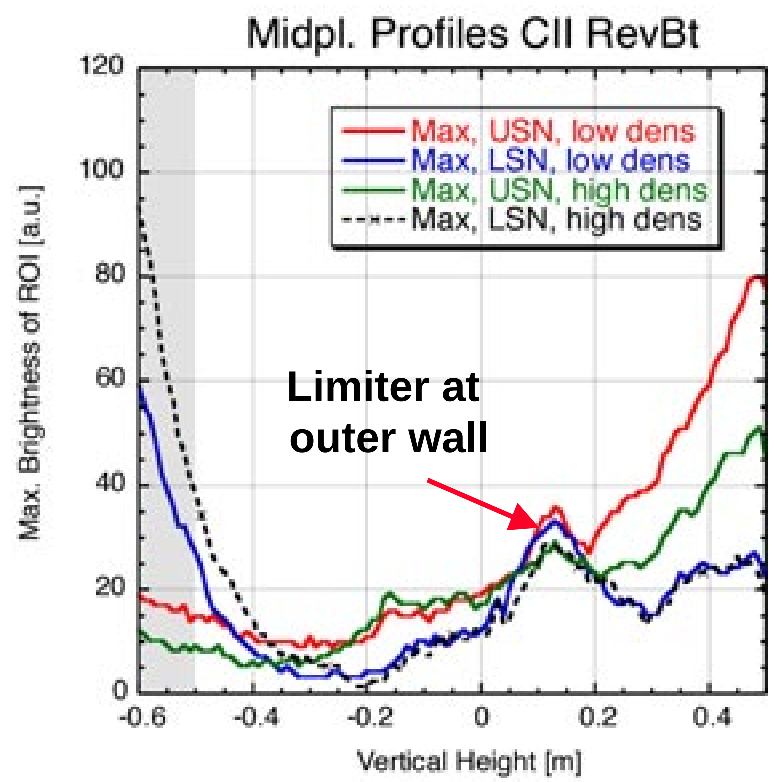


CII and CIII profiles also weighted toward divertor(s), CIII more extended

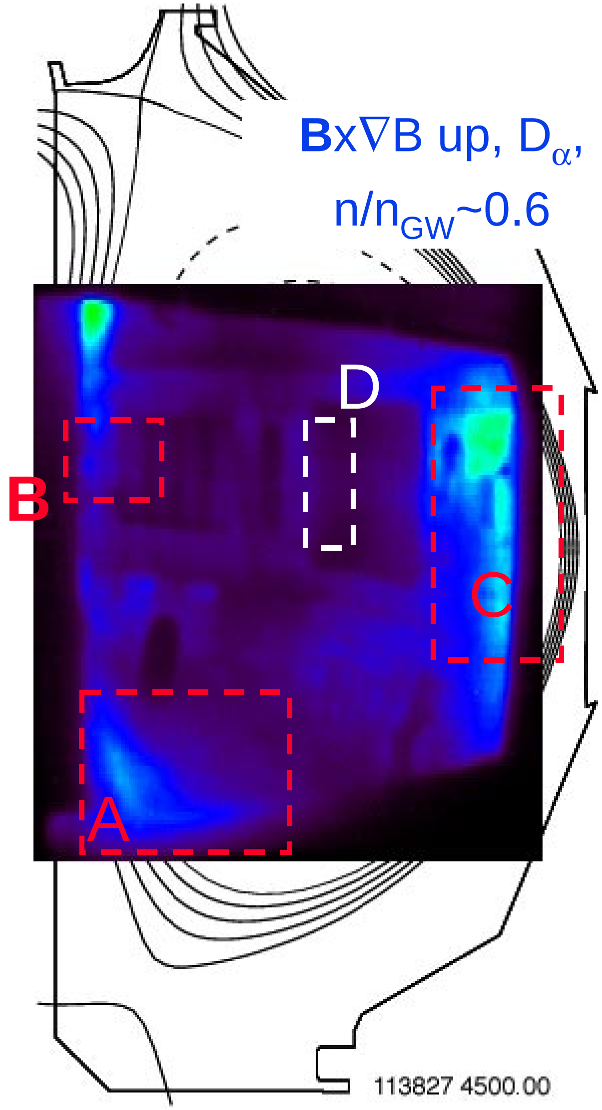
- CII emission peaks at outer strike zones in USN, DN, LSN, in lower divertor CII maps “extended” div. legs
- CIII emission in LSN indicated partially detached lower divertor, while in USN plasma remained attached to upper target plates

Div. and Midpl. CII (515nm), USN, n/n_{GW}~0.4





Assessment of outer wall reflection using numerical and experimental tools in progress



- With increasing P_{NBI} and density, reflection and/or local recycling outer wall complicate analysis
- Areas affecting all three wavelengths
  - » ADP baffle (A) - adjacent to lower x-point region
  - » ICRF antenna guard limiter (B) - above midplane
  - » Outer wall region, where view becomes more tangent with outer SOL (C)
  - » Intensity of reflection varies with power, density and magnetic configuration
- Area also affecting CII/CIII profiles,
  - » Neutral beam duct guard limiter (D)

Summary and Conclusions

- New spectroscopic analysis of SOL assessed main-chamber recycling in L-mode at n/n_{GW}~0.2, and in ELMy H-mode at n/n_{GW}~0.4 and 0.6

- Experimental results:
  - » Poloidally asymmetric D_α, CII, and CIII emission profiles in the inner SOL, weighted toward primary divertor(s)
  - » D_α emission inside LCFS at x-point region indicates strong x-point source
- Modeling results using UEDGE consistent with experimental data

$\Rightarrow$ X-point fueling contributes two orders of magnitudes more to core plasma fueling than main walls!

- Carbon modeling with purely diffusive radial transport in UEDGE
  - » Chemically sputtered carbon from the divertor walls and private flux region is transferred to the target plates
  - » A fraction of carbon from divertor region reaches upstream SOL (and hence core) at high field side due to dominant ∇T_i force in region above x-point; consistent with experiment

References

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