USTC SNST 2015 Spring Semester Lecture Series

Title: Introduction to Plasma-Facing Component (PFC) and Plasma-Material Interaction (PMI) R&D for Tokamak Fusion Energy

Lecture 6: Room 1617, 930-1130, Saturday May 30, 2015

L6: From plasma core to PFC: an integrated system

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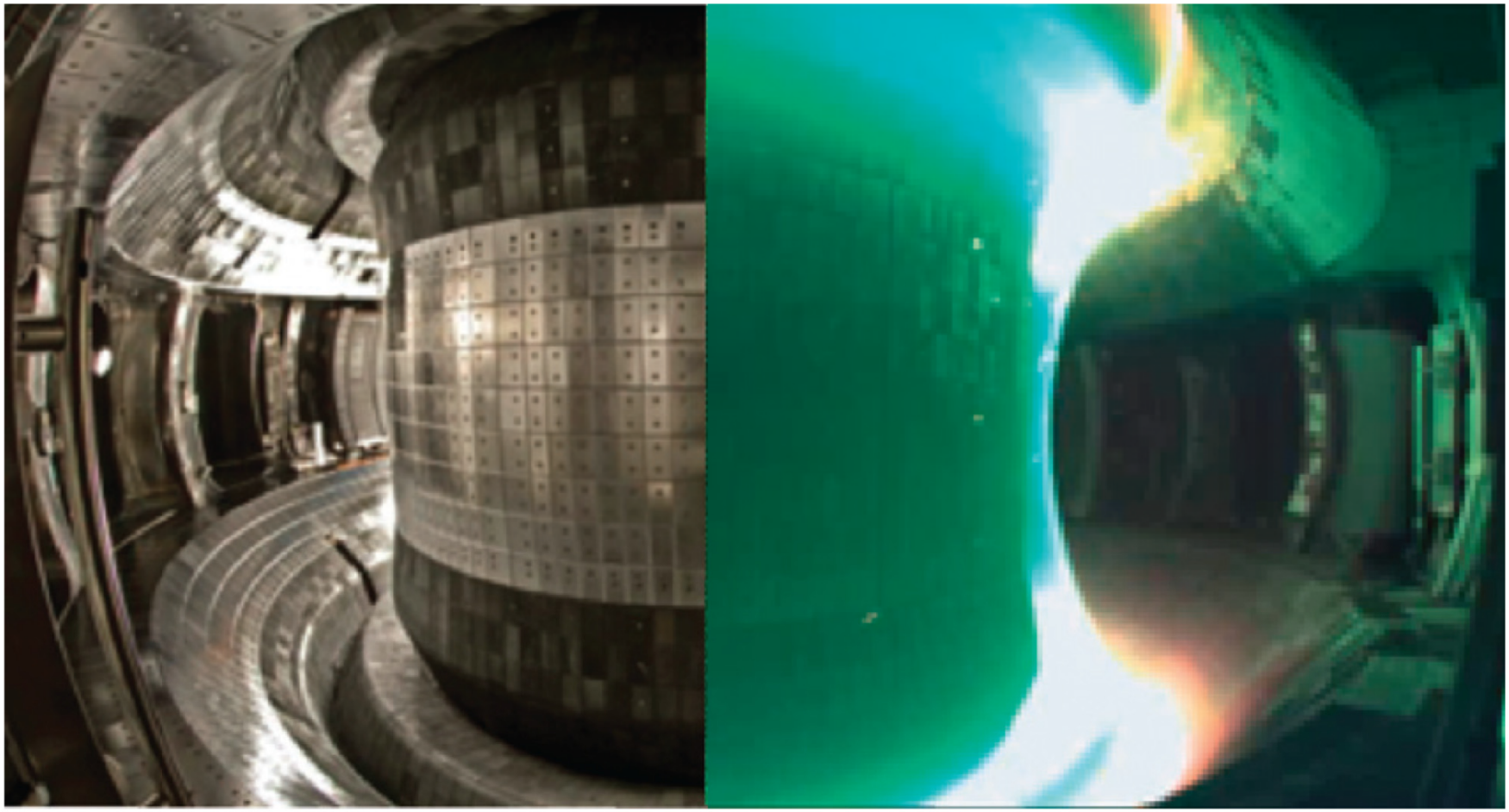
Plasma core zones (center, middle-way, edge pedestal), the SOL, the divertor plasma form a closely integrated system

- In absence of impurities, fusion energy would be much more achievable. That is, ITER would achieve sustained ignited plasma.
- This condition results from the **internal transport barrier** (center) and **edge transport barrier** (H-mode pedestal).
- Good confinement of fuel ions means **more so of impurity ions**.
- Impurity ions often travel from the **divertor target region**, move along the **SOL field lines**, reach the **plasma boundary**, and enter the plasma.
- Much progress has been made in understanding plasma and impurity transport in this integrated system.

Opportunities abound in developing the knowledge and know-how to reverse the direction of impurity migration.

Long-pulse tokamak operation will face the challenge of keeping the plasma core free of debilitating levels of impurity



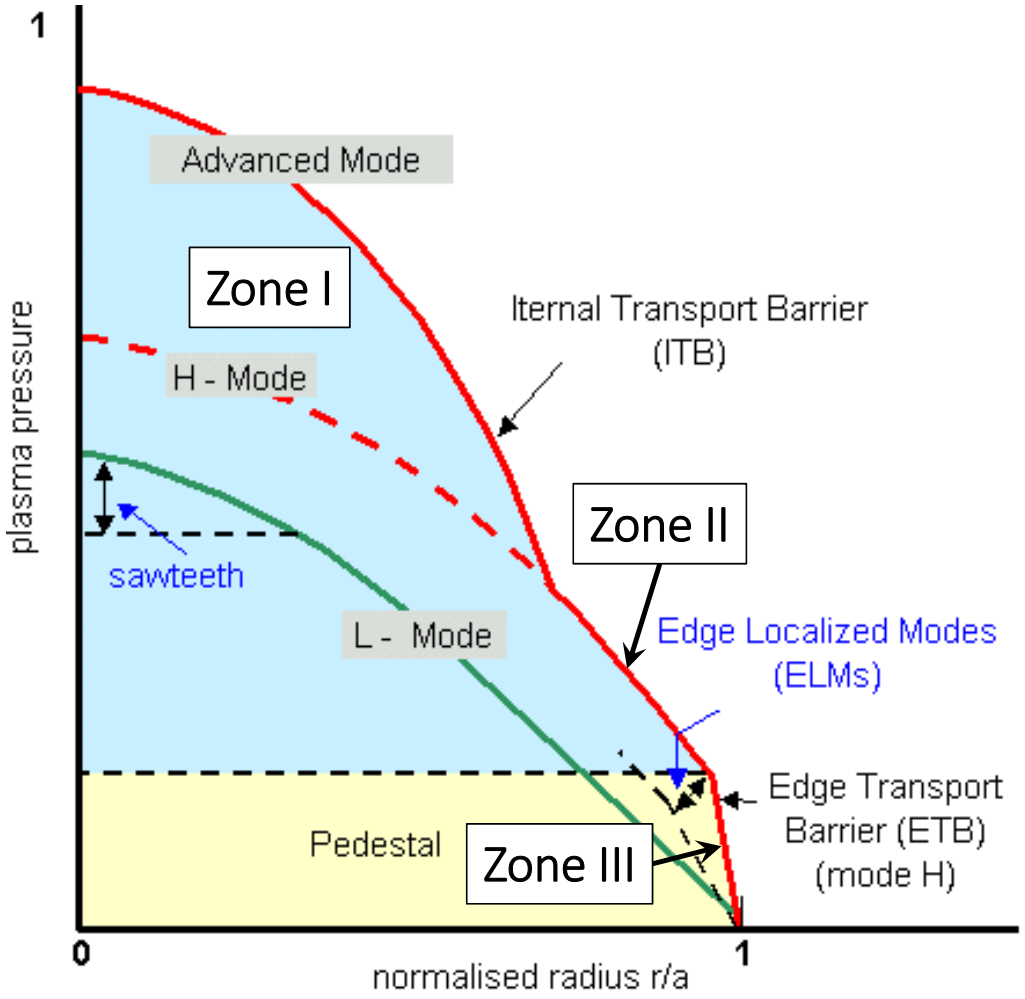
EAST Tokamak Vessel and photo of a long pulse plasma

[2013-Li-Nature Phys-v9-p817]

What do you see from this photo of plasma?

H-Mode plasma core contains two or three confinement zones

- Zone I: Internal transport barrier
- Zone II: normal transport layer
- Zone III: edge transport barrier (pedestal)
- The Scrape-Off Layer (zone IV) bridges to the PFC



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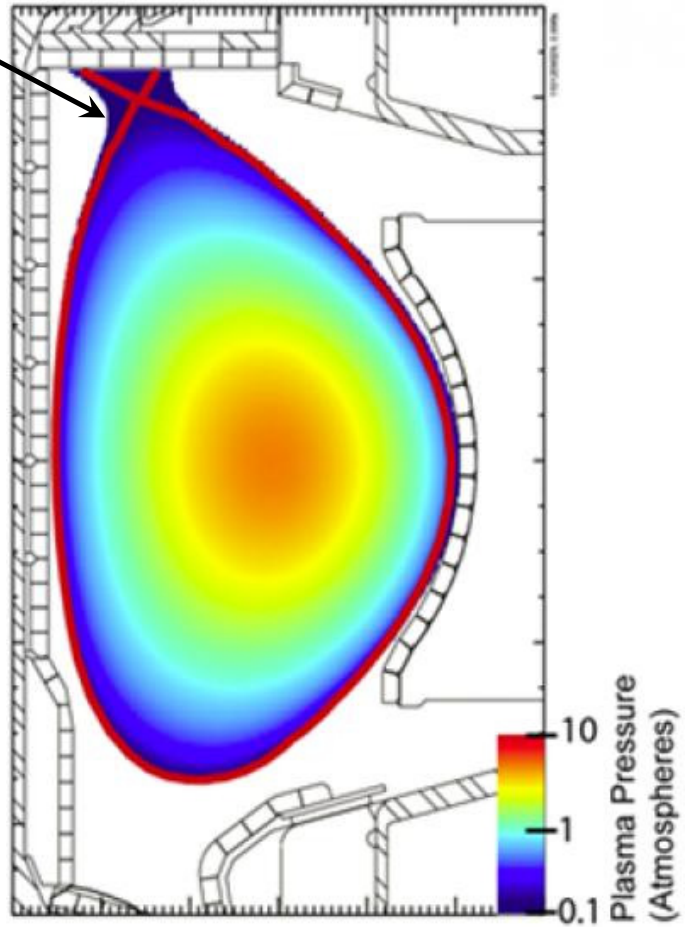
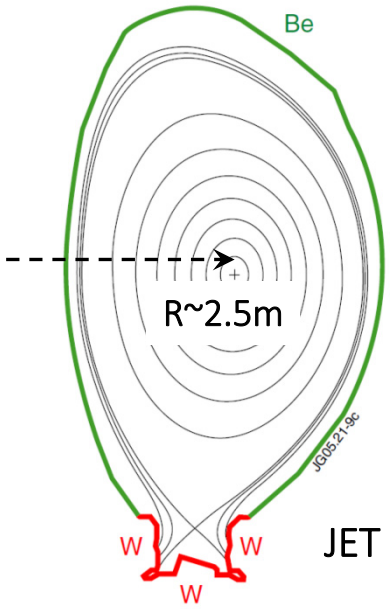
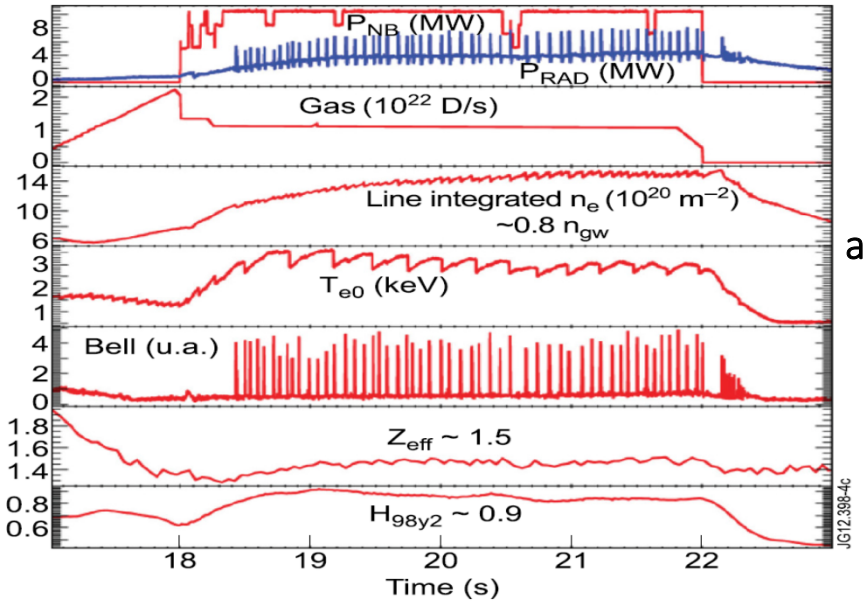


JET, with ITER-like W divertor and Be vessel wall, is working on understanding of core accumulation of impurities

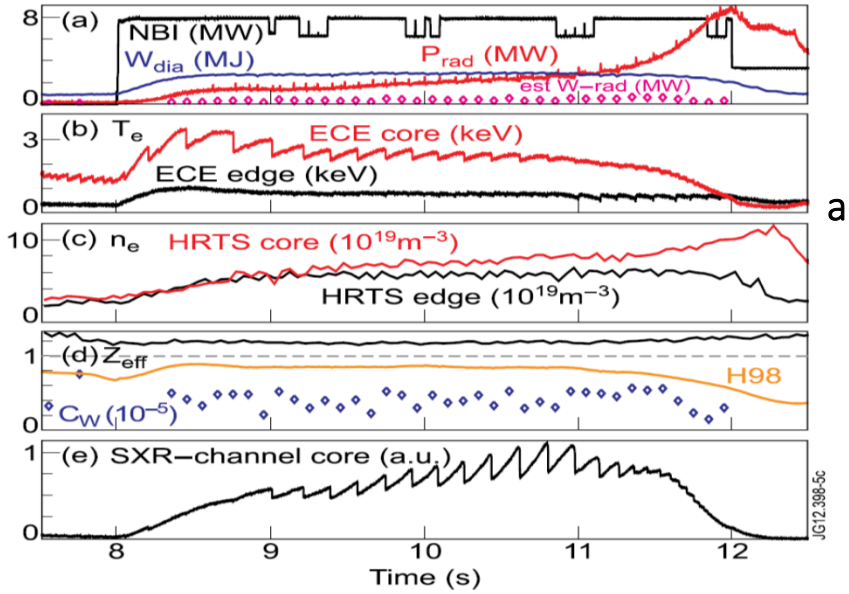


JET ITER-like PFC

[2007-Pamela-J. Nucl. Mat.-v363-365-p1]



Little or no accumulation



Much accumulation

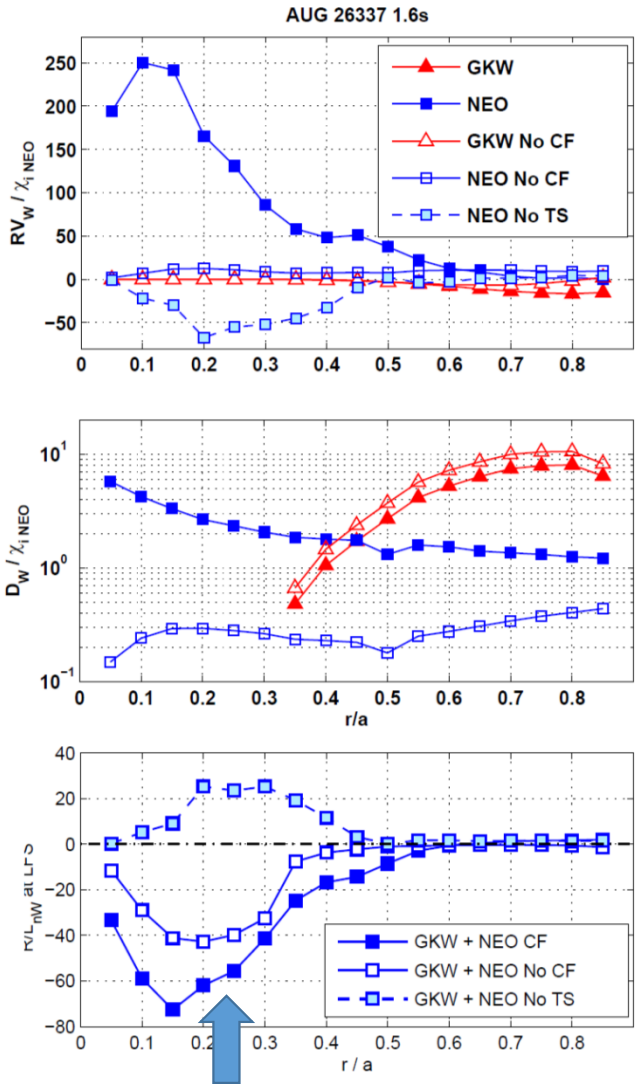
- Strong gas fueling leads to little or no core accumulation.
- Reduced gas fueling lead to much accumulation.

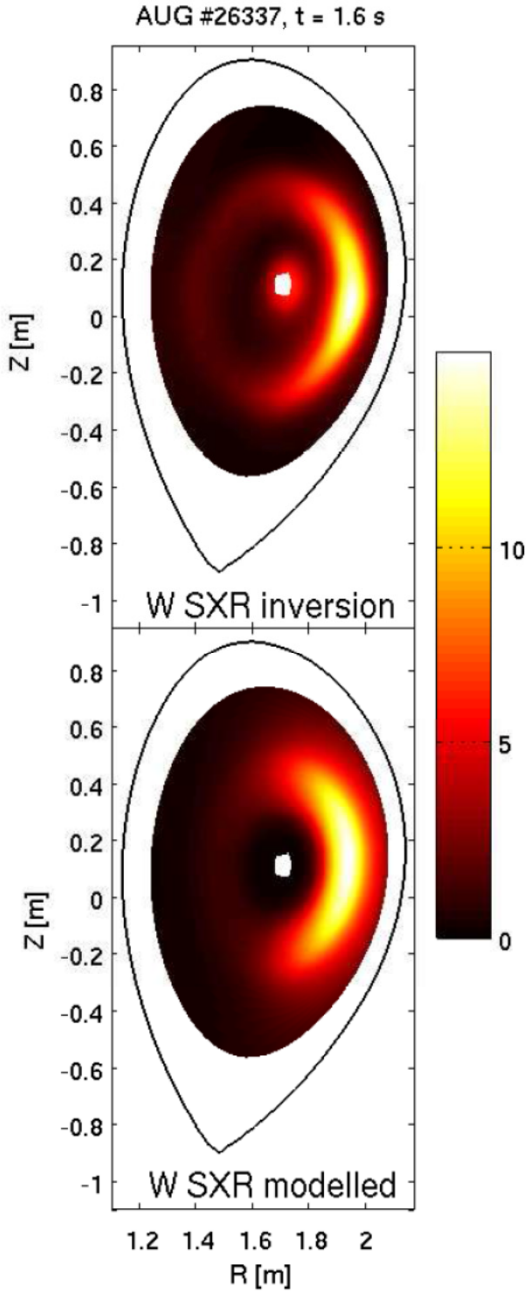
Is W the culprit?

[2013-Neu-Phys Plasmas-v20-056111]

In case ASDEX Upgrade, analysis confirms W accumulation

[2015-Casson-Plasma Phys Control Fusion-v57-014031]





- Soft X-Ray (SXR) tomography inversion measures W line radiation profile in 2D.
- NEO (neoclassical) with Gyro-Kinetic model for W density gradient profile (R/L_{nW}) using experimental boundary conditions.
- Modeled W SXR emission from plasma agrees reasonably well with data.
- Confirms the importance of centrifugal force due to strong plasma D ion rotation (Mach number > 0.3).

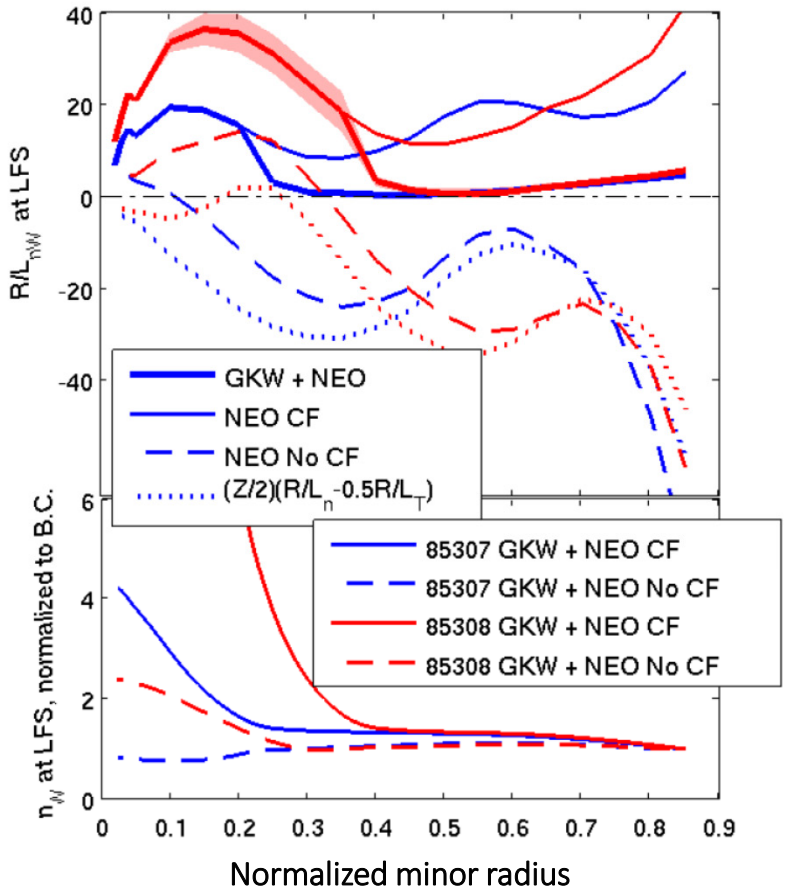
Hot plasma drives W inward!?

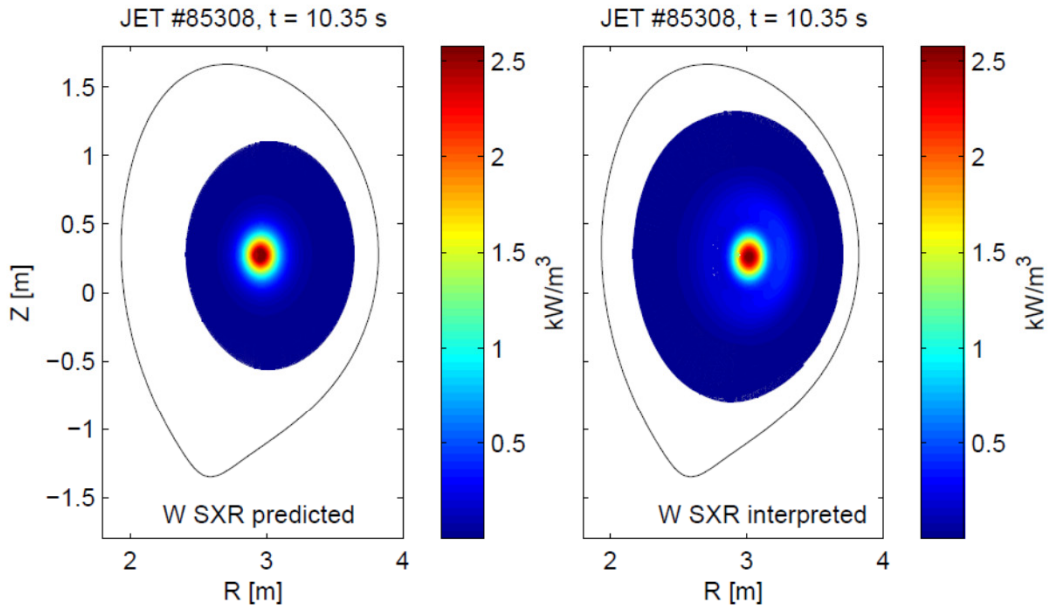
Similar modeling can explain the main feature of W in JET

[2015-Casson-Plasma Phys Control Fusion-v57-014031]

- Modeling indicates a similarly centered W density gradient R/L_{nW}.
- Much smaller plasma rotation (Mach number < 0.05) allows increased central concentration of W density, data confirming modeling.

ITER plasma expected to have small rotation; important to develop other methods to prevent W accumulation.

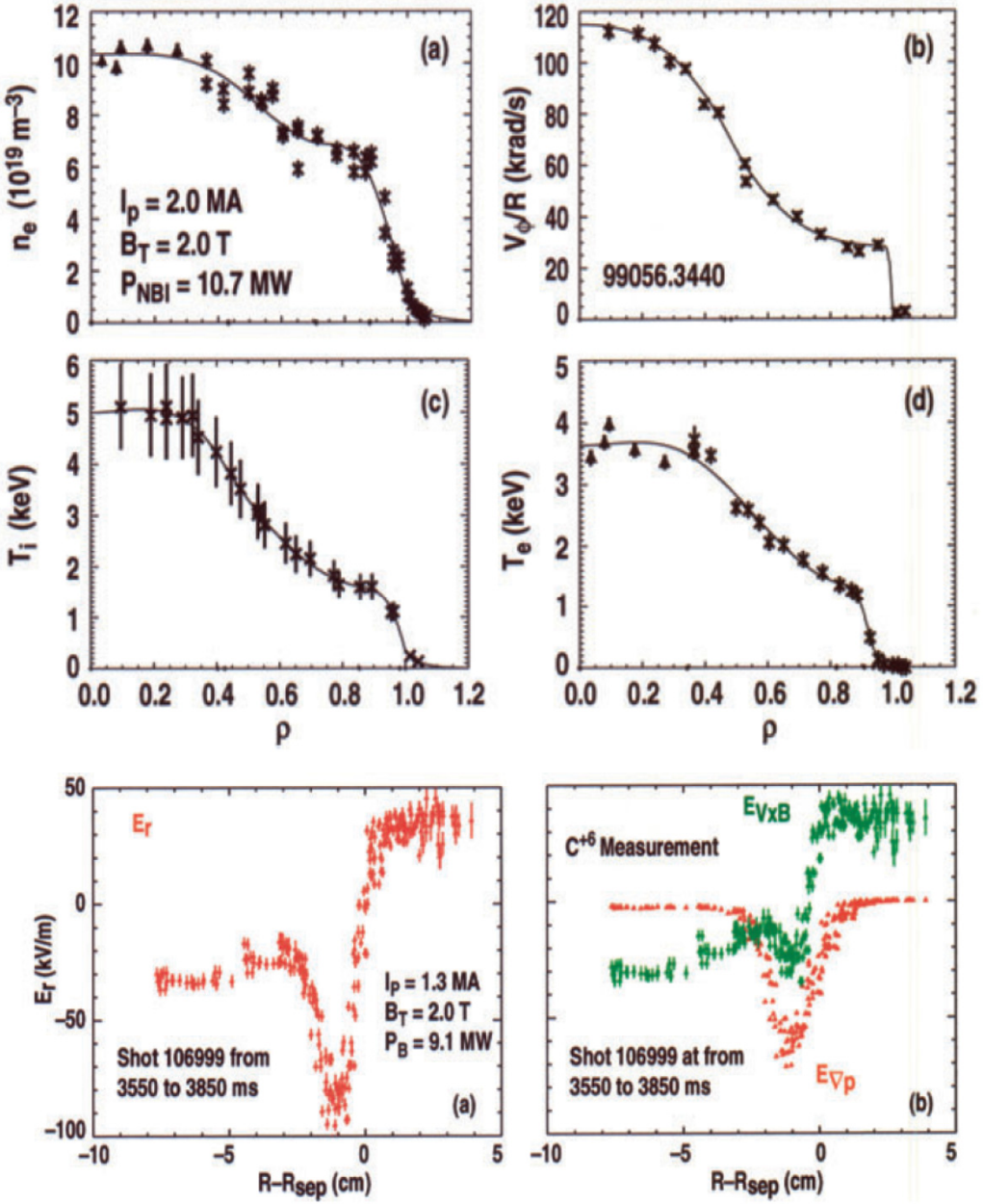




How about the H-mode Pedestal, Zone III?

[2004-Burrell-Plasma Phys Control Fusion-v44-pA184]

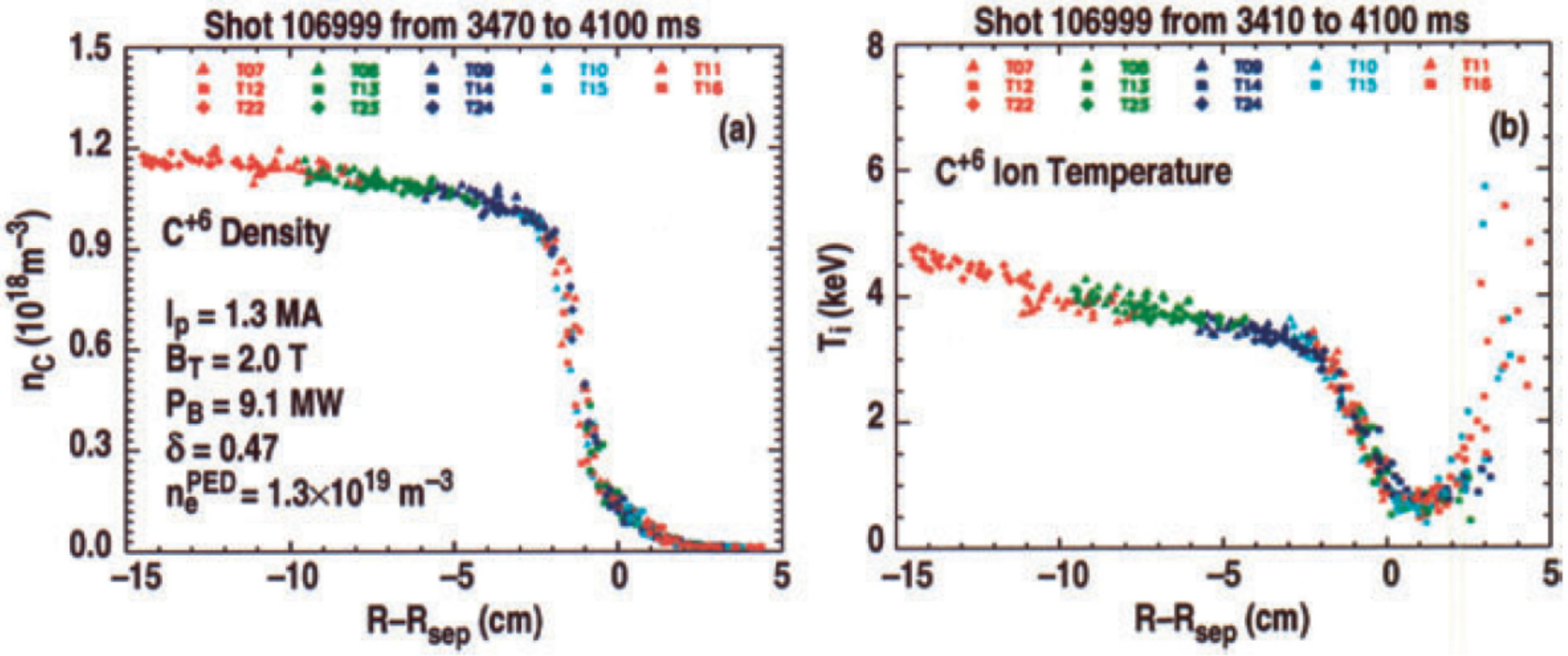
- Example: Quiescent H (QH) Mode plasma core in DIII-D shows three zones in temperatures and n_e, indication excellent confinement.
- This plasma is often associated with large plasma rotation.
- Note in the edge 5-cm, the pedestal zone exhibit a strong inward pointing electric field (up to ~kV/cm!).
- This field tends to push impurity ions inward harder than fuel ions!



This radial electric field confines D ions, as well as C ions

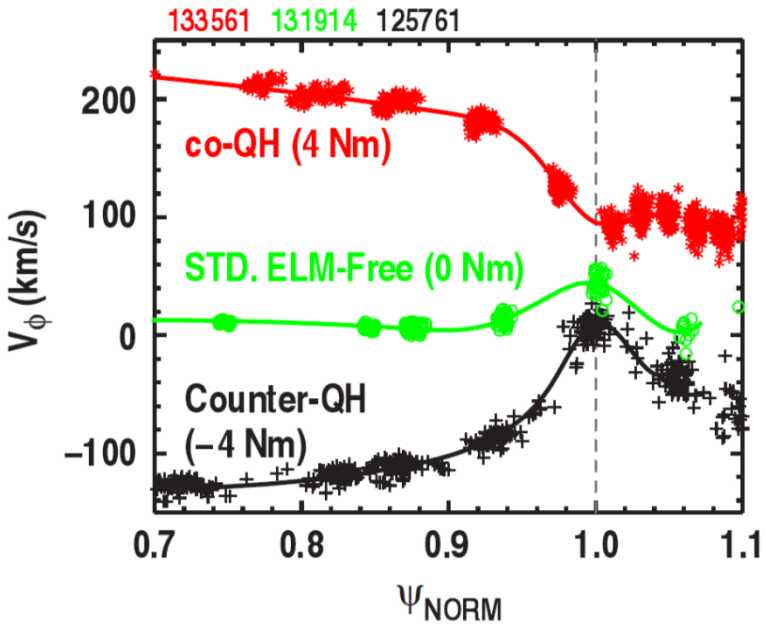
[2004-Burrell-Plasma Phys Control Fusion-v44-pA184]

- DIII-D uses carbon fiber composites (CFC) tiles for in-vessel wall and divertors; C is the main impurity in plasma.
- A strong C pedestal is formed, in temperature and density.
- C appears to have a negative density gradient, at least for the outer 15 cm of plasma, where magnetic axis would be 30 cm further inward.



How about changing the plasma rotation or perturbing the B field?

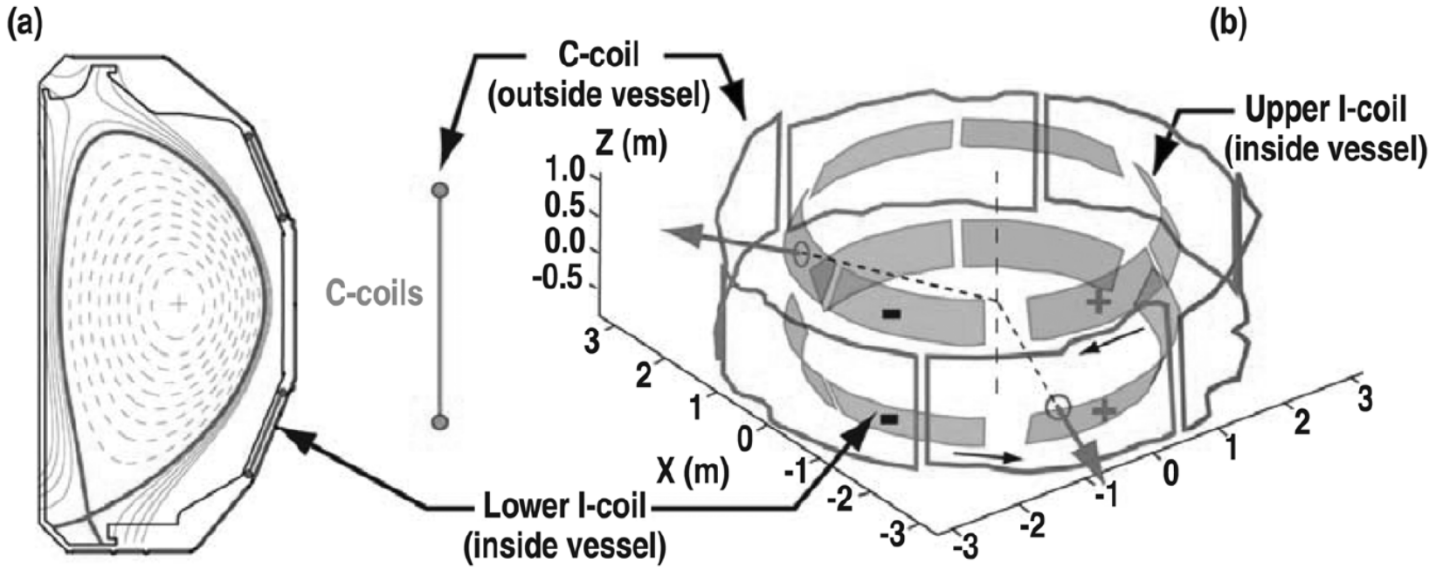
[2009-Burrell-Phys Rev Lett-v102-155003]



- QH mode plasma are produced with plasma rotation in either co-current or counter-current direction.
- Non-resonant field perturbation can slow down plasma rotation without preventing QH mode formation.

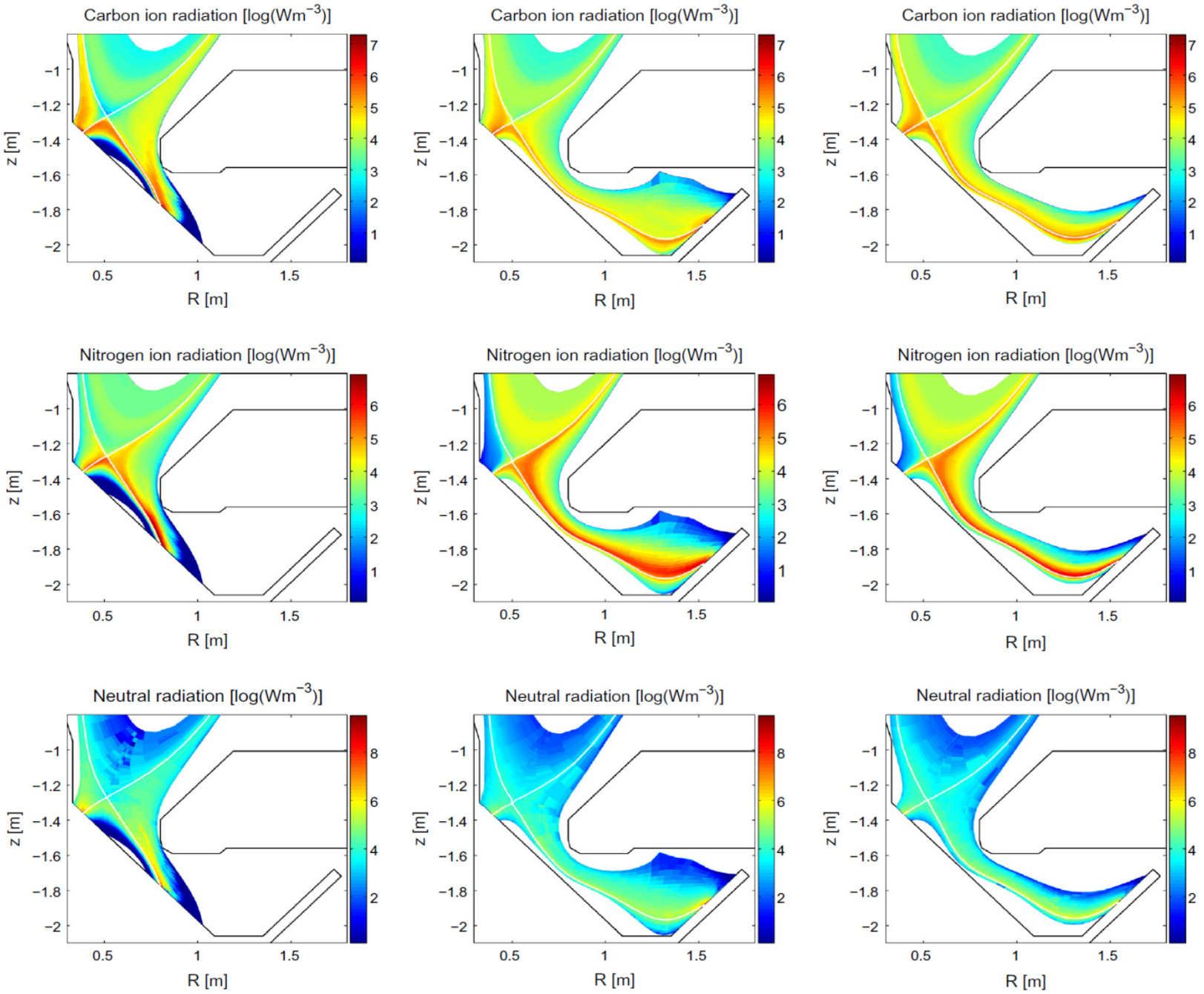
Can the pedestal electric field be modified?

[2012-Burrell-Phys Plasmas-v19-052117]



n=3 I-coil and n=1 C-coil configuration
(with up-down symmetric, even parity, I-coil)

Now we reached the scrape-off layer (SOL); how do we prevent impurities from traveling from the divertor target back to plasma edge?



[2014-Havickova-Plasma Phys Control Fusion-v56-p075008]

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Now we fill in the questionnaire and discuss your feedback for these lectures.