Thrust 9: Unfolding the physics of the boundary layer plasma*

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Theme 3 Workshop participants,
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Theme 3 on Plasma Material Interactions (PMI) is proposing 4 Thrusts

- **Thrust 9:** Enhanced boundary plasma studies in confinement devices
- **Thrust 10:** Fundamental PMI science in well controlled, well diagnosed test stands
- **Thrust 11:** PFC and magnetic configuration innovations
- **Thrust 12:** Integration of 9-11 in a confinement device compatible with good core performance

Originating question: How can we extrapolate observed PMI interactions in existing fusion devices to ITER and beyond?

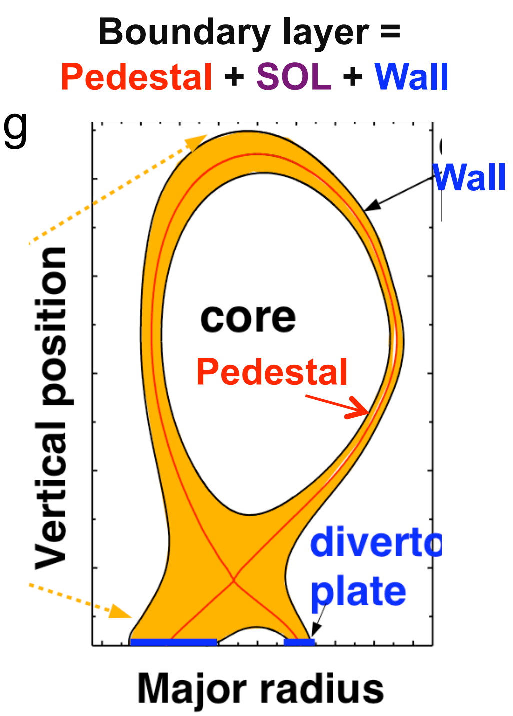
Outline for Thrust 9 – Boundary Layer

- **Introduction**
- **Needs for existing and future devices**
- **Proposed actions:**
  1. Develop and deploy new diagnostics
  2. Validate and extend existing models
  3. Plasma-RF edge interactions – diagnostics/modeling
  4. Utilize machines and design/construct upgrades/new facilities

Boundary layer includes plasma, neutrals, and photons from inside magnetic separatrix to wall

- **The boundary layer controls key functions**
  - distributes plasma power/particle fluxes to PFCs
  - helium/tritium pumping/deposition
  - edge fueling by neutrals
  - coupling RF power to core
  - impurity intrusion to core & surface material-mixing

- **Closely coupled physics involving the pedestal and the wall (aspects in other thrusts)**
  - flow shear, barrier formation, pedestal buildup
  - momentum coupling, rotation
  - ELMs (Thrust 2)
  - impact of RMPs on pedestal/SOL
  - material response to plasma/neutral fluxes



Edge physics is coming to the fore, but understanding the boundary is challenging

- Why now? Moving to high-power, long-pulse devices, challenges PFCs, and high plasma-pressure pedestal needed for fusion gain…
- European fusion program focusing its two major tokamaks (JET and ASDEX-U) on PFC and edge plasma issues
- Understanding the boundary extends challenges of core physics
  - combining plasma, neutrals, photons, & (liquids)
  - transition from closed to open B-field lines; thus strong 2D, some 3D variations
  - long/thin/twisted domain (high B-field shear)
  - Strong relative fluctuations (10-100%)

Despite complexity, important progress is being made in characterizing and beginning to understanding the boundary plasma

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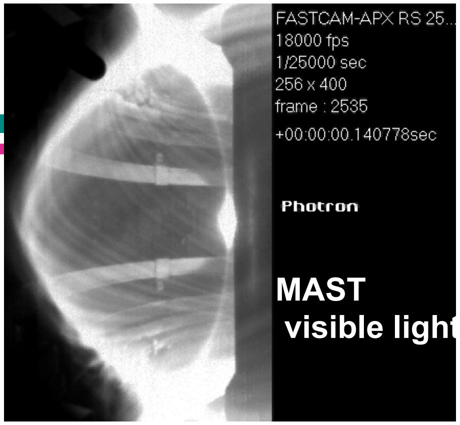
Identification of physics controlling SOL and PWI is still significantly incomplete

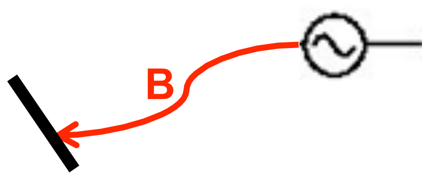


- **Measurements over the last decade have revealed a host of unanticipated features**

1. intermittent, filamentary nature of SOL turbulence
2. ELM filamentation in SOL
3. in/out asymmetry of ELM heat deposition
4. substantial plasma recycling from main chamber walls
5. large parallel flows in SOL
6. transport of C13 to inner divertor and PF regions
7. tritium SOL transport including hydrocarbons
8. substantial plasma in the private flux region
9. impact of RF sheaths on sputtering/boronization
10. effect on SOL of magnetized particle drifts/B-field direction
11. hydrogen retention in metals
12. flux dependence of chemical sputtering of C
13. tungsten "fuzz" and implications
14. inability to quantitatively model detachment and near-separatrix potential
15. dust production and transport
16. narrow target power profiles
17. evidence of strong kinetic effects in the SOL
18. SOL flows set a toroidal rotation 'boundary condition' on the confined plasma
19. X-point dependence of SOL flows and the L-H power threshold
20. critical gradient dynamics in near SOL and tokamak density limit…..

<u>Needs</u>: present SOL diagnostics inadequate; main impediment to identifying missing edge physics

- **New measurements often reveal complex features**
  - large ion flow along B-field; trace impurities swept to inner divertor
  - intermittent filamentary transport and wall recycling
  - enhance RF-sheath sputtering near divertor …

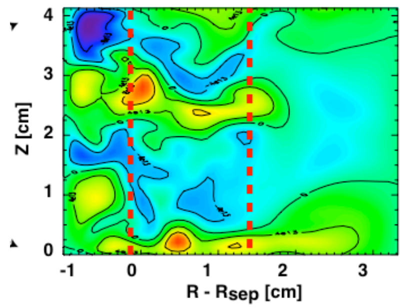


- **Strong poloidal (and some toroidal) plasma variations require measurements at many locations**
  - Thomson scattering typically only scan one radial cord
  - probe measurements at divertor or with few reciprocating probes
  - divertor heat load via IRTV; slow, but improving
  - visible-light of turbulence qualitative; hard to localize, quantify …
- **Hotter edge plasmas present difficulties**
  - probes vaporize
  - emission signals drop to unusable levels …

<u>Needs:</u> theory/simulation of boundary layer physics lags progress in core; some examples

- **Turbulence and transport models have long way to go**
  - lack consensus of dominant turbulent modes and transport
  - power width scaling for ITER very uncertain
  - detached plasma characteristics only fit qualitatively
  - characterize inward impurity transport with intermittency
  - L-H transition, pedestal structure, kinetic effects …

Fluid edge turb.; δn



- **Verification and Validation (V&V) in all areas need major emphasis**
  - theory/code and code/code verification is spotty
  - validation should be more systematic; analyze trends …

- **Understanding couple of associated regions is essential**
  - pedestal physics likely entwined with scrape-off layer (SOL)
  - dynamic plasma/neutral-induced wall sources (sputtering/recycling)
  - RF antennas and related sheaths …

Action 1: Develop and deploy new diagnostics (see Thrust 1)

- **Advanced probes at many locations to measure**
  - flows, flow shear
  - fluctuations of n_e, T_e, Φ, B

- **High-resolution spectroscopy and RF scattering**
  - flows, ion temperature, impurity distributions
  - turbulence in pedestal and SOL

- **Extended Thomson scattering for n_e, T_e, and $f_e(v)$**
  - higher resolution through pedestal gradient and SOL
  - divertor region

- **Real-time, *in situ* surface diagnostics**
  - H-uptake, erosion, deposition, co-deposition

Action 2: V&V existing theory/simulation models and extend development (see Thrust 6)

- **Clearly identify dominant a turbulence character (first fluid)**
  - compare existing theory and codes
  - extensive multi-code validation with data
  - extend to kinetic simulations

- **Generalize transport models**
  - include/couple to turbulence models
  - resolve detached plasma behavior; efficient neutral model

- **Integration of dynamic near-surface and SOL models**
  - erosion, re-deposition
  - sheath response

- **Integration of models across regions**
  - SOL + pedestal/core + material wall

Action 3: Development of plasma-RF interaction diagnostics and models

- **Measure RF-sheath potential/sputtering in existing devices**
  - determine field-line connection, amplitude, sensitivity to plasma
- **V&V of RF-sheath models**
  - compare and consolidate RF-sheath models
  - validate with “hot-spot” measurements
- **Integrate RF sheath models in full SOL codes**
  - transport effects, especially sputtered impurities at surfaces connected to the antenna via B-field line
  - impact of RF-sheaths/antenna on SOL turbulence
- **Integrate RF sheath models in antenna codes**
  - determine impact on antenna
  - assess effect on wave propagation into plasma

Action 4: Utilize devices and design/construct upgraded/new facilities (see Thrusts 4, 10-13)

- **Enhance resources (personnel, runtime) on existing machines**
  - SOL/divertor heat-flux scaling; edge flows and E-field
  - ELM/blob ejection and transport including impurities
  - divertor-plasma detachment; RF-sheath sputtering; …
- **Help design/interpret upgrades/new devices (Thrusts 4, 11-13)**
  - innovative divertor upgrades/expt.
  - improved RF launchers to minimize RF-sheath erosion
  - new facilities addressing DEMO, high heat-flux, and nuclear issues
- **Collaborate in studies of Plasma Wall Interaction (Thrust 10)**
  - new/upgraded lab facilities to carefully measure erosion, re-deposition
  - improve models of surface modification/erosion for complex geom.

Summary of Thrust 9

- **Understanding boundary plasmas is key for design and operation of successful of magnetic fusion devices**

- **Predictive understanding will require a substantial investment**

- **Proposed actions:**
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