Understanding of Neutral Gas Transport in the Alcator C-Mod Divertor

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Outline

- Validated neutral transport codes needed to design future devices.
- Experiments on Alcator C-Mod provide good test.
- Atomic & surface physics data central to neutral transport models.
- Experimental behavior not completely understood,
  - Improved atomic physics will help.
  - True resolution may require better plasma models.

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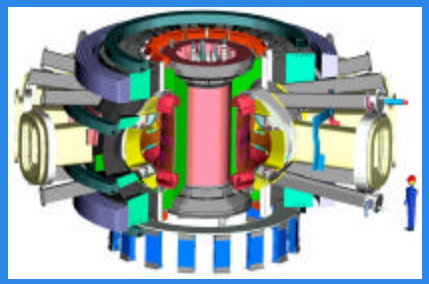
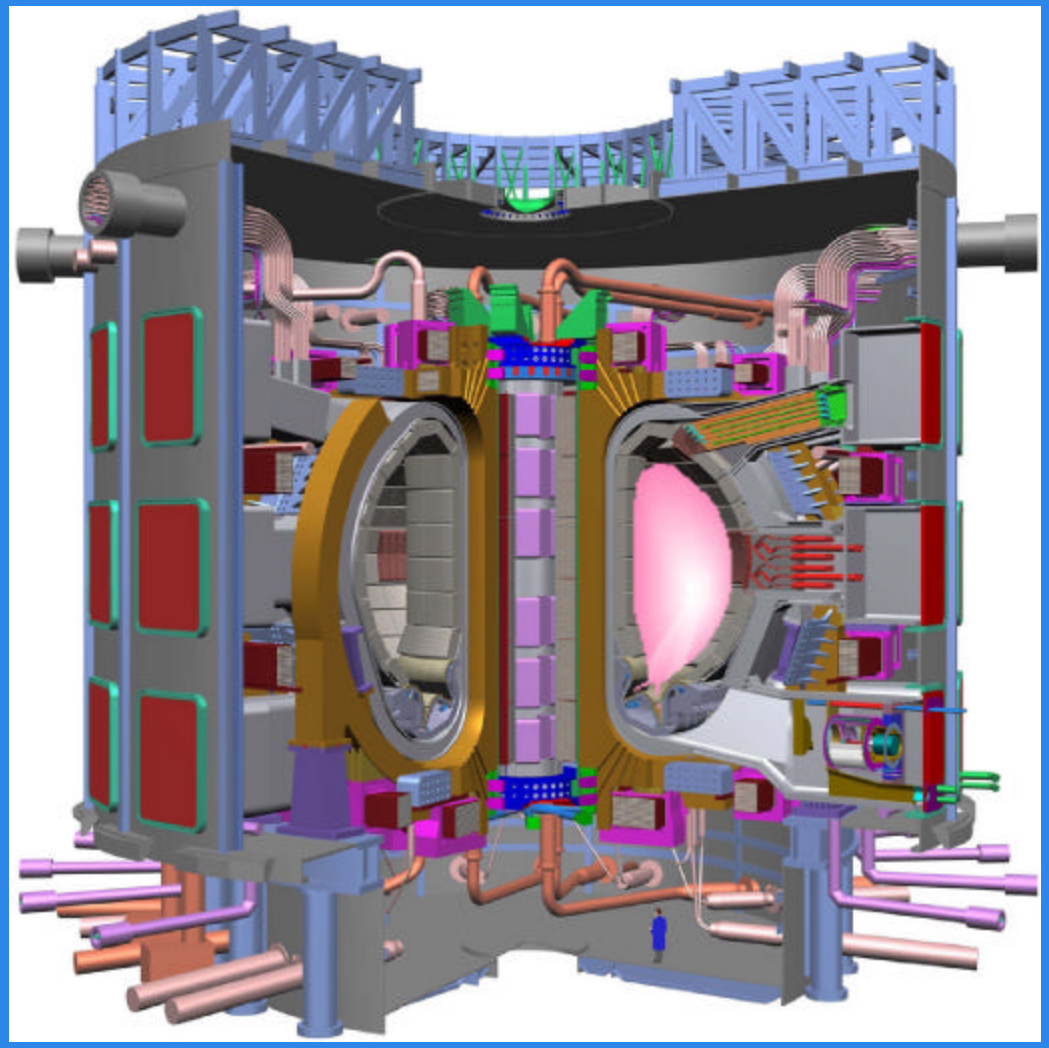
Three Approaches to Burning Plasma Physics Being Discussed

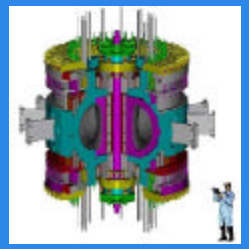


FIRE

(same scale)



ITER-FEAT



IGNITOR

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PMI Parameters in Long Pulse bpx Are Factor of ^{3} 10 Extrapolation

Parameter	Existing	ITER-FEAT
DT Particles / Pulse	6×10^{22}	3×10^{25}
Type I ELM Energy (MJ)	0.4	10
Disruption Magnetic Energy (MJ)	15	300
T Retention Fraction	> 10%	0.1%

Federici et al., Nucl. Fusion (2001)

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Will Need Validated Edge Modeling Codes to Evaluate bpx Designs

- Plasma transport codes: boundary conditions for core & n, T near materials,
- Codes to track impurity flows into core,
- Neutral transport codes:
  - Plasma & neutral sources input,
  - Yields plasma & impurity sources,
    - Couple to plasma & impurity codes.
  - Compute source rate in core impact on microinstabilities & fast particle loss,
  - Evaluate pumping rate hardware design.

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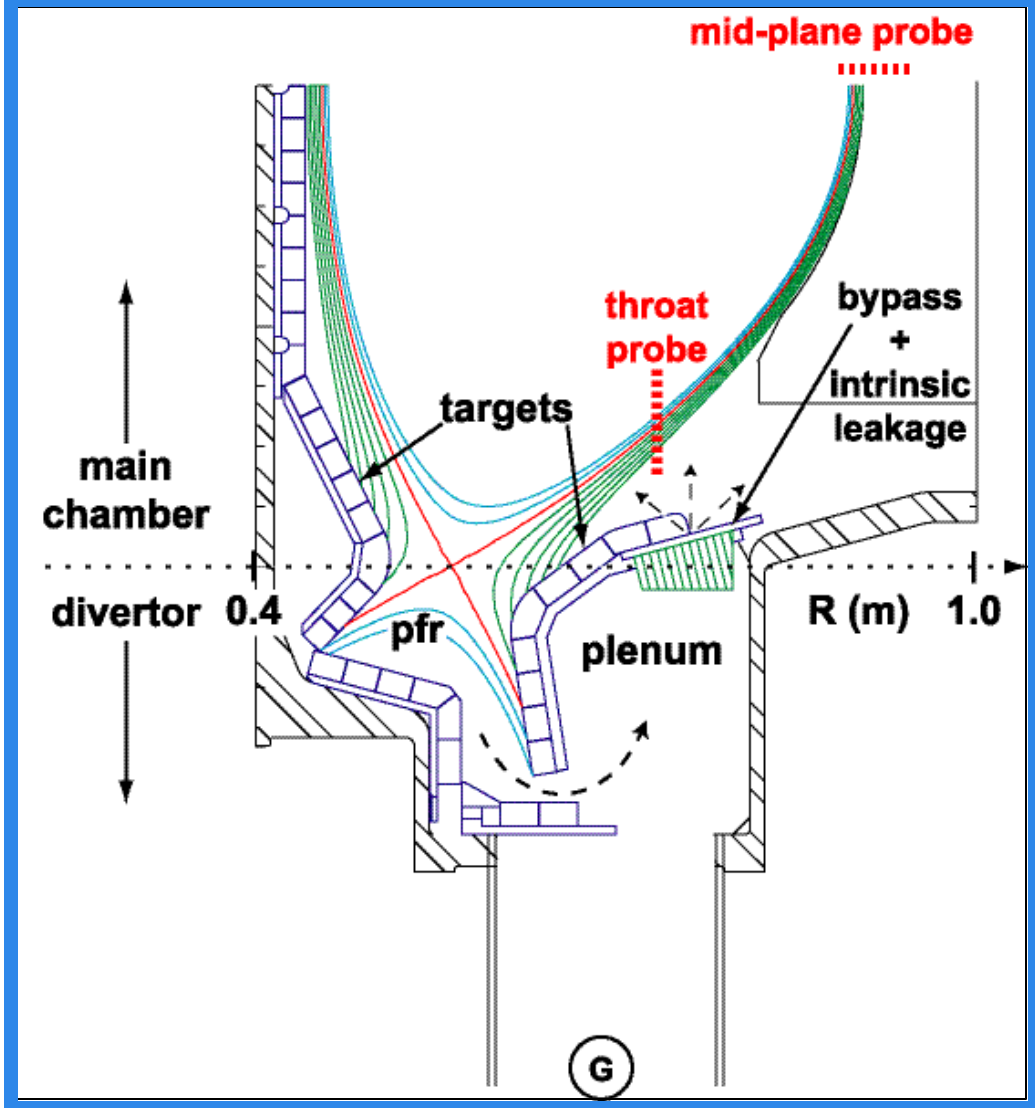
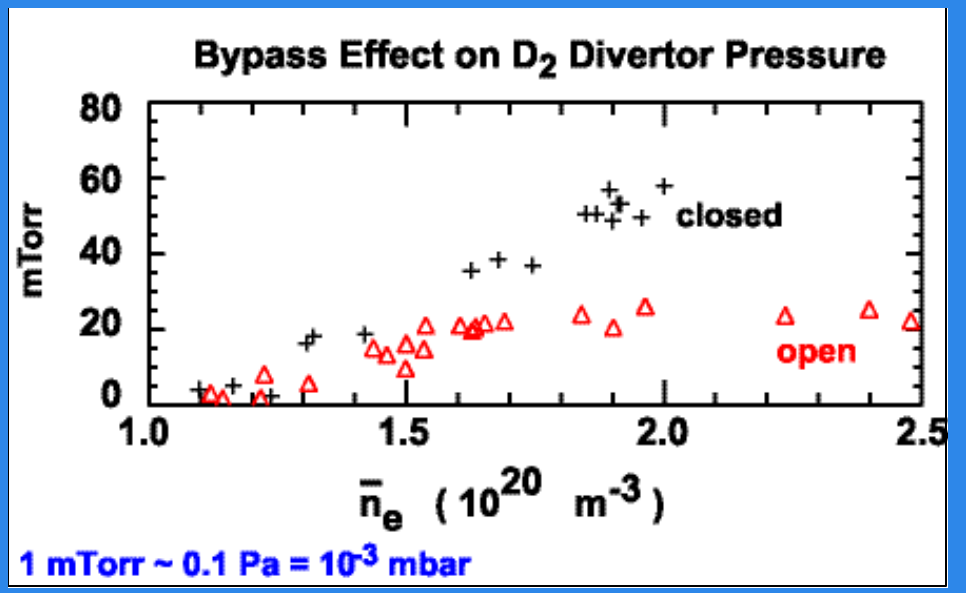
C-Mod Experiments Examined Effect of Divertor Neutral Baffling





Pitcher et al.,
Phys. Plasmas (2000)

C-Mod Experiments Examined Effect of Divertor Neutral Baffling

- Shot with: $\bar{n}_e = 1.46 \times 10^{20}\,m^{-3}$
  - Plasma data from scanning and fixed probes,
  - P_{div} = 15 (open), 30 (closed) mTorr,
  - Also compare with divertor-viewing D_a array,
  - Well diagnosed.
- Ideal for neutral transport modeling,
  - Plasma conditions suitable for simple model,
  - And don't change with bypass state,
  - Input for neutral transport code set up with few adjustable parameters.

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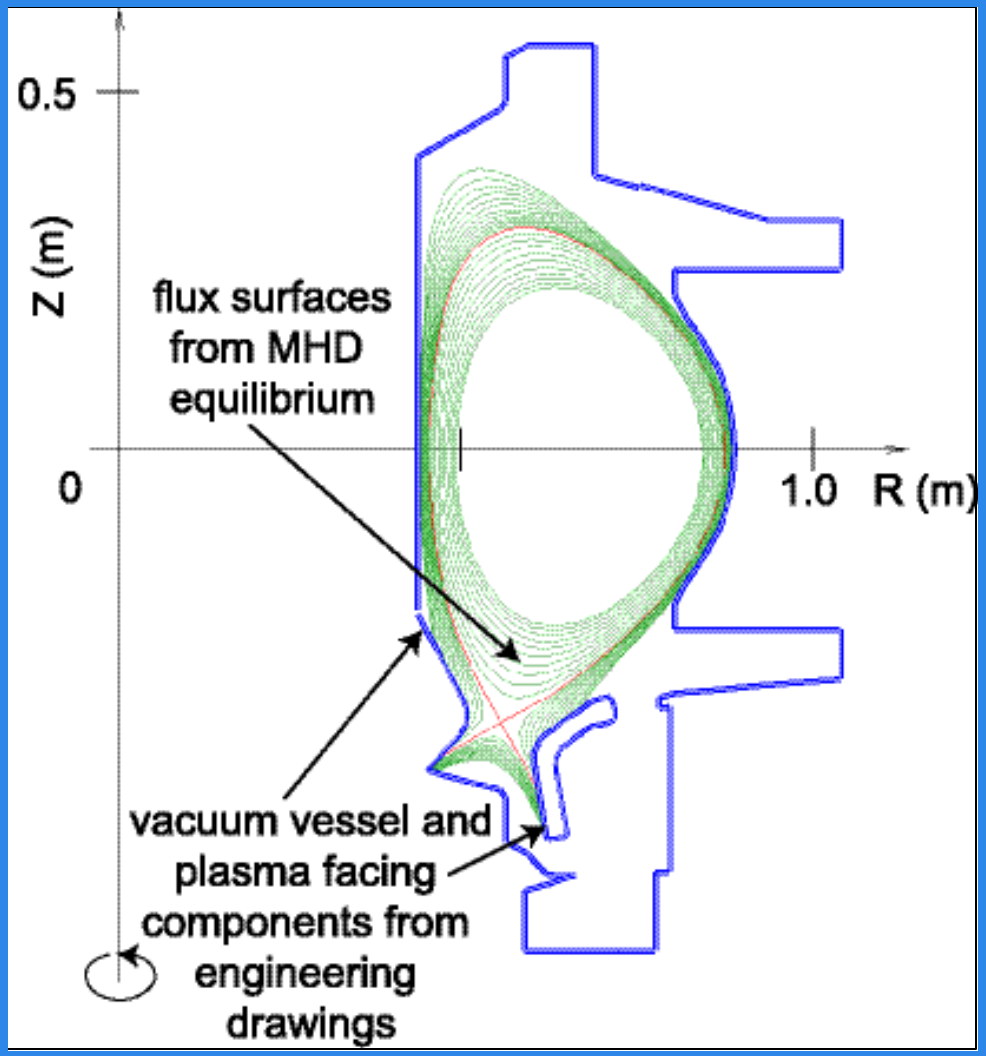
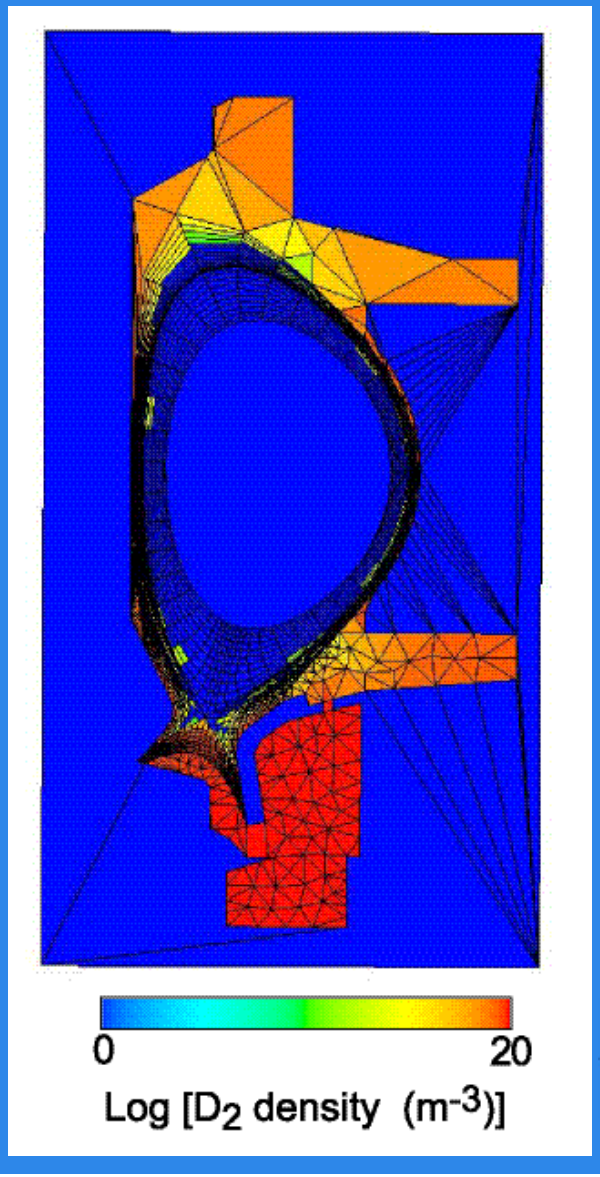
Monte Carlo Neutral Transport Code DEGAS 2 Uses Detailed Geometry





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Atomic & Surface Physics Data Are Core of DEGAS 2 Model

- Neutral source due to recycling,
  - Current taken from probe data.
  - Incident ion / atom reflection probability & velocity distribution.
- Neutral source due to recombination,
  - Computed from plasma n & T using…
- Collisional radiative model for e + H ionization and recombination,
  - Optically thin.
- Neutral-ion & neutral-neutral elastic scattering.

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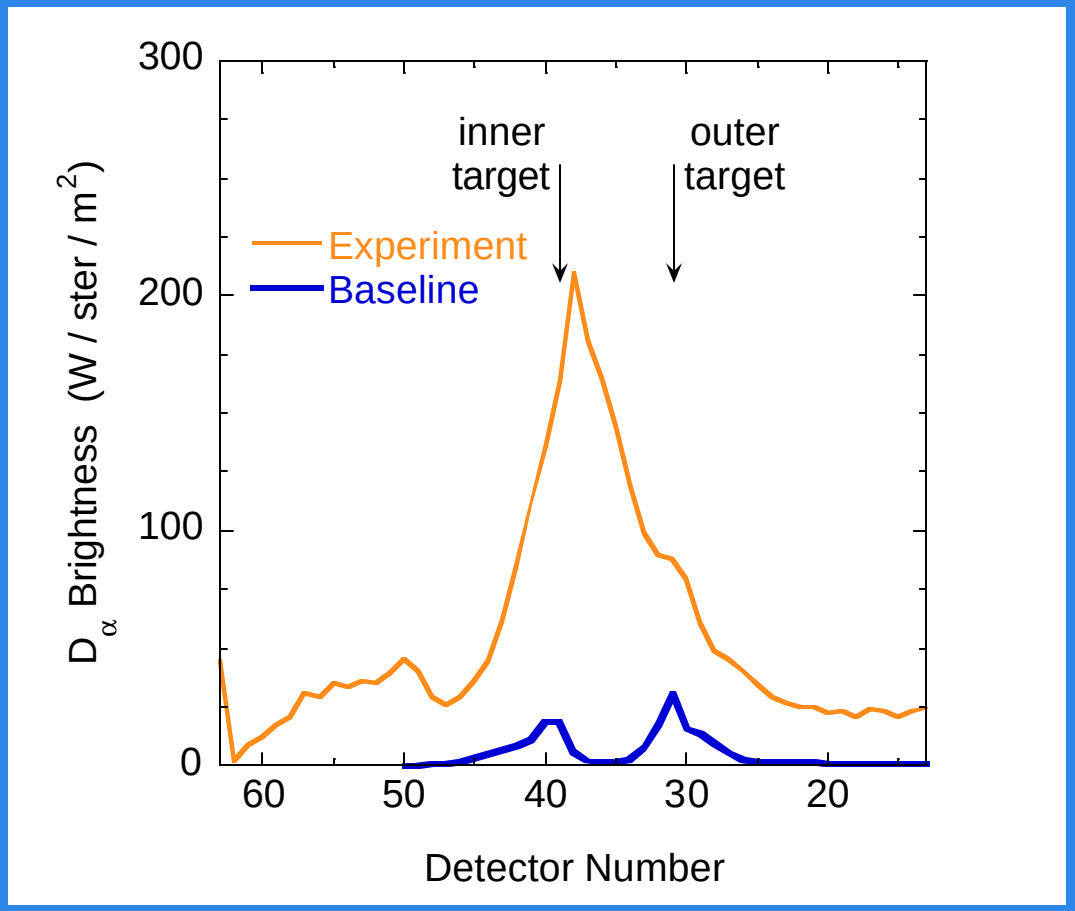
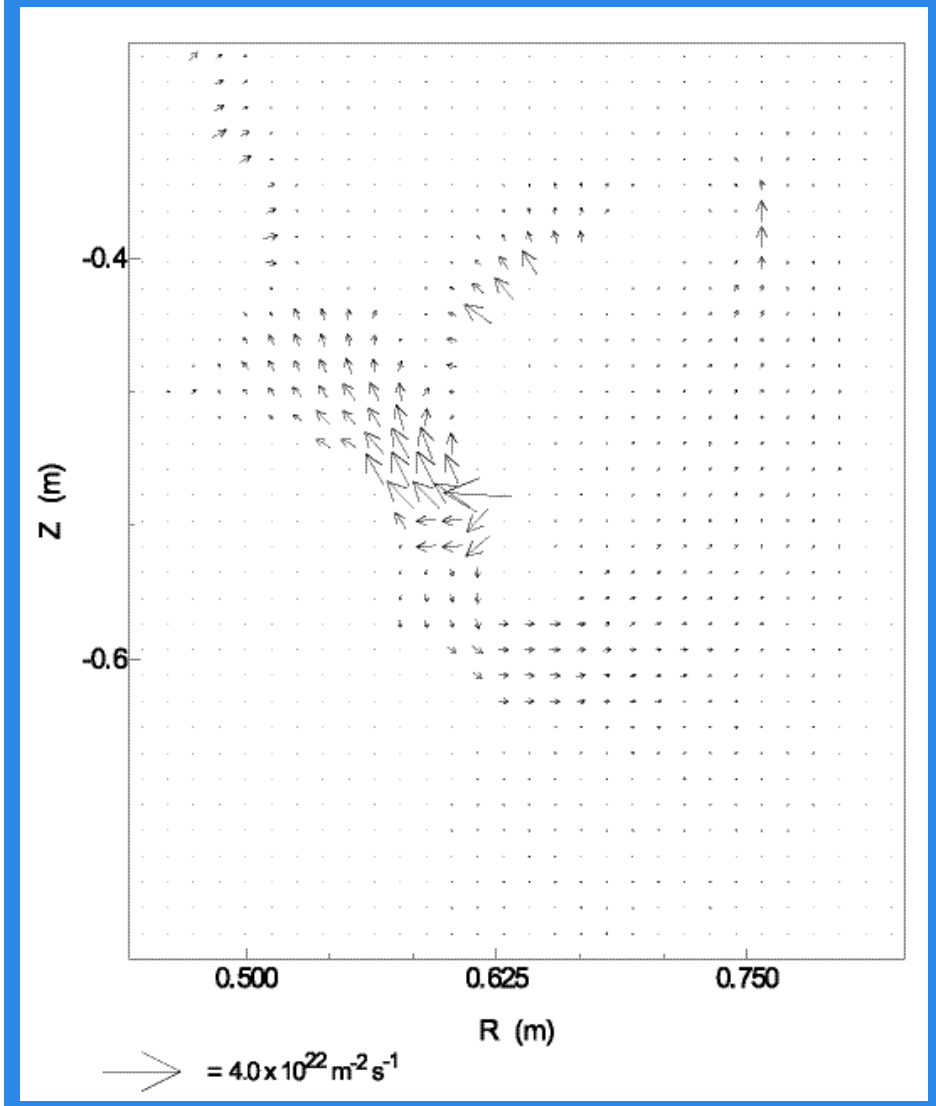
Baseline Simulation Neutral Pressure & D_a Too Low

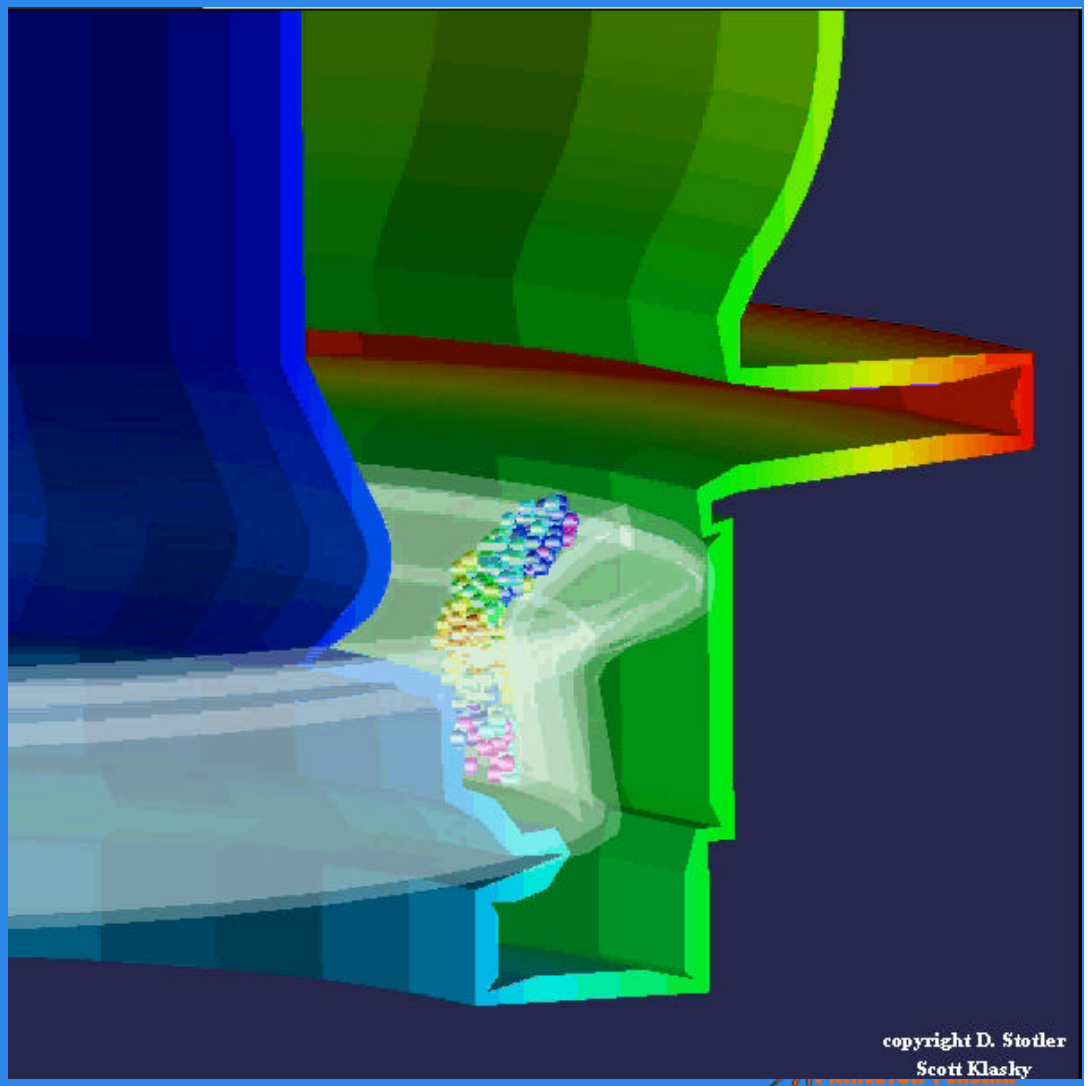
- **Neutral pressure: 0.74 (open) , 0.97 (closed) mTorr, << experiment, 15 & 30.**



Stotler et al., J. Nucl. Mater. (2001)

Atoms Primarily Flow From Outer Target into Divertor Plasma





Neutral Pressure Governed by Elastic Scattering

- Neutral-ion elastic scattering,
  - $s(q,E_r)$ computed by Krstic,
  - Enforce min. scattering angle for efficiency.
- Neutral-neutral elastic scattering,
  - Iterative, BGK treatment.
- Atoms have ~ few eV energies,
  - Fast reflection, dissociation, & coupling to ions,
- Molecules enter with 0.03 eV energy,
  - Gain momentum from ions & atoms by elastic scattering,
  - Sensitivity study Þ pressure halved when turned off.

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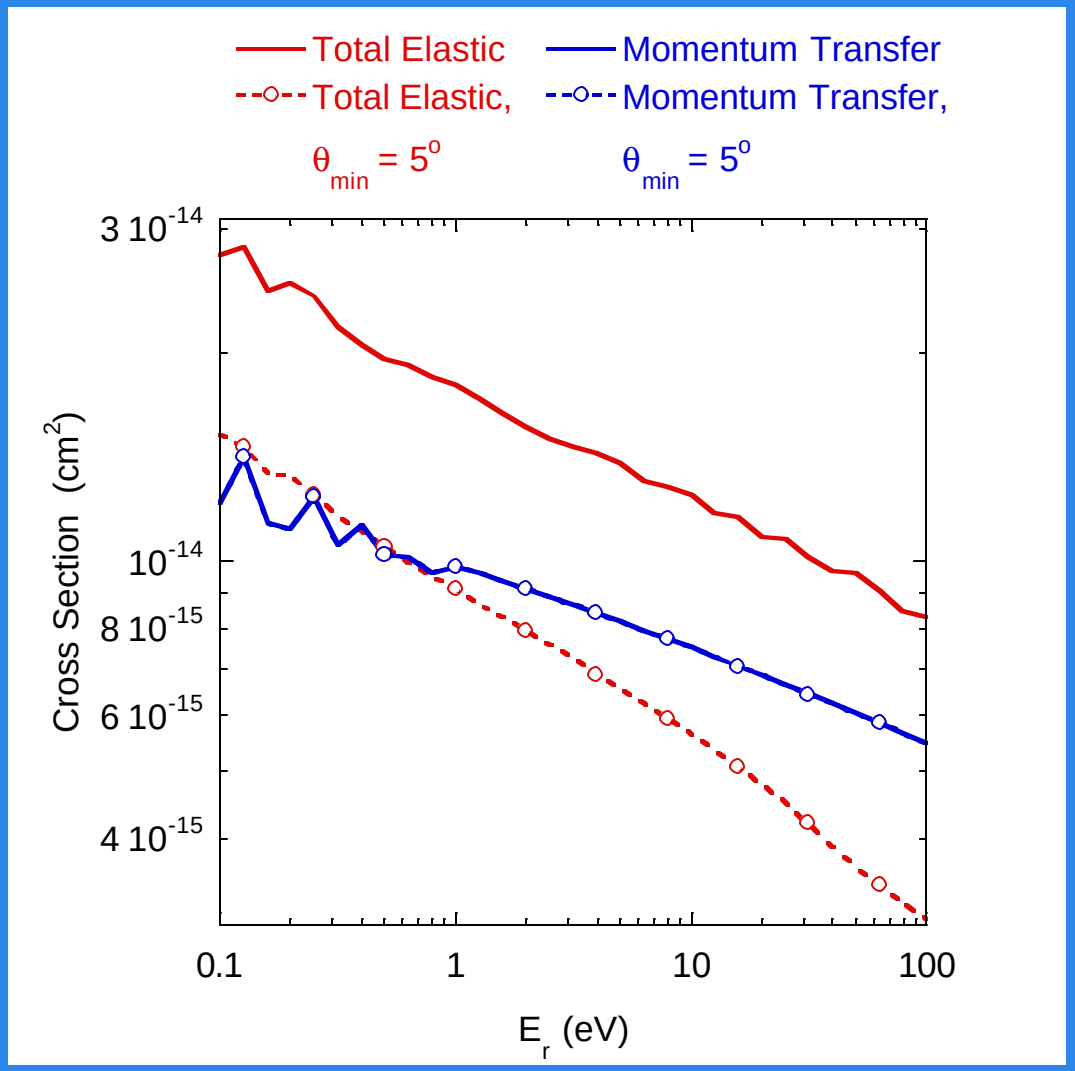
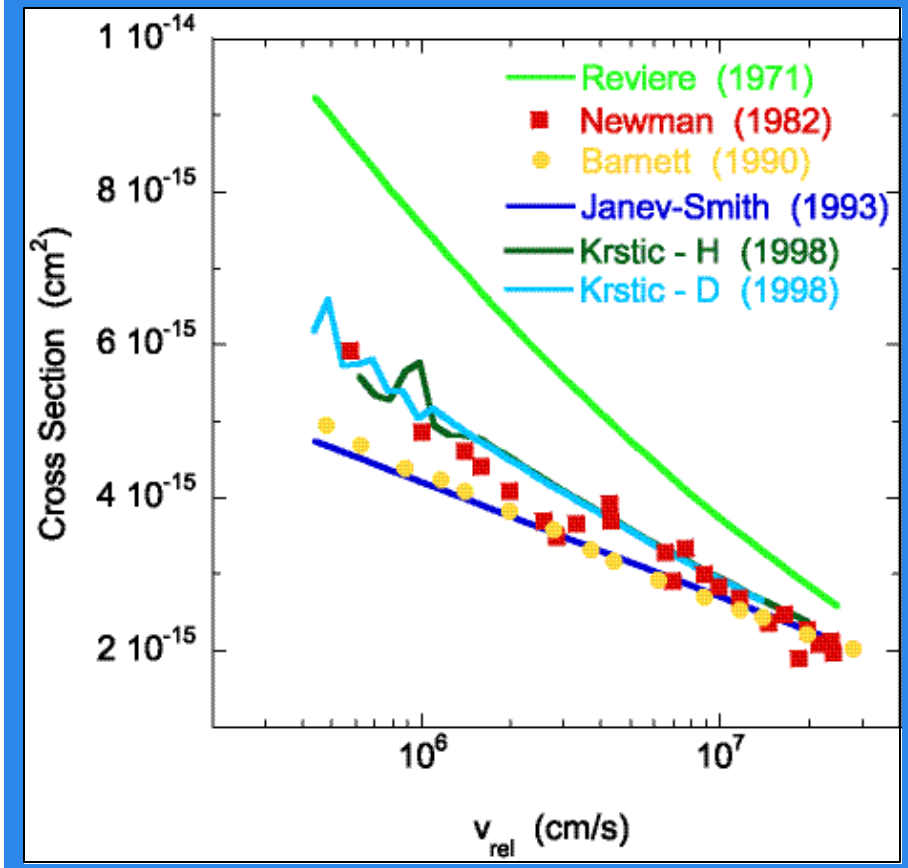
D + D+ Elastic Scattering Data From Controlled Fusion Atomic Data Center

Kanzleiter et al., Phys. Plasmas (2000)





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Neutral Pressure Sensitive to Surface Physics Data

- Pitcher's semi-analytic model obtained neutral pressures > 10 mTorr.
  - Due in part to simple surface physics model,
  - Þ emulate in full DEGAS 2 simulation.
  - Þ Factor of two increase in neutral pressure.
- Should revisit surface physics models,
  - But, difficult to recreate tokamak conditions in laboratory,
  - Diagnosing PMI in situ even more problematic.

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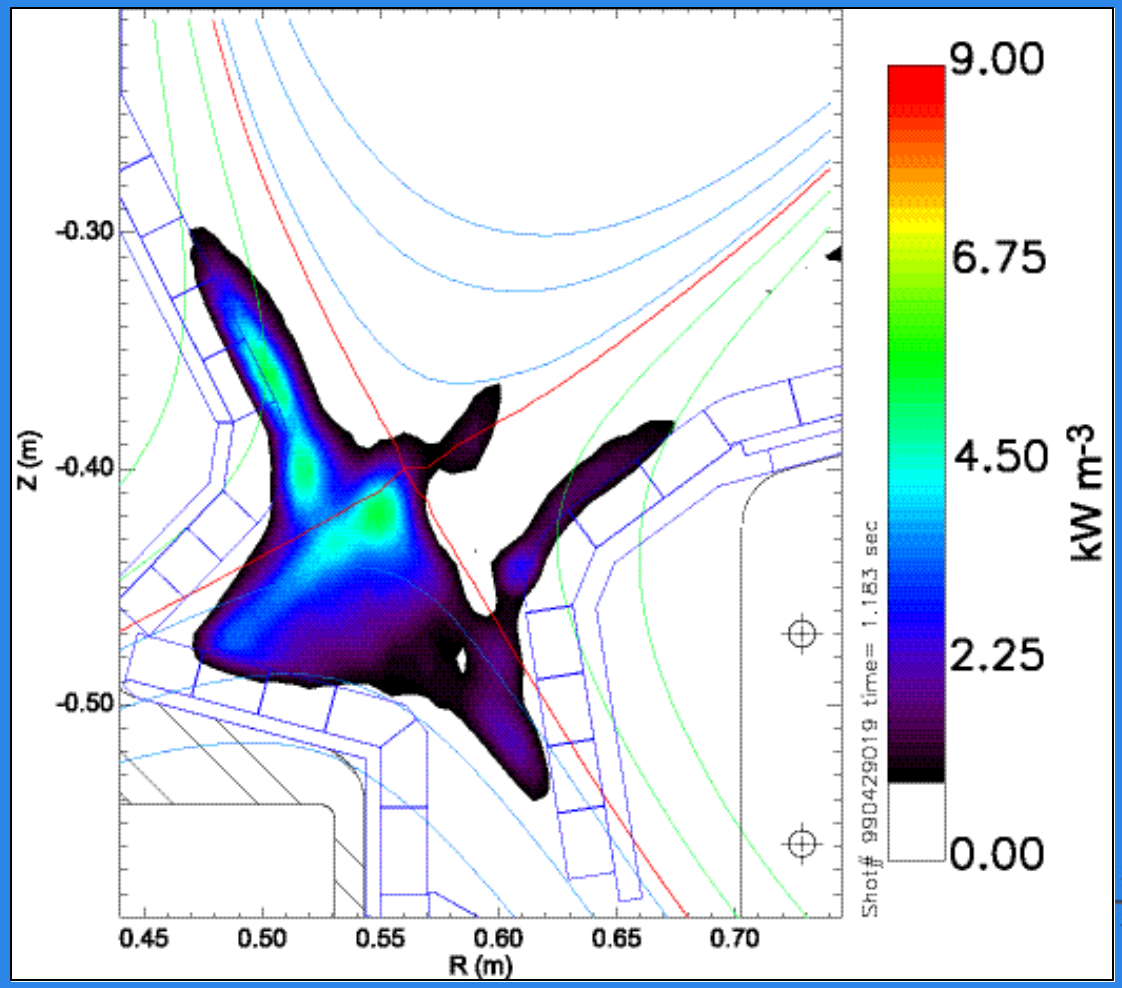
Data Suggest More Recombination Than 1% in Baseline

- D_g emission shows strong recombination in PFR:



Boswell et al., J. Nucl. Mater. (2001)

OSM Code Provides Detailed Approach to Interpolating Probe Data

- OSM - "Onion Skin Model",
  - In PFR, adjusts plasma to best fit D_a and D_g.
  - Integrates plasma equations along field lines,
  - Self-consistently treats neutral sources in SOL,
    - Coupled to EIRENE neutral transport code.

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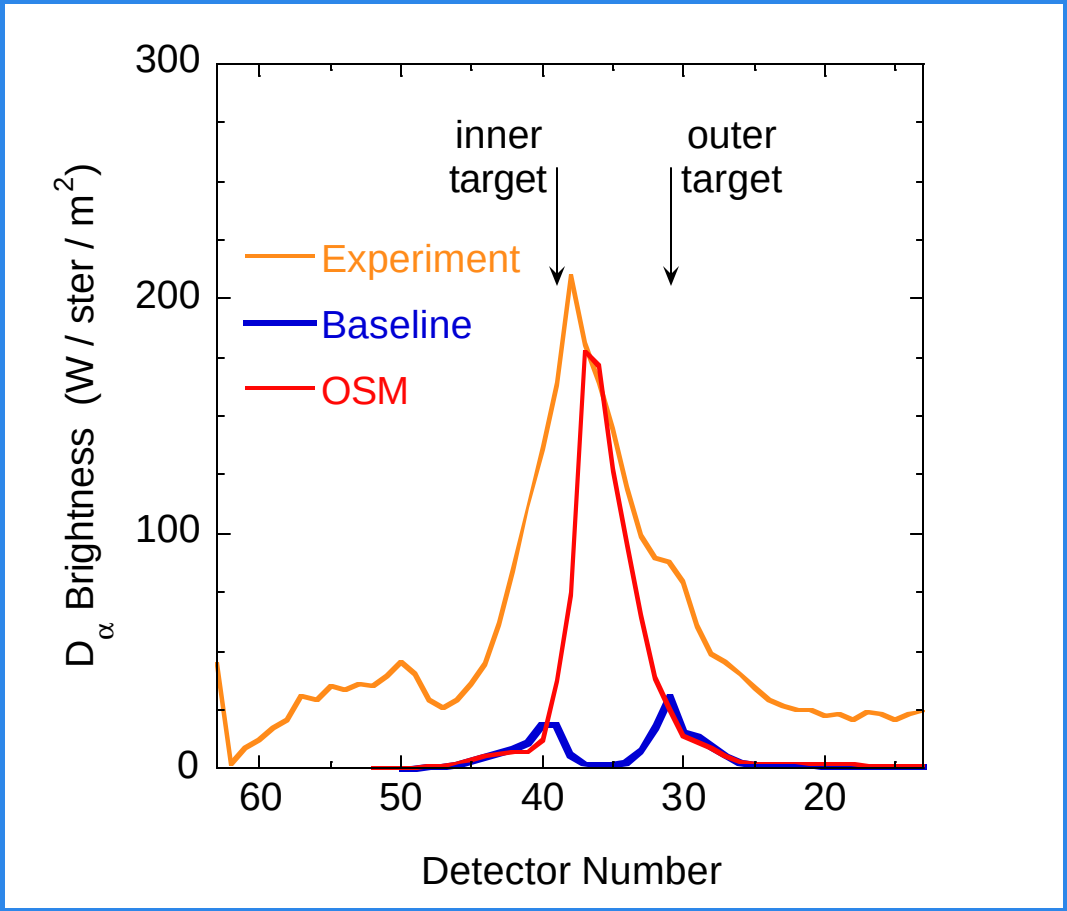
Using OSM Plasma in DEGAS 2 Improves Agreement

- **Neutral pressure 2.02 mTorr,**
  - **Still much smaller than experiment, 30 mTorr.**



Present Atomic Physics Needs

- Collisional-radiative model incorporating ro-vibrationally excited molecules,
  - Molecule Assisted Recombination,
  - Estimated to be small here.
- Lyman-α and –β radiation opaque under dense divertor conditions,
  - Has been treated with escape factors,
  - More accurate and comprehensive treatment needed that can be adapted to / coupled with existing boundary plasma & neutral codes.

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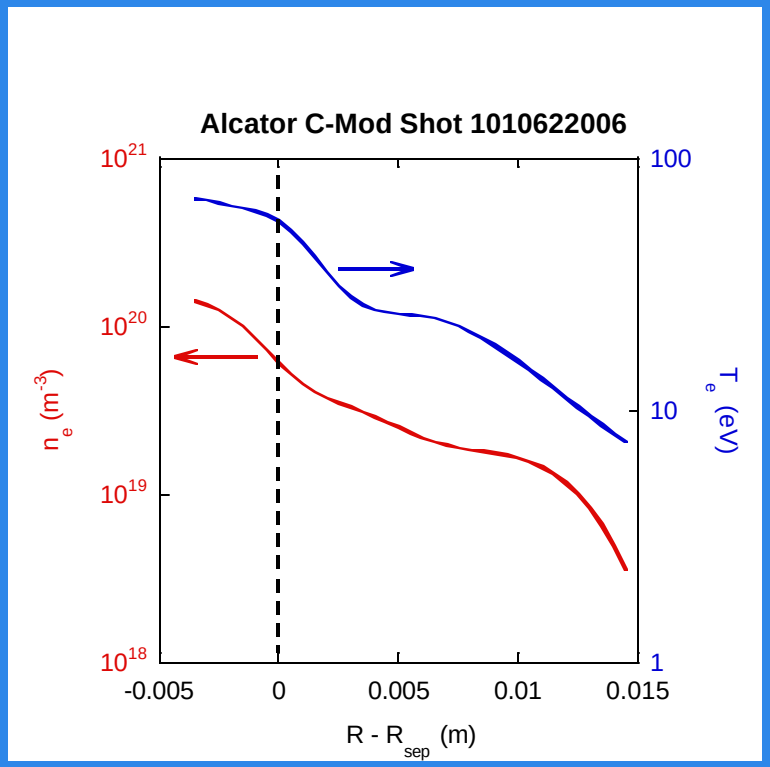
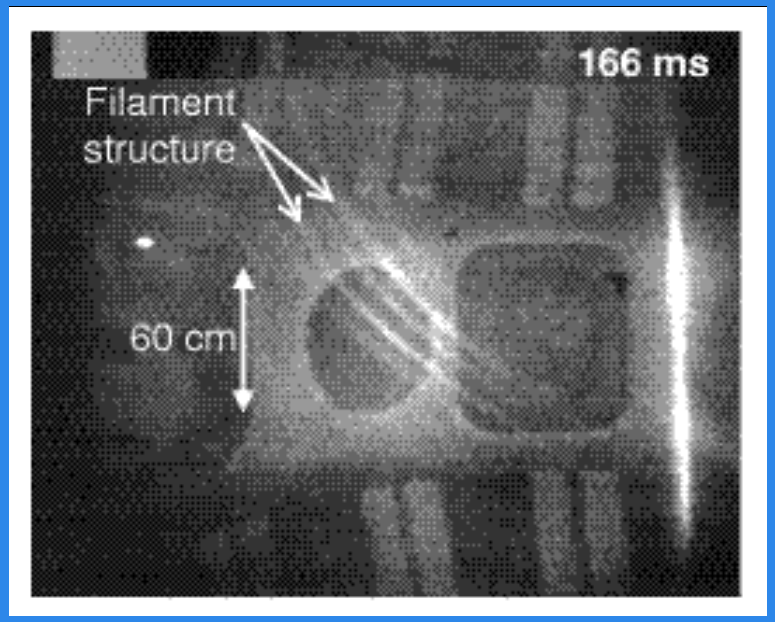
Understanding of Plasma Divertor Operation Being Questioned

- **Observe broad SOL profiles & large, intermittent structures Þ standard diffusive characterization incomplete.**



Zweben et al., Phys. Plasmas (2002)



Maqueda et al., Rev. Sci. Instrum. (2001)

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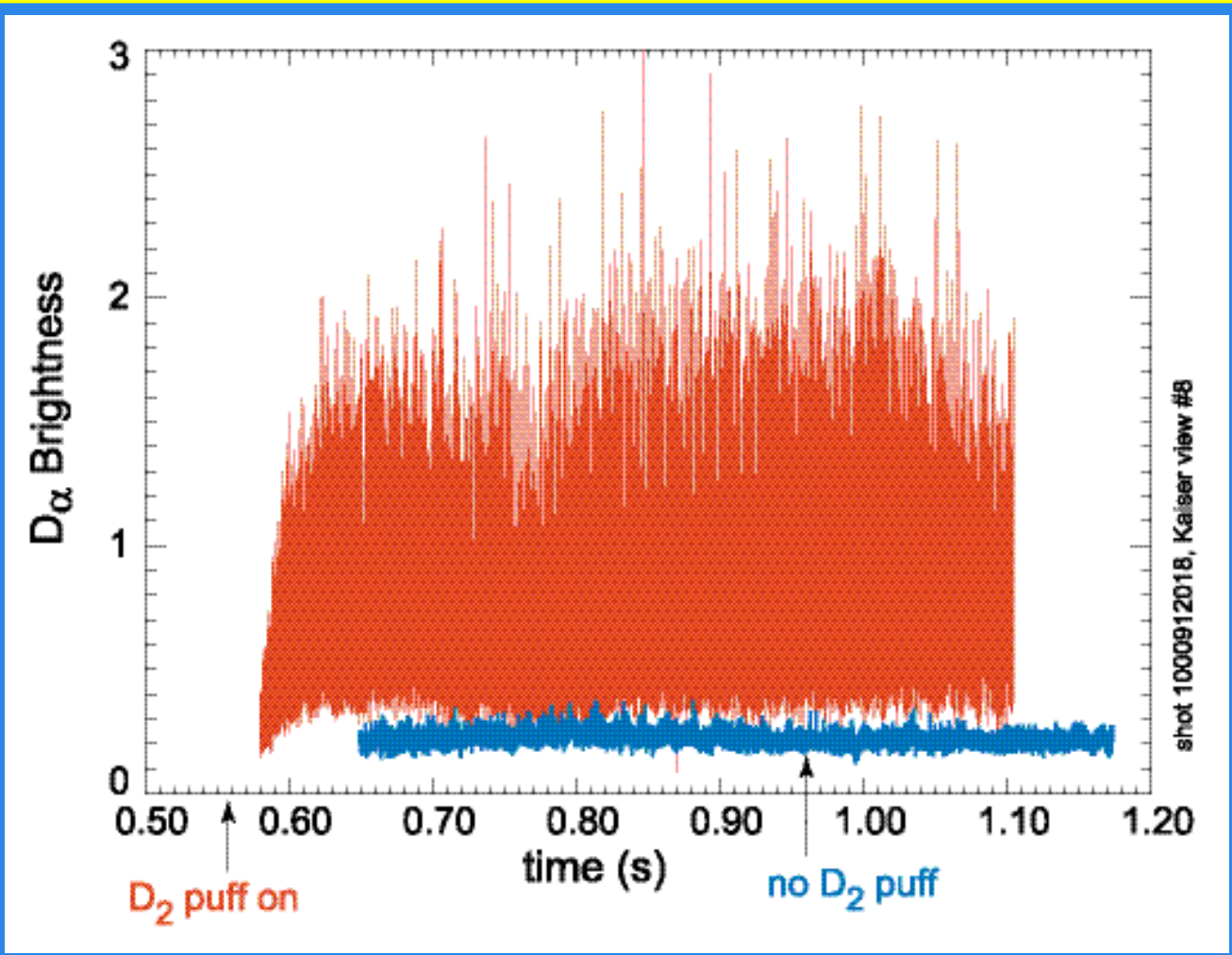
Bursty Transport in SOL & Divertor Complicate Diagnostic Interpretation



Terry et al., Transport Task Force Meeting (2001)

New Plasma Models Could Explain Simulation Discrepancies

- C-Mod experiments show neutrals fueling core coming from main chamber,
  - Not from divertor as in standard picture.
- Broad profiles inconsistent with usual exponential falloff,
  - Þ SOL models need to modified.
  - Could explain D_a profile.
- Provide additional neutral source in divertor?
- Plasma plugging of bypass & leakage?

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Conclusions

- Low neutral pressures & D_a Þ deficiencies in physics model.
- Identified possible areas of improvement:
  - Surface physics needs further validation,
  - Add radiation trapping,
  - And ro-vibrationally excited molecules.
- Biggest problems appear to be with plasma model,
  - Experiments underway to better understand SOL transport.

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