AMPERE

Advanced **M**aterials for **P**lasma-**E**xposed **R**obust **E**lectrodes

GAMOW Kickoff Meeting
January 21–22, 2021

Prof. Richard Wirz, UCLA, PI
Prof. Troy Carter, UCLA, Co-I

Team members and roles

UCLA

- Prof. Richard Wirz – PI
  - Director, Plasma & Space Propulsion Lab

- Prof. Troy Carter – Co-I
  - Director, Basic Plasma Science Facility

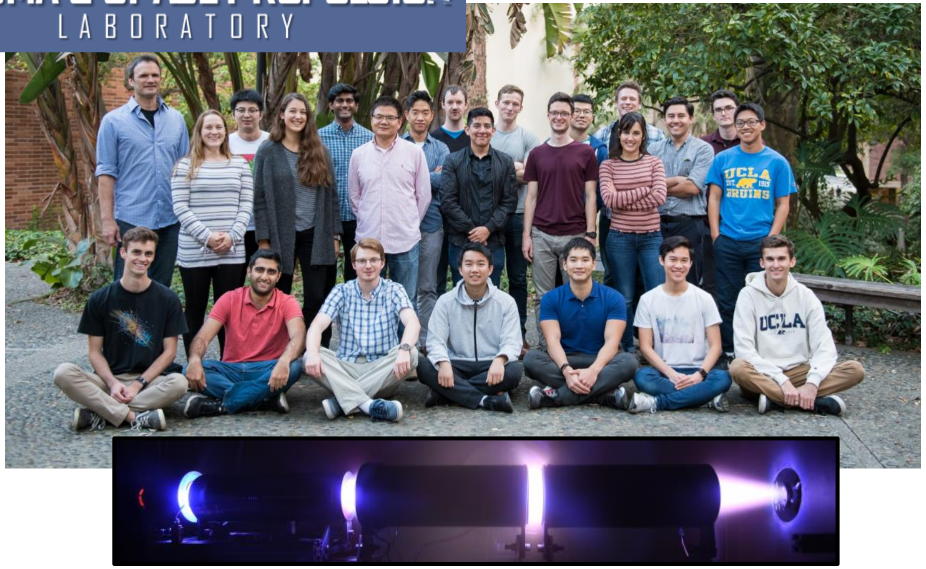
- Dr. Pablo Guerrero
  - PMI experiments and modeling

- Angelica Ottaviano
  - PMI for complex surfaces

- Anirudh Thuppul
  - Plasma analysis

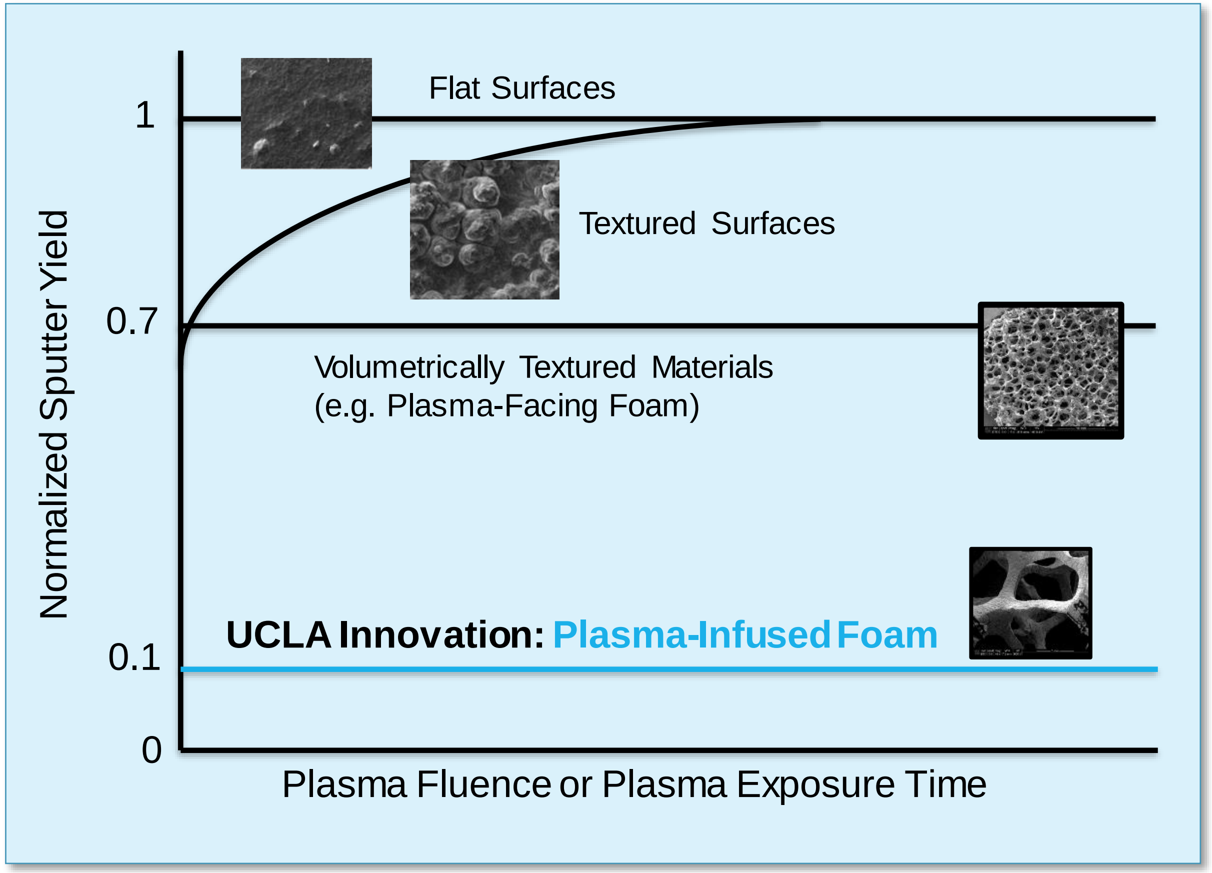
- Mary Konopliv
  - Advanced diagnostics

PLASMA & SPACE PROPULSION LABORATORY



UCLA Basic Plasma Science Facility

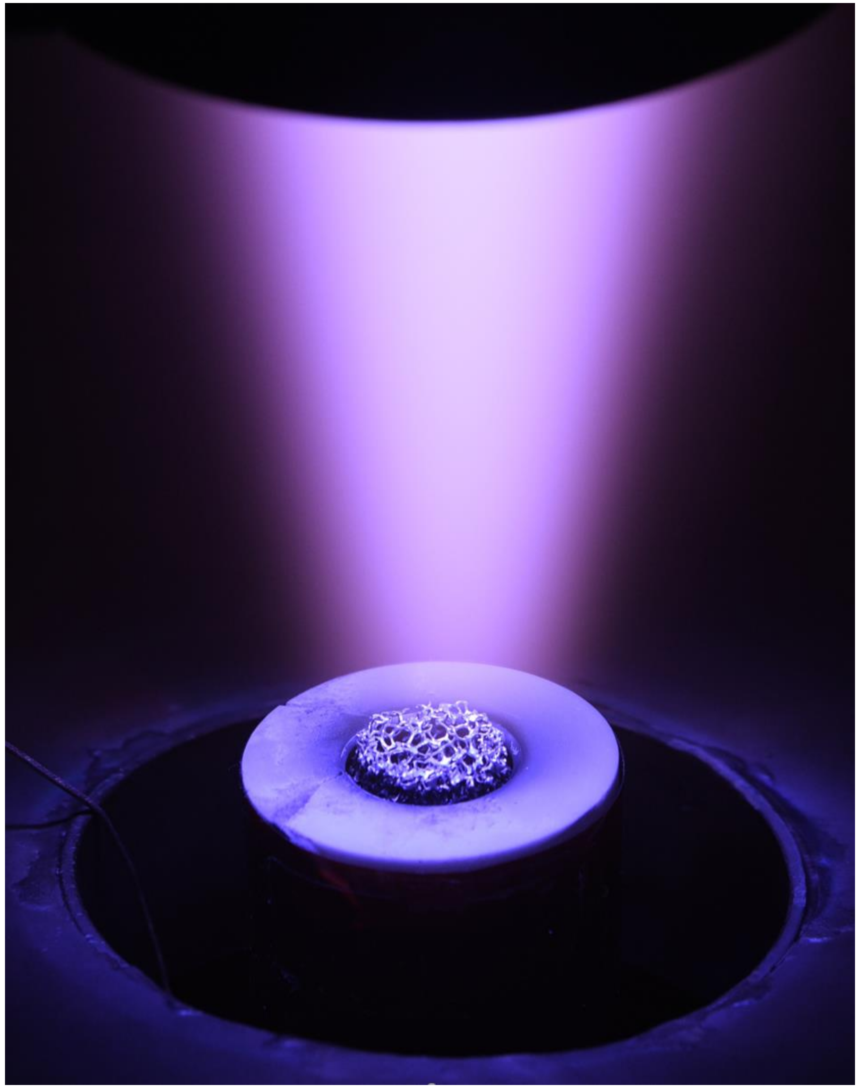
Goal: Next generation of plasma-resilient/favorable materials



Li G., Wirz R.E., "Persistent Sputtering Yield Reduction in Plasma-Infused Foams," *Physical Review Letters*, 2021

- **Motivation**:
  - Current fusion grade plasma-facing materials carry a significant annual cost and are not plasma-favorable
  - Textured surfaces can reduce sputter yield temporarily
- **Discovery/Innovation**:
  - Volumetrically-architectured materials provide persistent sputter reduction
  - Further and significant reduction is found by designing these materials to allow plasma-infusion
- **Goals**:
  - Develop the next generation plasma-resilient/favorable materials that persistently reduce sputter for fusion devices:
    1. Demonstrate plasma-favorable materials by significant reduction (up to 80-90%) of plasma-contaminating sputterants
    2. Reduce operational cost by increasing the lifetime (5X steady to 10X pulsed over SOTA) of critical fusion components

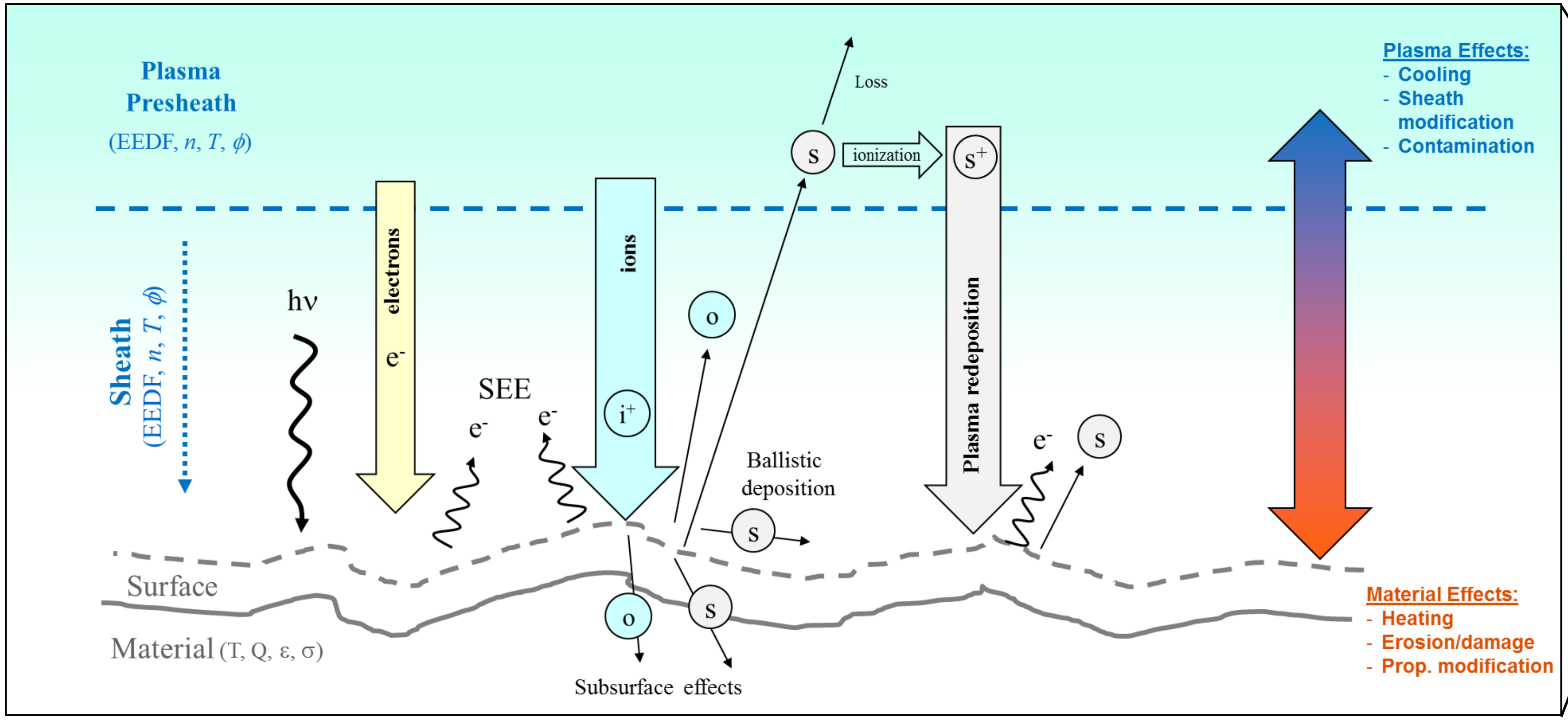
Major tasks, milestones, risks, and desired project outcomes



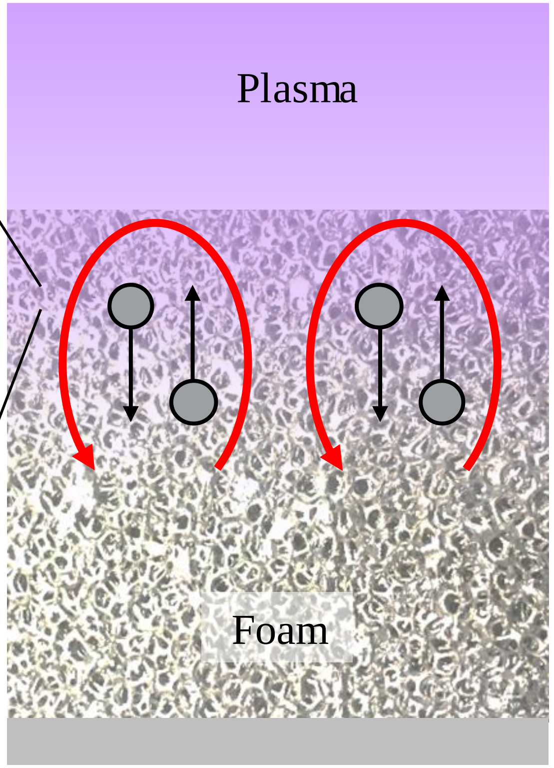
- **Objective**
  - Demonstrate multi-phase foams (MPF) that provide persistent sputter reduction up to 80-90%
- **Approach**
  - Use experiments and validated models to iteratively design, test, and demonstrate the MPF design
- **Major tasks and milestones**
  - Year 1
    - Critical MPF experiments to validate design models.
    - Design and manufacture MPF materials to capture the fusion-relevant design space.
  - Year 2
    - High-flux and high-fluence MPF testing and demonstration
    - Heat Flux: 1-5 MW/m^2 steady, 100-300 MW/m^2 pulsed
    - Targets
      - Total Charge Fluence: 0.9-9 x 10^{12} C/m^2
      - Fusion electrodes: 10^{8-9} C (Pulsed), 10^{10} C (Steady)

Plasma Material Interactions and Plasma-Infusion

Traditional PMI



Plasma-Infused Surfaces



T2M and follow-on plans

▸ Techno-economic targets

– Pursue ambitious targets in plasma-facing components and electrodes performance

– Improve heat flux, life, total charge flux, and O&M maintenance

Table 1: State of the Art (SOTA) and Technical Performance Targets [12, 15, 18–22]

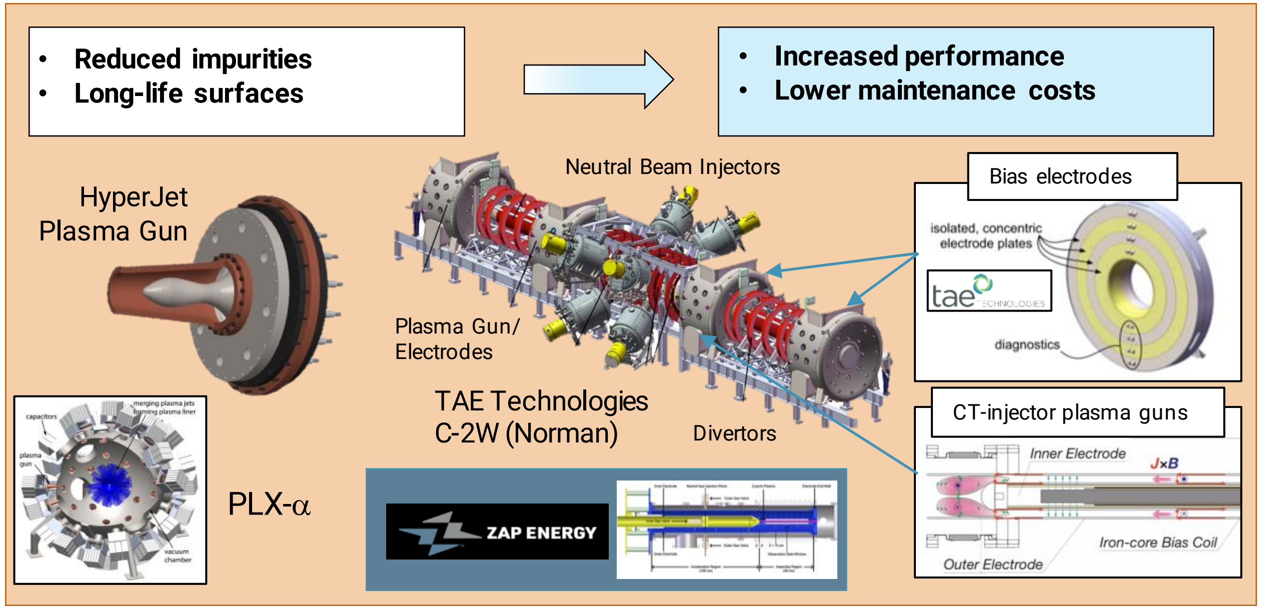
Metric	SOTA Values		Commercial Targets		Project Targets	
	Steady	Pulsed	Steady	Pulsed	Steady	Pulsed
Heat Flux (MW/m^2)	0.5 – 0.75	10 – 100	2 – 10	300 – 7000	1 – 5	100 – 300
Current Density (MA/m^2)	0.1 – 1	2 – 500	0.1 – 1	2 – 500	0.1 – 1	2 – 500
Duty Cycle	1	$10^{-7} - 10^{-3}$	1	$10^{-5} - 10^{-2}$	1	$10^{-7} - 10^{-3}$
Total Life (hours)	500	0.023 – 0.23	8,750	0.875 – 8.75	2,500	0.25 – 2.5
Total Charge Fluence (C/m^2)	$0.18 - 1.8 \times 10^{12}$		$1.6 - 31 \times 10^{12}$		$0.9 - 9 \times 10^{12}$	
Annual Cost of Maintenance	$19-155k	$0.28-2.2M	~$50k		**$6.5-43.2k**	

▸ Test & deployment plans

– Engage commercial fusion partners during MPF development
  - Ensure MPF will improve life and performance for critical and challenging fusion surfaces
  - Assess cost benefits from both life and performance with customer input

– Applications (Customers) include:
  - Z-pinch electrodes (Zap Energy)
  - Plasma guns/injectors (General Fusion, HyperJet, TAE)
  - Bias electrodes (TAE)
  - Divertors (Commonwealth Fusion)

– Develop electrode and surface designs by end of Year 2 for Year 3+ deployment to customers



BONUS SLIDES

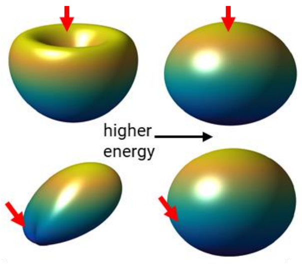
AMPERE: Computational Modeling

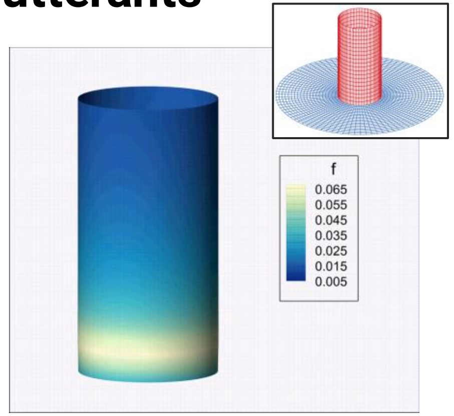
SPICY Suite: Surface Particle Interaction Codes with Yield

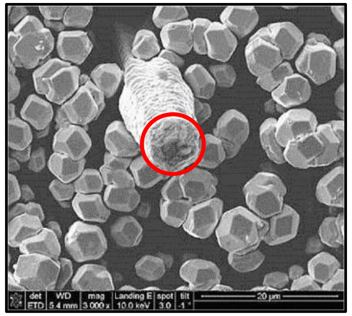
Theory + Mesh Geometries + MC Simulations + View Factor Modeling

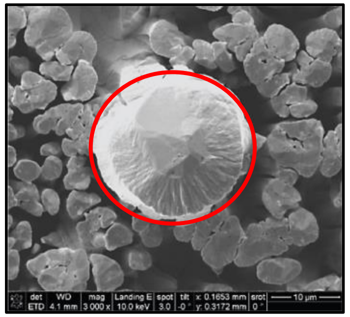
Ions and Sputterants

Sputtering angular distribution









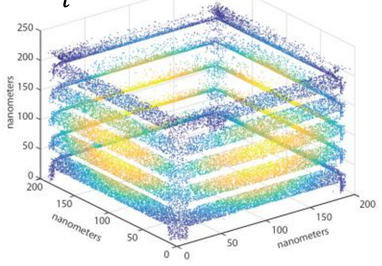
Pre-burn Φ8.5μm

Post-burn Φ21.7μm

Electrons

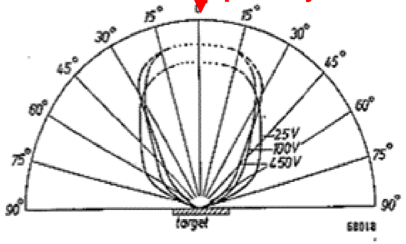
Collision Heatmap

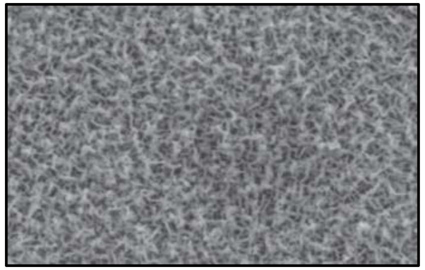
$\theta_i = 0°$



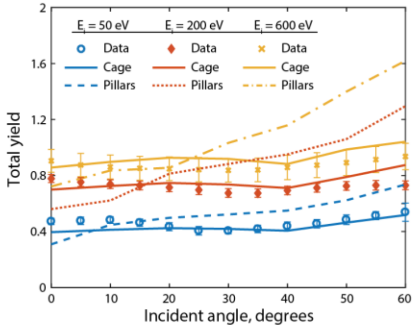
Angular Distribution of SEs

primary beam





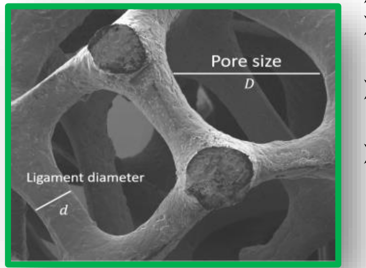
Cage Geometry
~ foam structures
~ fuzz surfaces



AMPS: Analytical Model for Plasma Sputtering

$$\frac{Y_{eff}}{Y_{flat}} = \frac{2d}{D} f_A(\xi) f_\beta(E,\xi) + \frac{2d}{D} f_A(\xi) f_\beta(E,\xi)\left[1 - f_{dep}^{(2)}\left(\frac{d}{D}\right)\right] + \cdots$$

Foam Dimensions



- Realistic foam geometry
- Assumes ballistic deposition
- Sputter theory incorporated
- Accounts for plasma-infused and plasma facing case

Effective Sputtering Area

Effective Sputtering Area
Plasma-infused ($\xi > 1$) $f_A = \pi,\ f_\beta = 0.5$
Plasma-facing ($\xi \ll 1$) $f_A = 1,\ f_\beta =$ plot

Ballistic Deposition