

An Integrated Approach to Understanding Electric Breakdown

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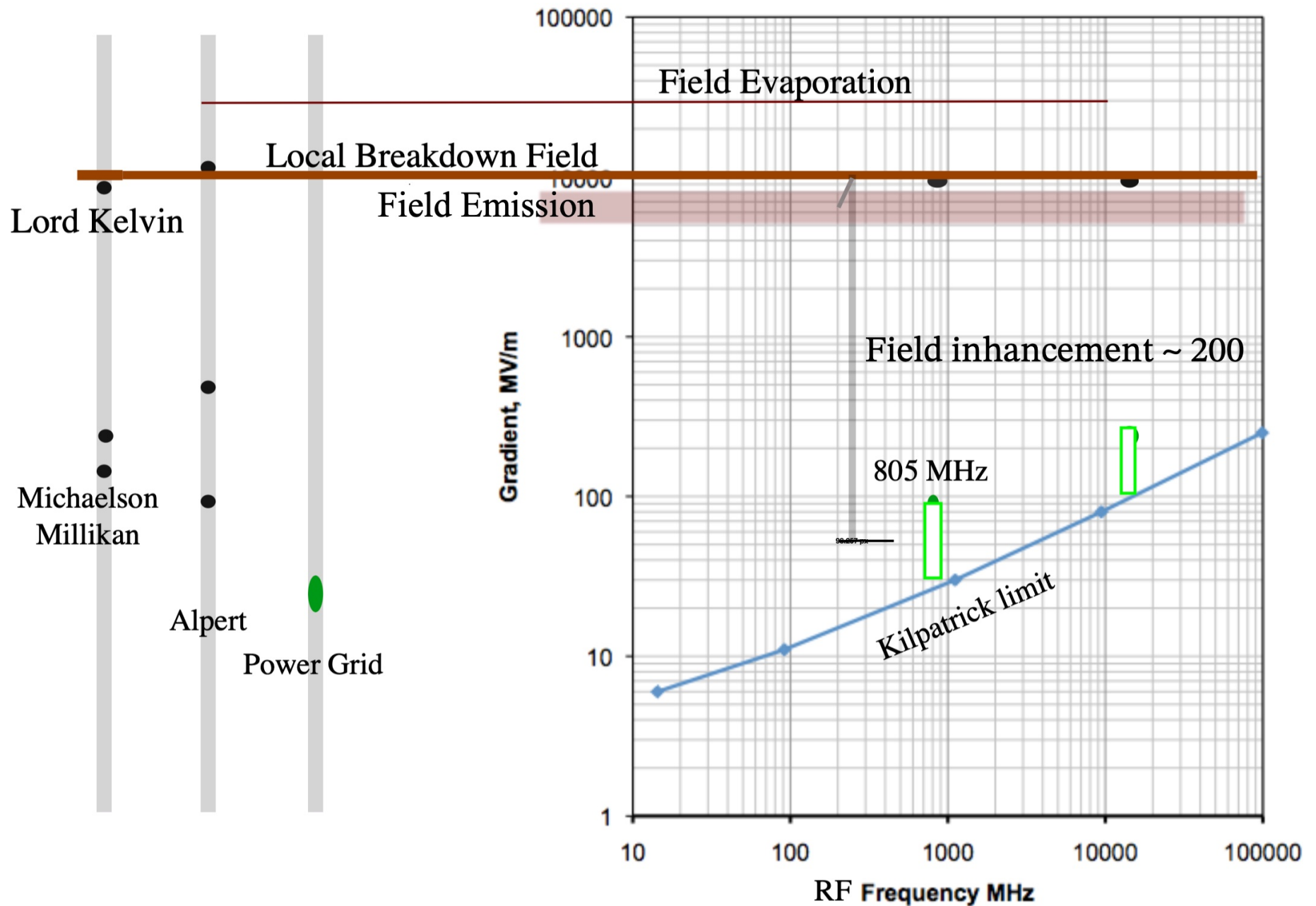
Because of the size, speed, unpredictability and low power, arc triggers can be undetectable. This complicates modeling.

Modeling done with Ahmed Hassanein and Zeke Insepov at, and after, Argonne.

Data comes from the Muon Accelerator Program at Fermilab.

Breakdown modeling involves the evolution of asperities at high fields.

1: RF Accelerator designs are constrained by gradient limits.



2: Arcing produces Tokamak power losses and stability problems.

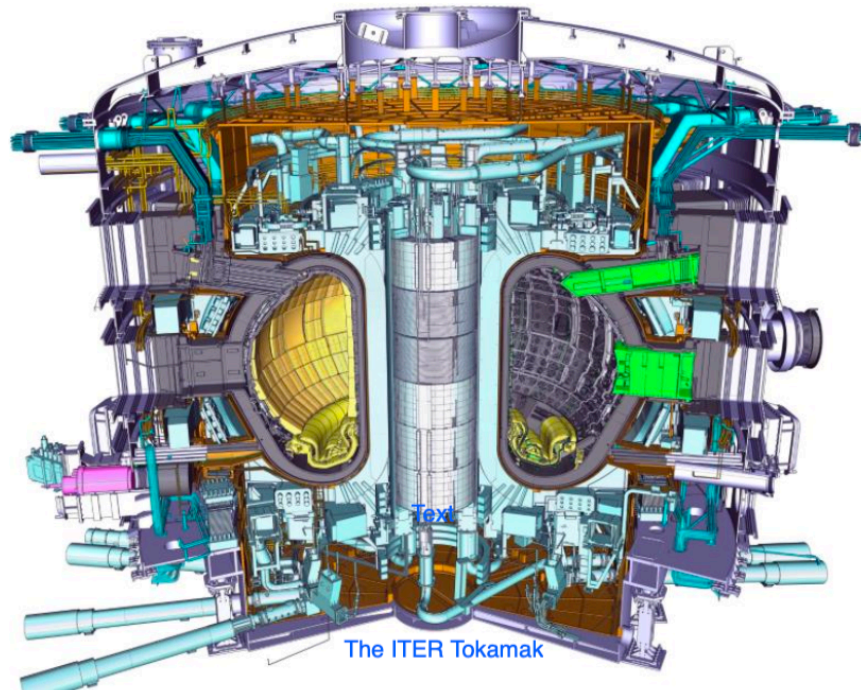
Unipolar arcs on walls harmless in small devices, but real trouble in large ones.

Arcing produces current disruptions

Runaway electrons are produced during disruptions

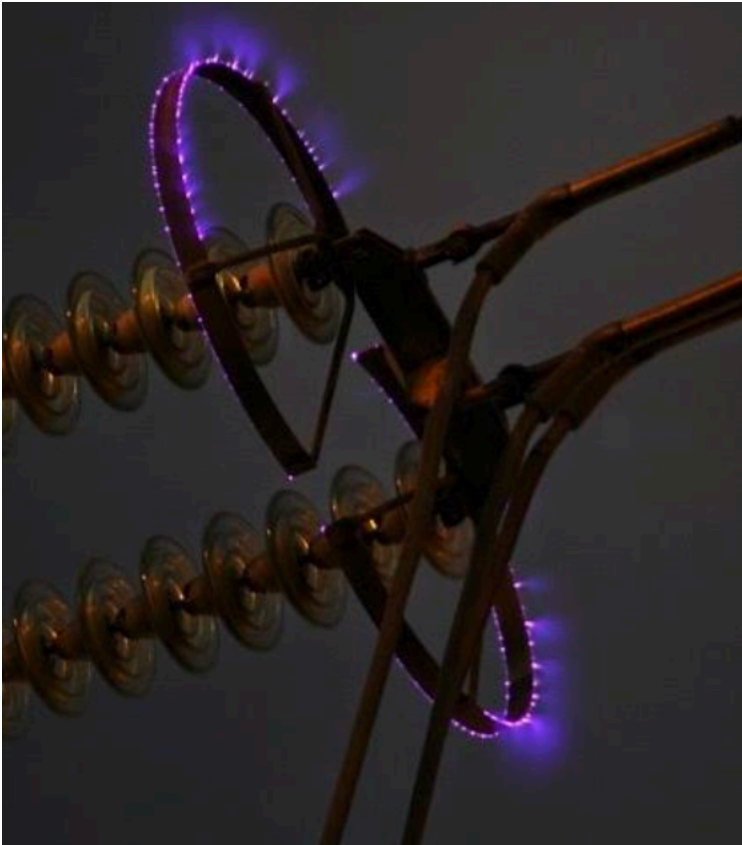
Runaways damage the vacuum system

Runaways must be suppressed in ITER



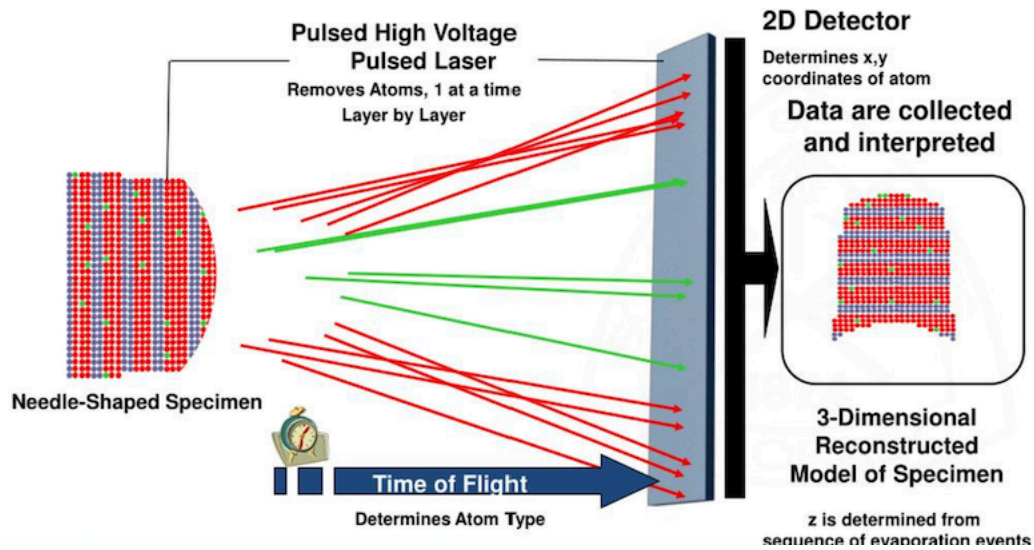
3: **Power Grid**; Arcing reduces V_{\max} , Power and efficiency.

Arcing on wires limits voltage, primarily in bad weather

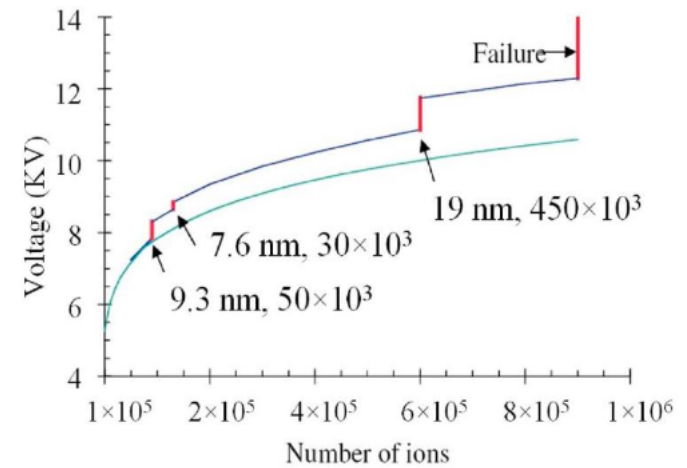


Zeke Insepov has continued this effort with experiments designed to increase the operating voltage of power lines and has published some of his results.

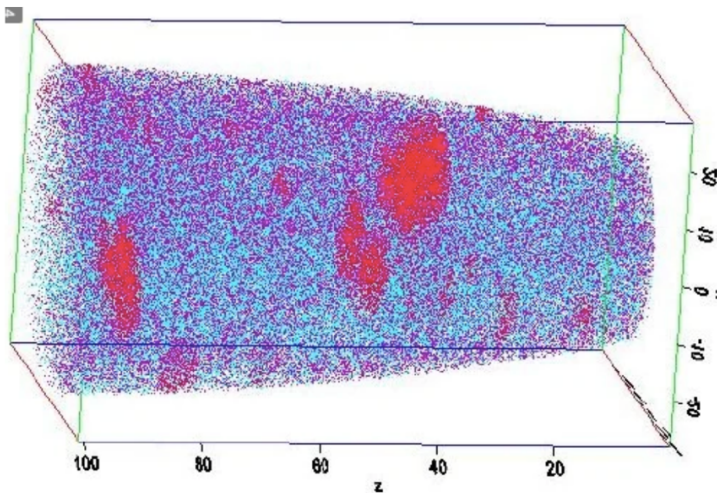
4: Atom Probe Tomography samples sometimes self-destruct.



Fragment production



Amazing 3D images of millions of atoms when it works.



APT areas $\sim 10^{-14} \text{ m}^2$, ion milled

Cavity areas $\sim 10^{-2} \text{ m}^2$, lathe cut

The physics of arc triggers may be accessible.

The trigger for arcing could be similar to "flashing" in these systems.

"Flashing" occurs in Atom Probe systems when the sample seems to explode.

The damage can be total or partial.

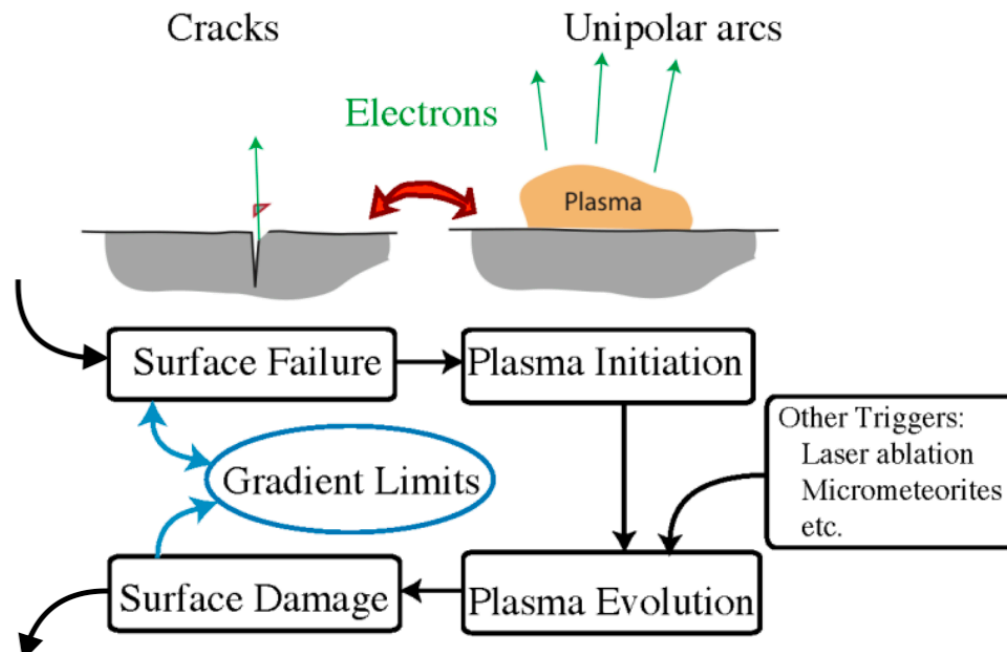
It requires high fields, as would be present at sharp corners.

Easy to study in Atom Probe systems, but David Seidman, NW U, said all this data is systematically flushed.

Our modeling has evolved and converged.

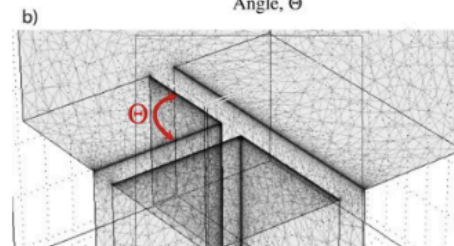
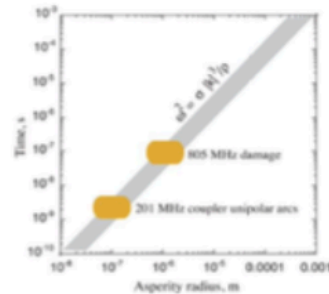
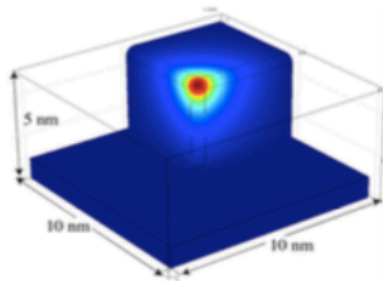
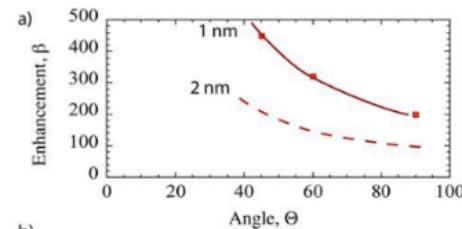
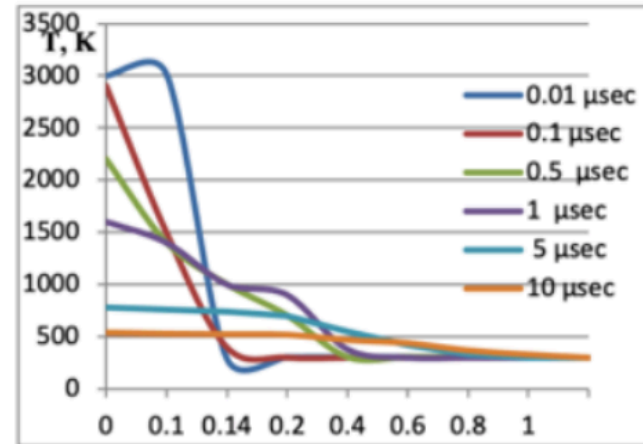
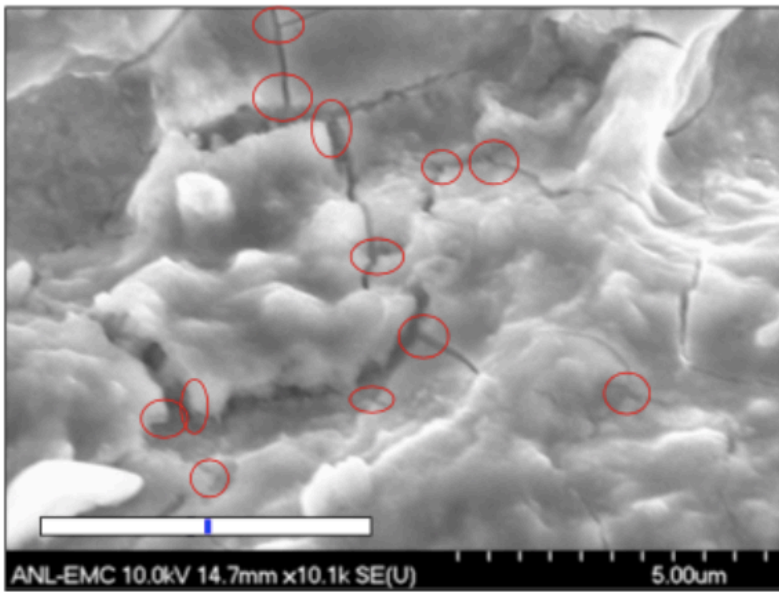
The model divides the breakdown process into four stages.

1. Fracture at cracks can initiate the arc
2. A local ion cloud increases surface fields, field emission and plasma density
3. The unipolar arc produced is "essentially stable", but subject to B fields
4. Surface tension and thermal contraction dominate surface damage.



Surface Damage after Quench

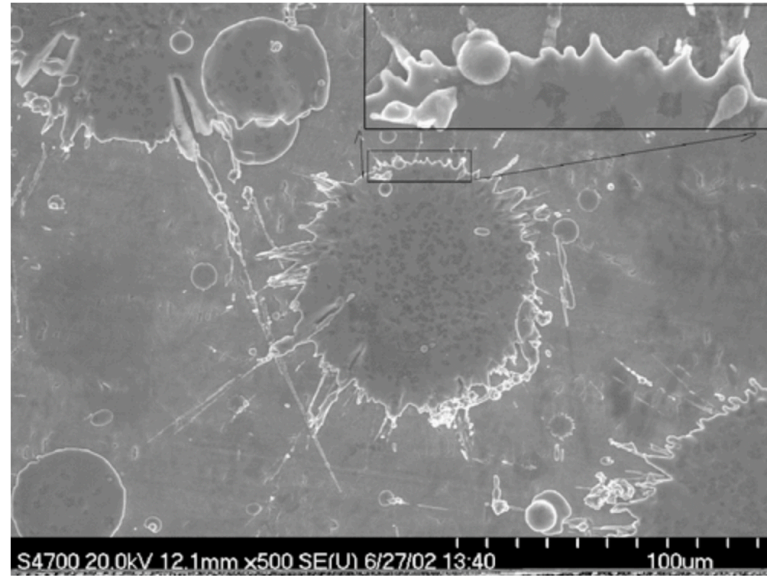
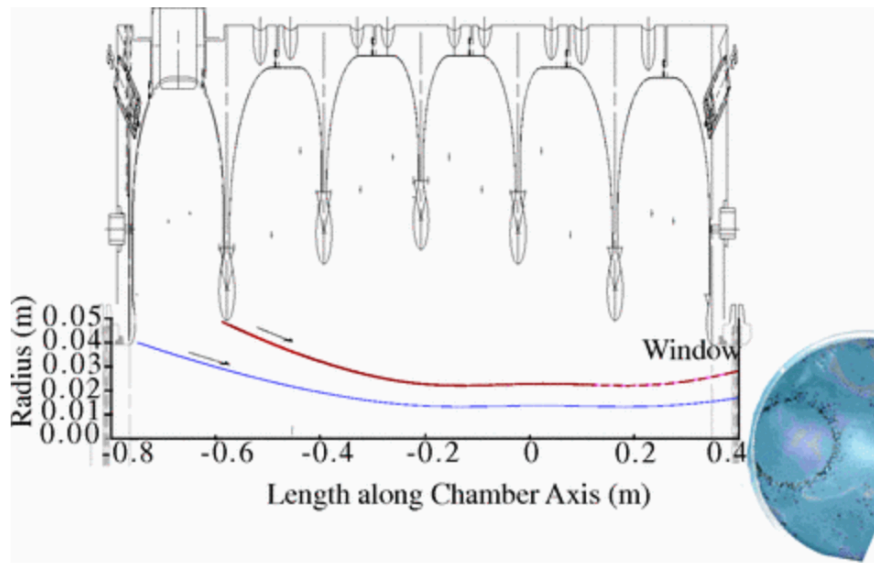
The dominant mechanism in plasma damage seems to be damped capillary waves, driven by surface tension, smoothing the surface. Differential cooling can produce surface cracking with high β s at rectangular corners (Feynman Lectures II, 6.11).



β at crack junctions

$\sim 10^{-14}$ sec thermal decay for nm structures

We've seen evidence for flying liquid drops on a cavity window.



Note that the liquid metal drops seem to be transmitted the length of the cavity along field lines, to image the iris on the window. This implies that the drops must be highly charged to be pinned to magnetic field lines.

When disassembled, the cavity showed deposits of copper powder in the individual cells.

Drops could be produced by electrostatic pulling, surface tension cutting surface.

Surface tension rapidly smooths structures seen in SEM images.

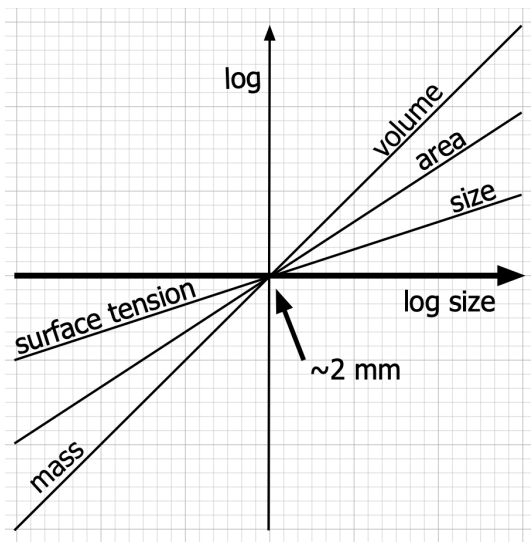
Surface tension: Copper ~ 1.1 N/m, water ~ 0.07 N/m. (\sim density)

Surface tension forces depend on dimensions

Pressures depend on dimensions²

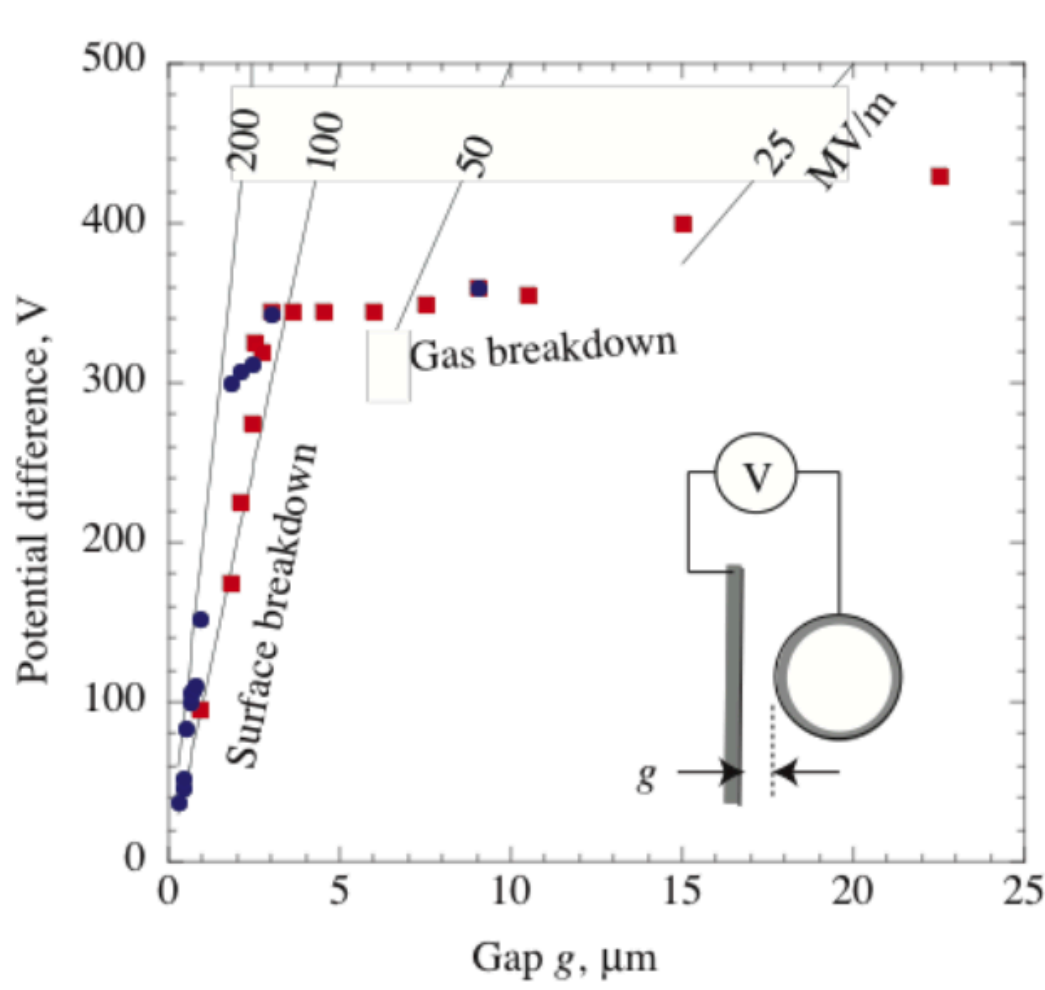
Masses depend on dimensions³

Motion can be fast for small structures, $a = F/m = 1/\text{dimensions}^n$



More data would be useful for understanding the arc trigger.

Michelson looked at single events, this should continue.



We see no evidence for hairlike asperities required for European BD models.