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Sandia National Laboratories

Particle-in-cell modeling of the Saturn accelerator vacuum section

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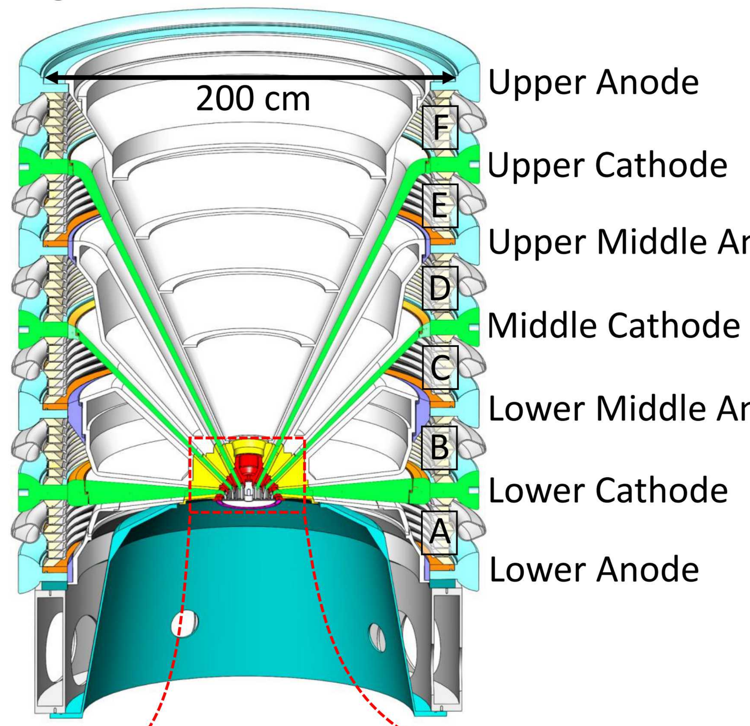
The Saturn accelerator

- Saturn is a low impedance, very high current, short pulse accelerator
- Nominally 10 MA, 1.6 MV, 40 ns power pulse

Figure 1. Saturn's vacuum stack



- Saturn has 5 anodes and 3 cathodes forming 6 vacuum magnetically-insulated transmission lines (MITLs)
- MITLs are labeled with letters starting with A level on the bottom through F level on the top
- The current driving each cathode is setup such that the ratio between the outer/middle/inner cathodes is 1/2 : 1/3 : 1/6

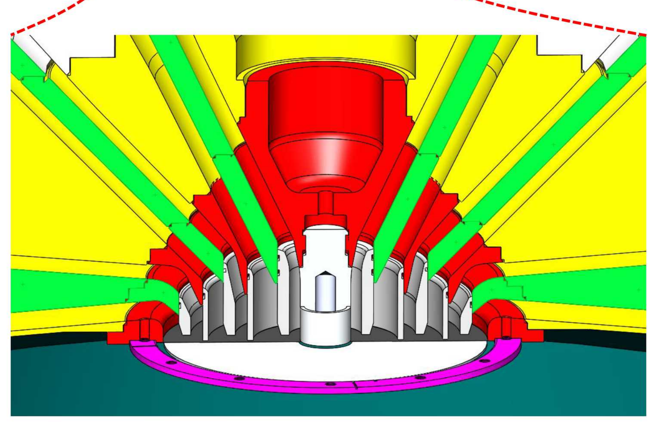


Figure 2. 3-ring pinched beam diode

- Saturn drives a variety of loads but the baseline configuration is the 3-ring pinched beam diode bremsstrahlung x-ray source
- This source is three parallel diodes at different radii to create a large, planar radiation source
- Saturn has also driven reflex triodes, electron and ion beam sources as well as plasma radiation sources

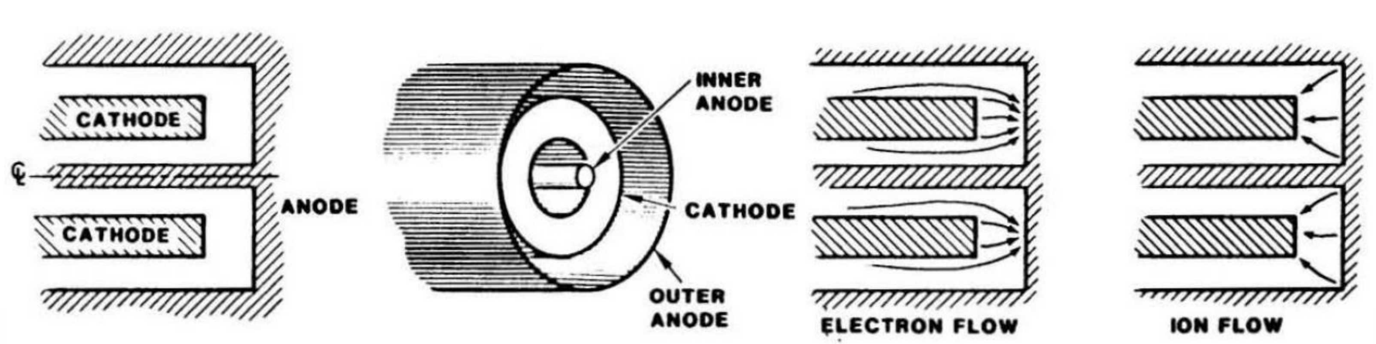


Figure 3*. Each of the 3 pinched beam ring diodes operates independently

* Figure from SAND85-2585

Motivation

- Saturn, which began operations in 1987, is presently undergoing a recapitalization effort to ensure its continuing performance over the coming decades
- Some components, such as the vacuum stack and MITLs are being redesigned
- We desire a solid understanding of the present operating parameters using a combination of experiments, circuit modeling and particle-in-cell simulations to inform the new design

Particle-in-cell code setup

- We are using the Chicago PIC code which is the next iteration of the Large Scale Plasma (LSP) code from Voss Scientific LLC
- Driving waveforms were created using a Bertha circuit simulation matching to transmission line monitors since Saturn has no reliable vacuum stack monitors
- The geometry was 2-D axisymmetric with 1.1 million cells; runs took about 6 days using 8 cores on a dedicated Intel i7 laptop

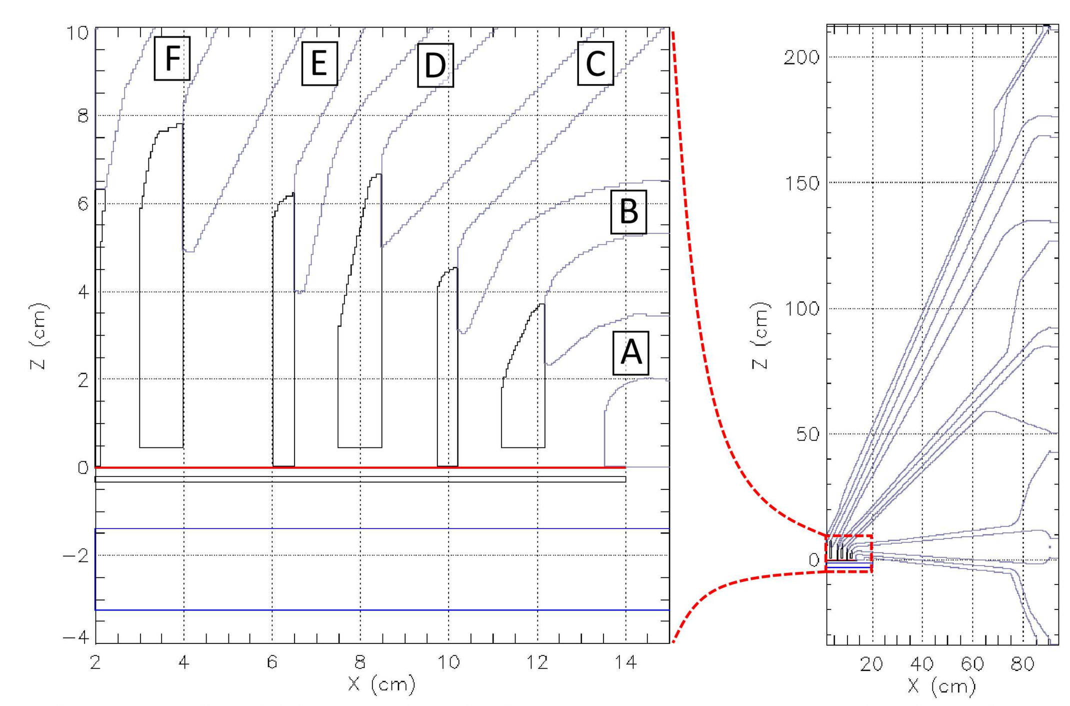


Figure 5. The Chicago simulation geometry was meshed and simulated out to the vacuum insulator with enhanced gridding near the cathode tips

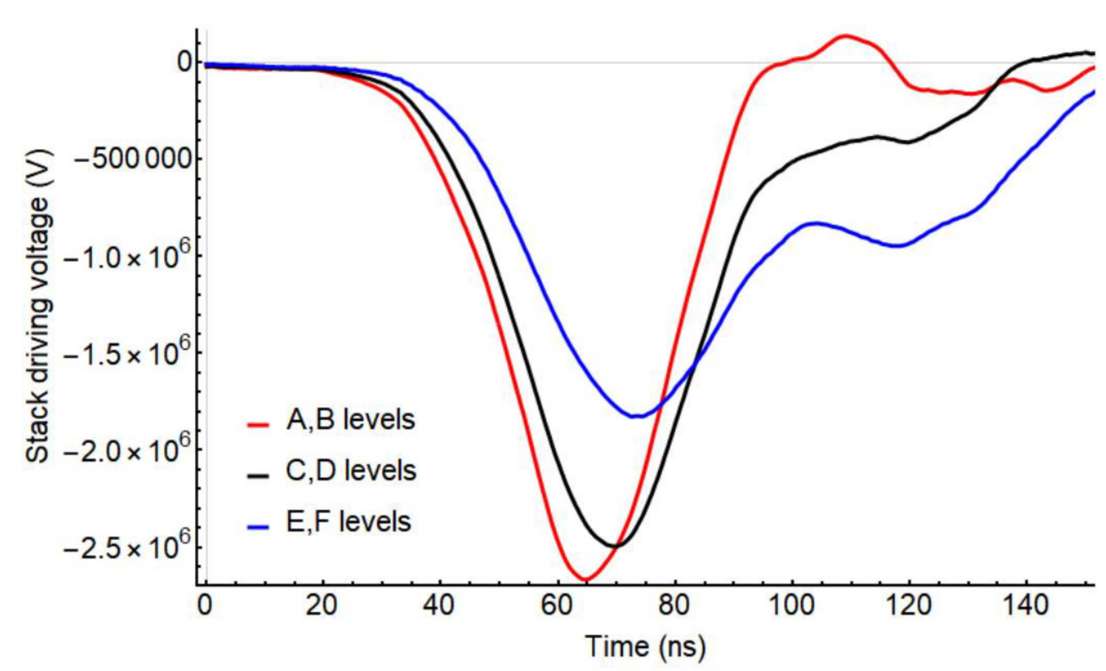


Figure 4. Waveforms used to drive the simulation

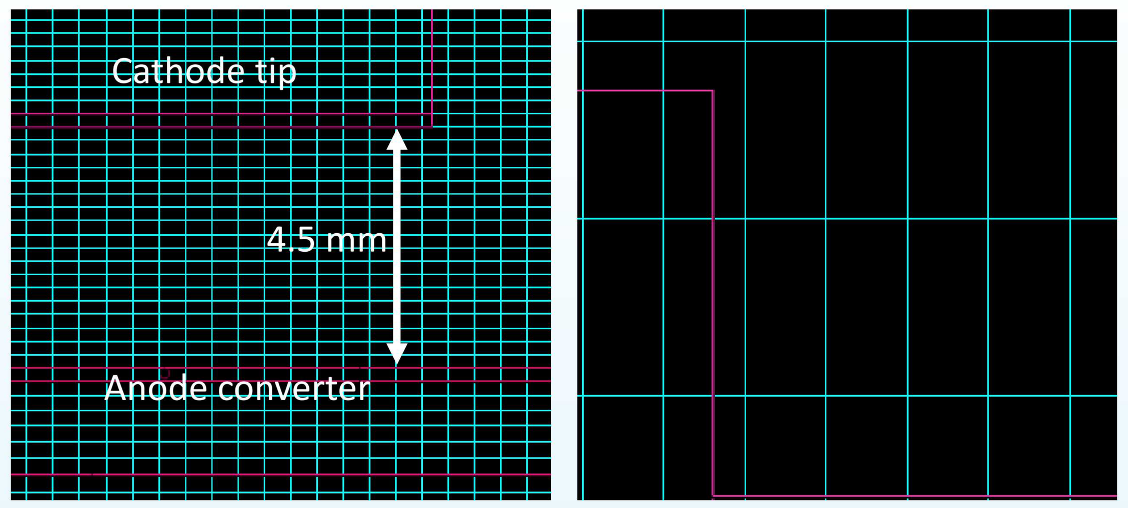


Figure 5. Variable grid spacing, very small near the cathode tip gaps (left) and large at large radius near the vacuum insulator stack (right). The scale is the same on the two images.

Simulation Results

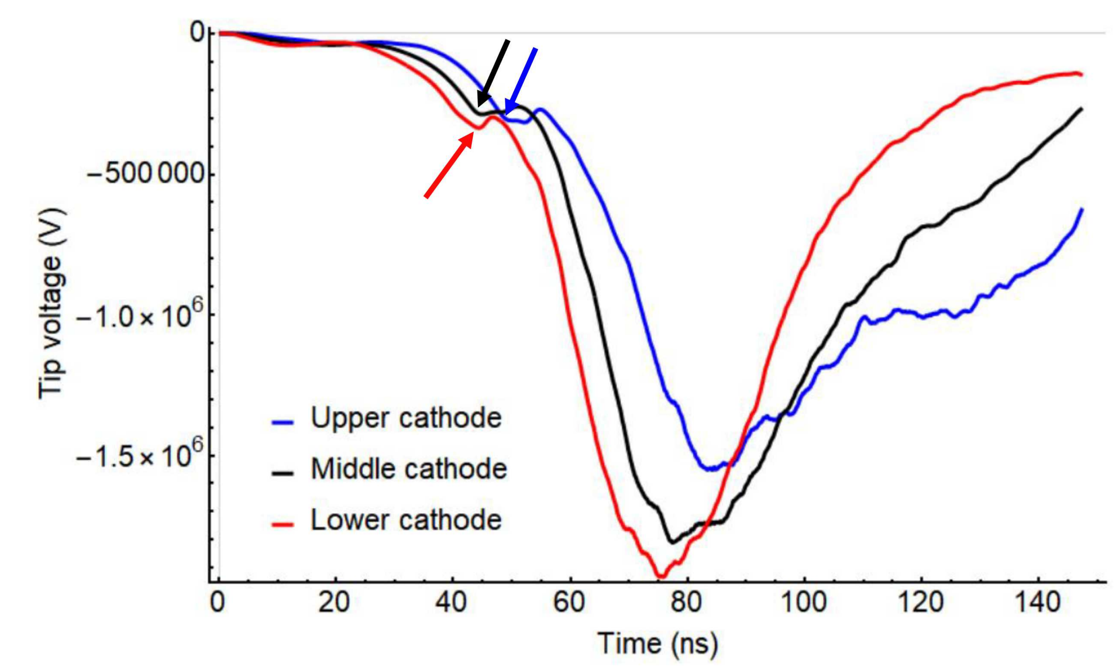


Figure 6. The knees in the curves around 50 ns is an indication of the onset of bipolar flow

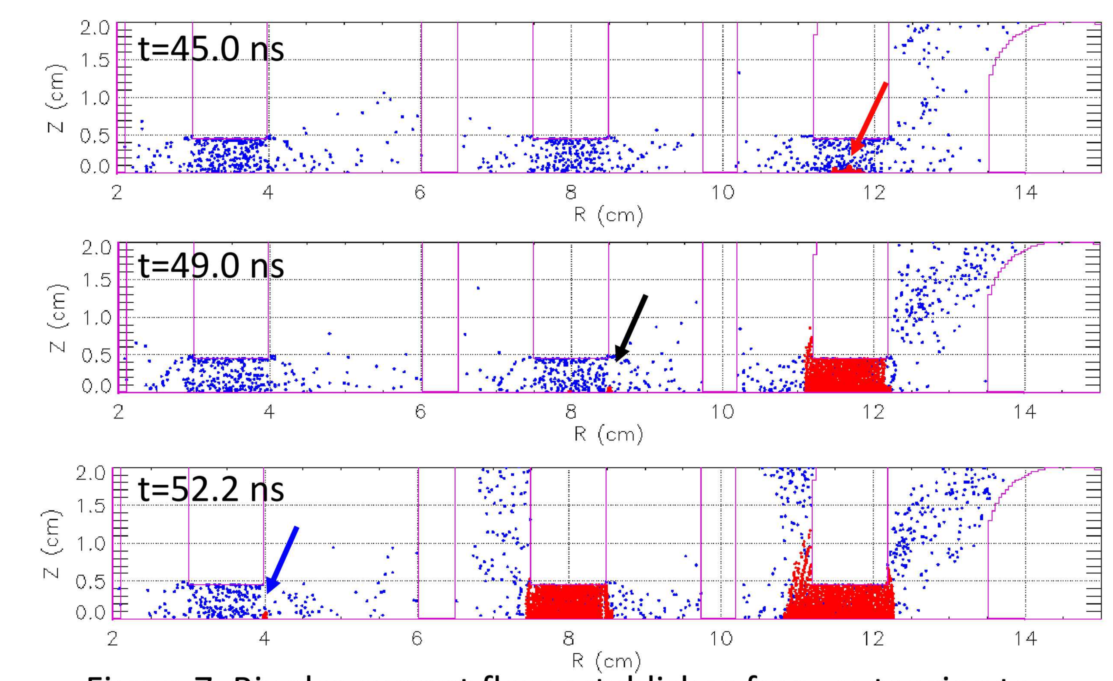


Figure 7. Bipolar current flow establishes from outer ring to inner ring within 7.2 ns. (Ions in red, electrons in blue)

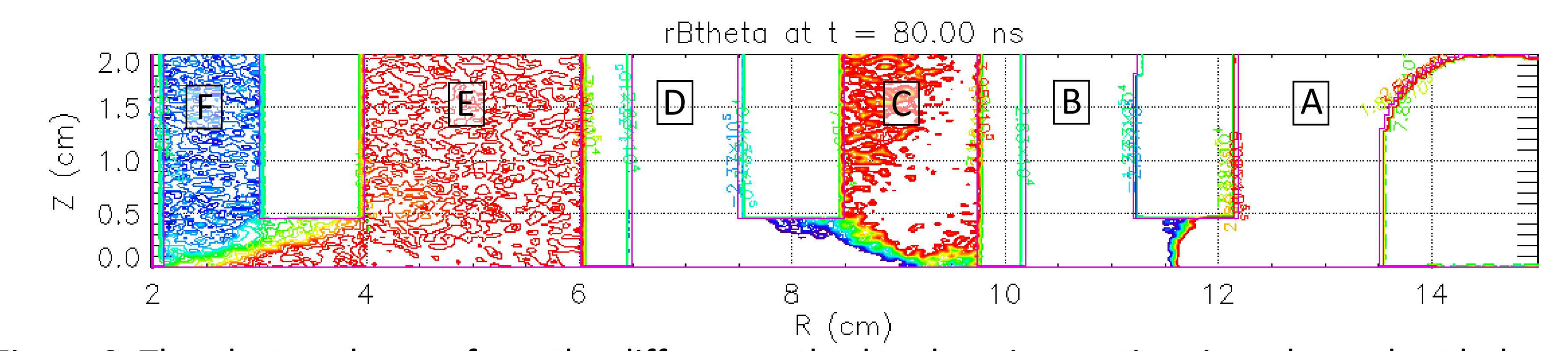


Figure 8. The electron beams from the different cathodes show interesting time-dependent behavior. Electrons beams not pinching in the center of the cathode tip is indicative of inductive imbalance in the MITLs

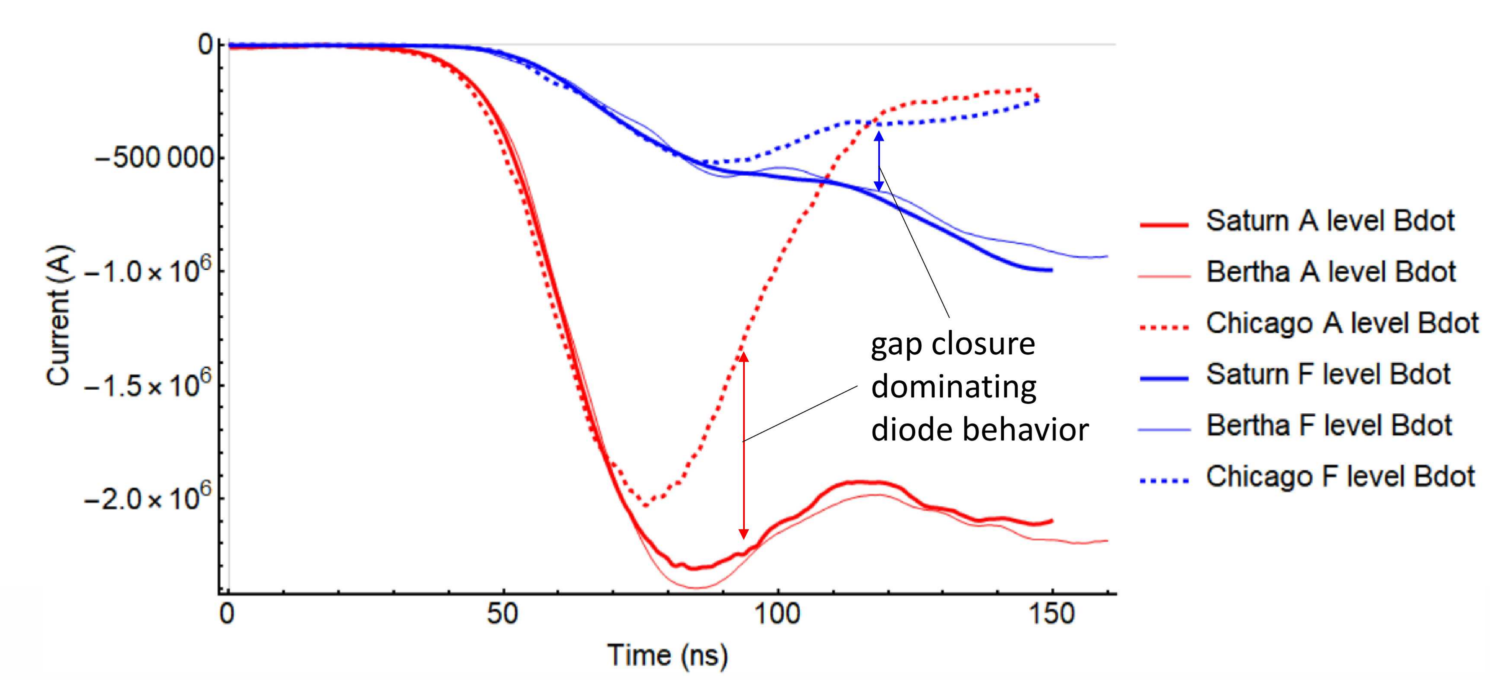


Figure 9. Comparison of Chicago PIC, Bertha circuit simulation, and machine data show good agreement up until the lack of gap closure physics in the Chicago simulation causes it to diverges from the others

- B-dot monitors in the Chicago and Bertha models replicate the physical position in the Saturn A and F level MITLs.
- Bertha simulation uses a pinched beam diode load with gap closure (5 cm/μs) whereas there is no gap closure in the Chicago simulation
- The 3 cathodes operate independently and so the Chicago simulation diverges from Bertha and machine diagnostic data at different times as gap closure begins to dominate the diode physics
- Gap closure causes the diode impedance to collapse therefore the voltage should also collapse while the current should rise. This is seen in the experiment and circuit code

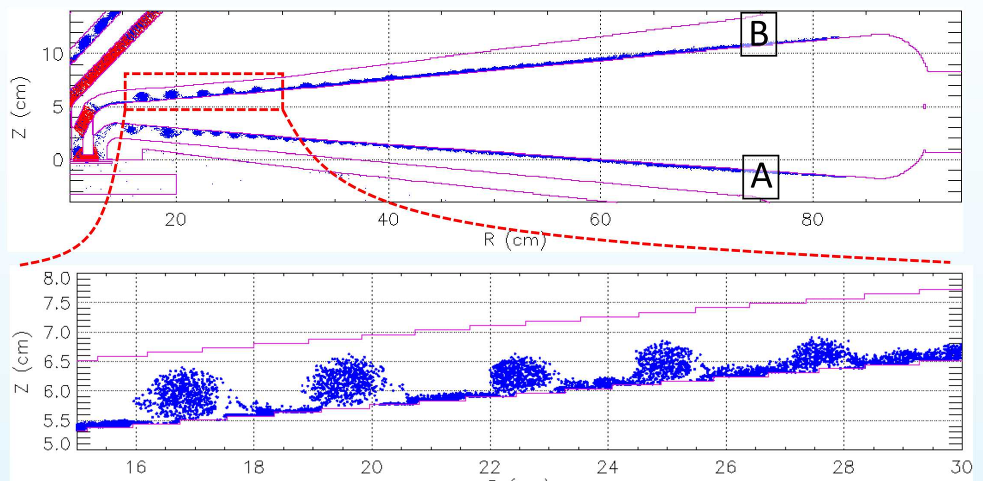


Figure 10. Diocotron instability forms in Saturn's long MITLs

Take-away message

- We can do a reasonable job of simulating the current and voltage of the diode until plasma gap closure becomes dominant
- A gap closure model is necessary to replicate the diode behavior all the way through the power pulse (and more importantly through the radiation pulse)

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