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Wire/Bridge initiation and the MHD approximation…..

What does that mean?
AND why you should care.

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Christopher J. Garasi, Dept. 1443
cjgaras@sandia.gov
(505) 284-2691
Sandia National Laboratories

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Can you simulate detonator physics & performance using an MHD code?

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Problematic Technical Interchange (Garasi & Kennedy)

"We have used ALEGRA-MHD to simulate the electrical initiation of wires; we can study the time-history of wire phase from solid through melt and evolution into the plasma regime. From this we should be able to understand what wire burst is."- C. Garasi

"And then you can follow the formation of the arc generation *through the plasma and capture the resulting drop in resistance and voltage………"* - Jim Kennedy

"The MHD approximation does not cover electrical breakdown." – C. Garasi

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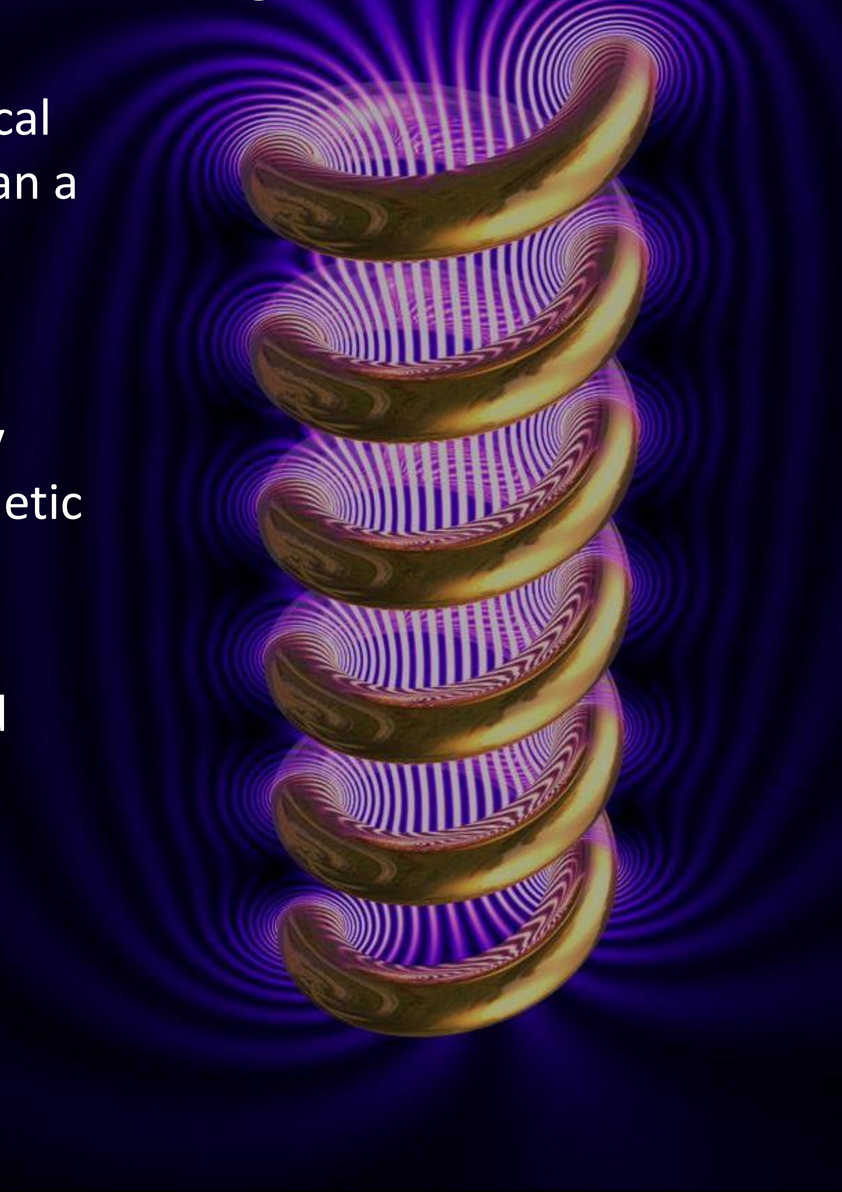
Magnetohydrodynamics (MHD):

Solid / fluid dynamics of an electrically conducting continuous medium.



Continuum approximation:

Represent the material properties using local averages (e.g. pressure, velocity) rather than a statistical distribution representation.

Electrically conducting :

Able to carry electrical current, which may generate and/or interact with electromagnetic fields.

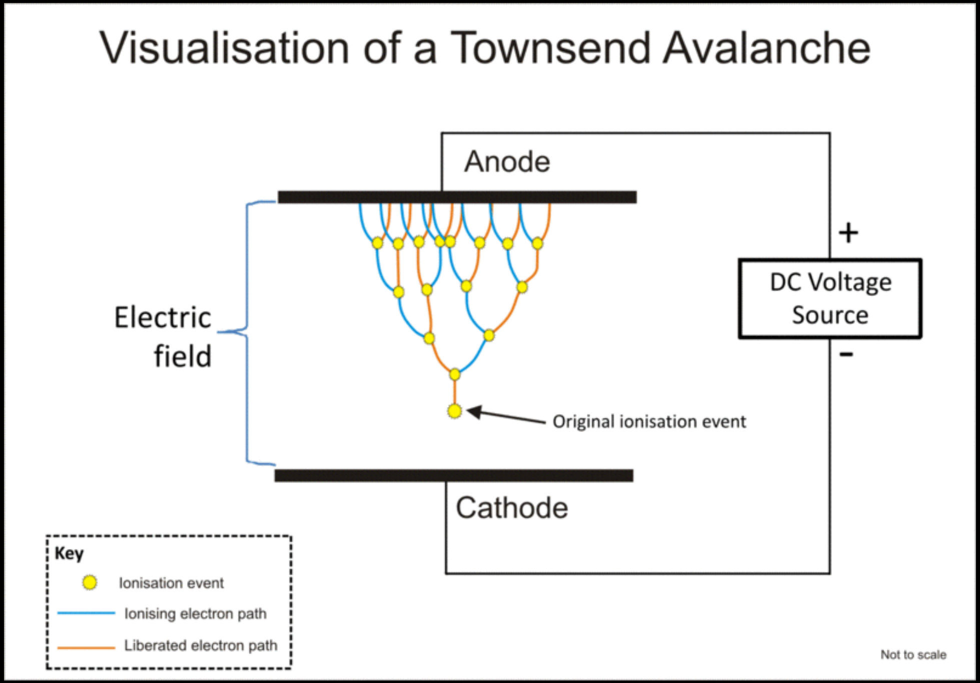
MHD is a **coupling** of electromagnetic and hydrodynamic phenomena.

Phenomena in ideal and resistive MHD:

- Magnetic advection/diffusion
- Resistive heating
- Magnetosonic wave propagation
- Magnetic acceleration

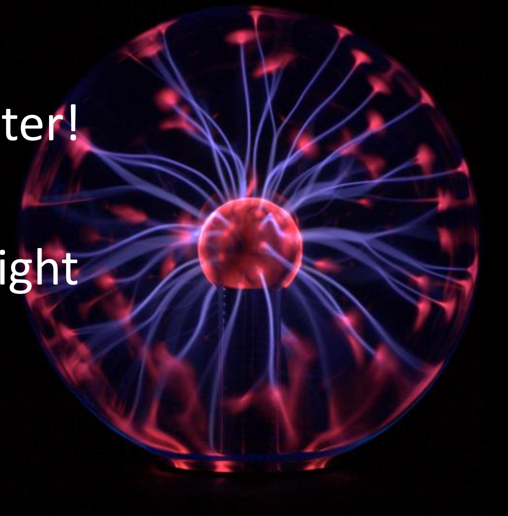
Electrical Discharges (not MHD):

Given a voltage per unit distance (Electric field) an electron will drift toward the anode, gaining energy before it experiences a collision with a gas molecule.



Inelastic collisions can remove a weakly bound electron from an atom (ionization). As current increases via ionization, the ions impact the cathode and liberate additional electrons (can lead to exponential growth).

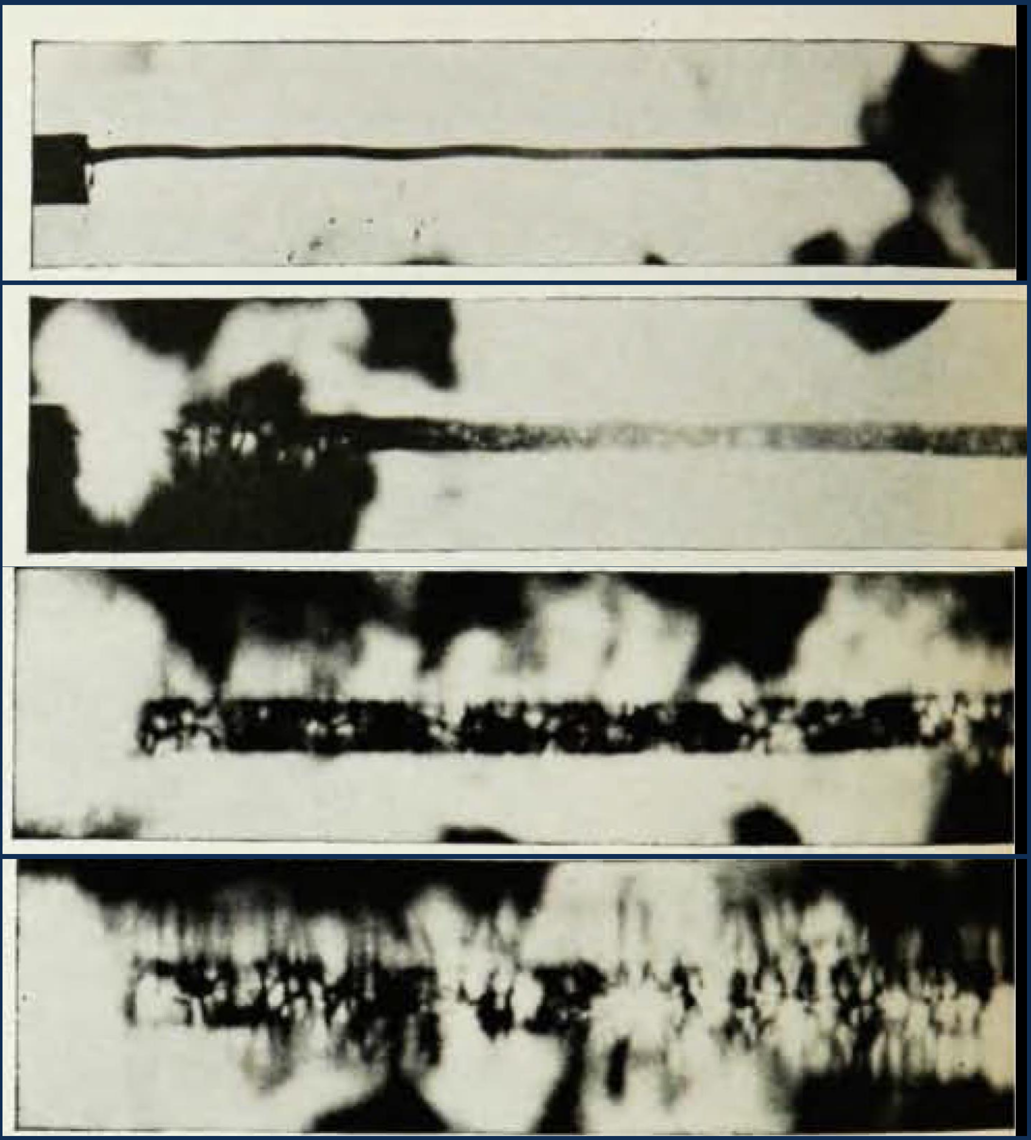
Secondary ionization can cause the current to increase even faster!



This transition (spark) is accompanied by an increase in visible light between the two contacts. The spark is what initiates the “arc”.

Paul G. Slade: *Electrical Contacts: Principles and Applications (1999)*
http://en.wikipedia.org/wiki/File:Electron_avalanche.gif

Chase's view of wire electrical initiation (1959)



The wire is heated by the current, brought to its melting point, and melted (little to no change in shape)

When the boiling point is reached, superheating occurs (surface not activated).

Sudden change from homogeneous liquid to discontinuous structure due to metal vapor bubbles ("transplosion").

Rapid expansion reduces the density, increasing the mean-free-path resulting in ionization by impact hence avalanching occurs ("restrike").

W. G. Chase, Physics Today, Aug. 1964, p. 19
W. G. Chase, Phys. Fluids, 2, 230 (1959)

Behavior of Exploding Wires (Tucker, 1961)

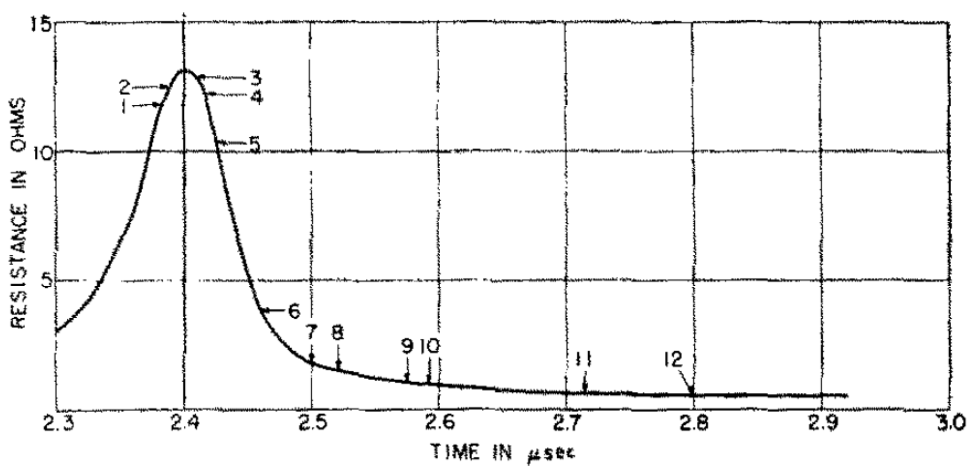
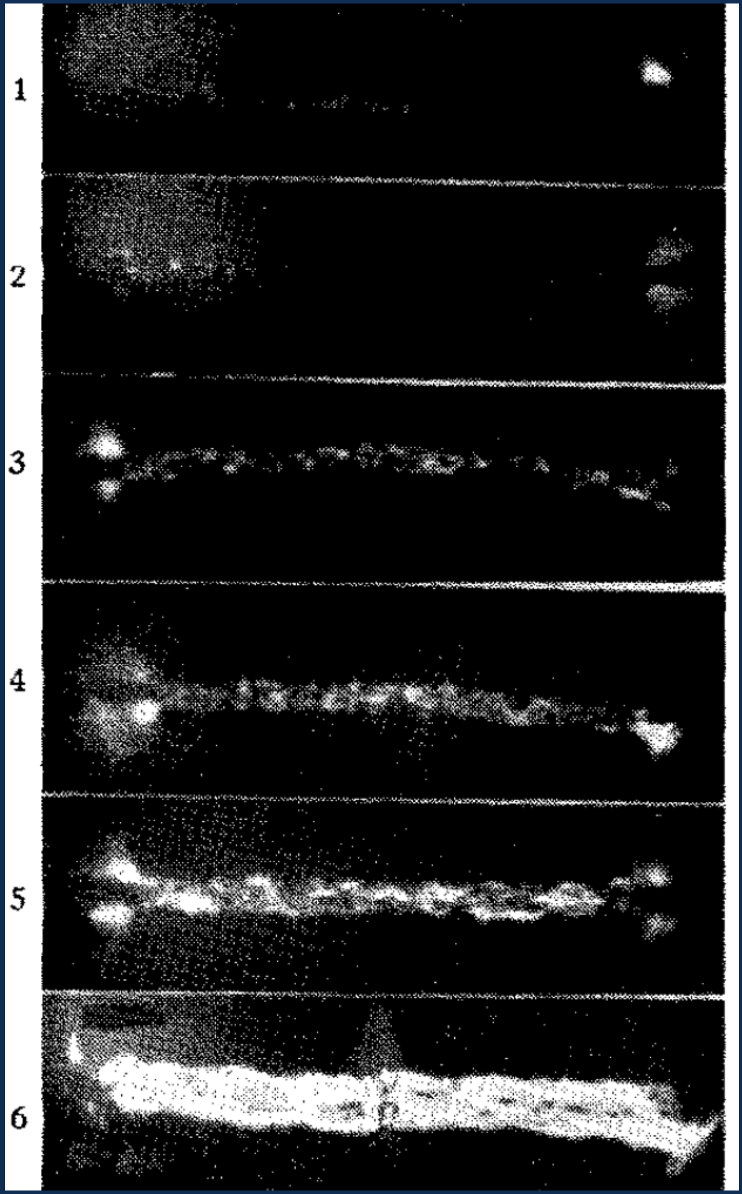


FIG. 12. Wire resistance versus time at a current density of 0.24×10^8 amp/cm².



Evidence suggests that arcing DOES NOT occur prior to the resistance peak.

Observed resistance and energy density dependency on current density.

T. J. Tucker, J. of Appl. Phys. 32, 1894 (1961)

Reithel & Blackburn's view of wire electrical initiation (1962) - LASL

Quasi-static case

Current begins to rise in wire with uniform temperature and resistance (heat is generated uniformly over the cross section)

If depositing energy slowly enough the solid can expand as the temperature reaches the melting point. Isothermal melting will occur followed by further expansion as the liquid is heated to the boiling point. Vaporization would then occur isothermally.

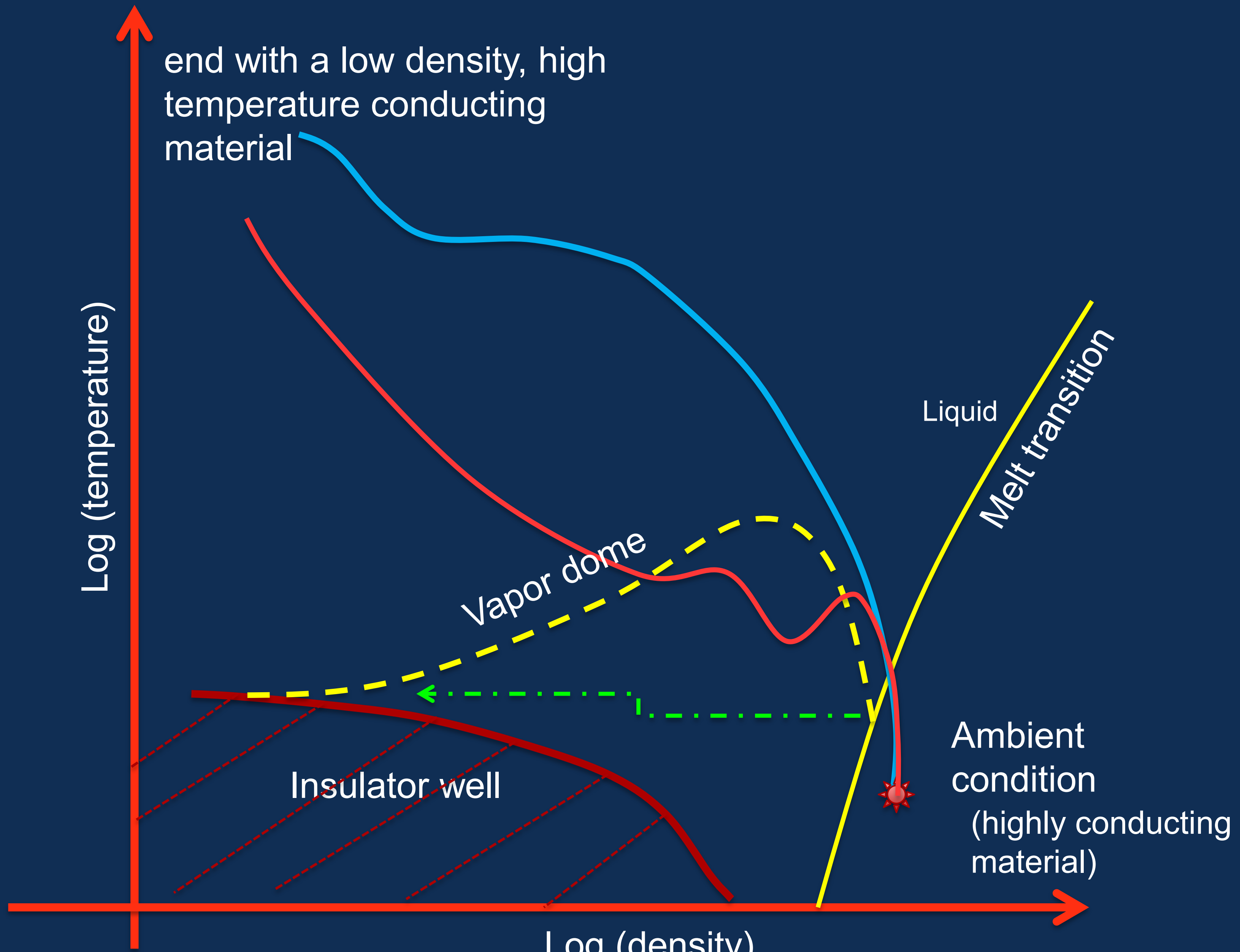
Faster dI/dt

The increase in temperature is not limited to the boiling point (ambient), but might reach the critical point. With a faster energy deposition rate the average density would be greater than the quasi-static case, hence the resistance would be lower.

The expansion of the wire can be hindered in such a way that the electrical resistance approximates that of a liquid long after the energy capable of evaporation (at ambient) has occurred.

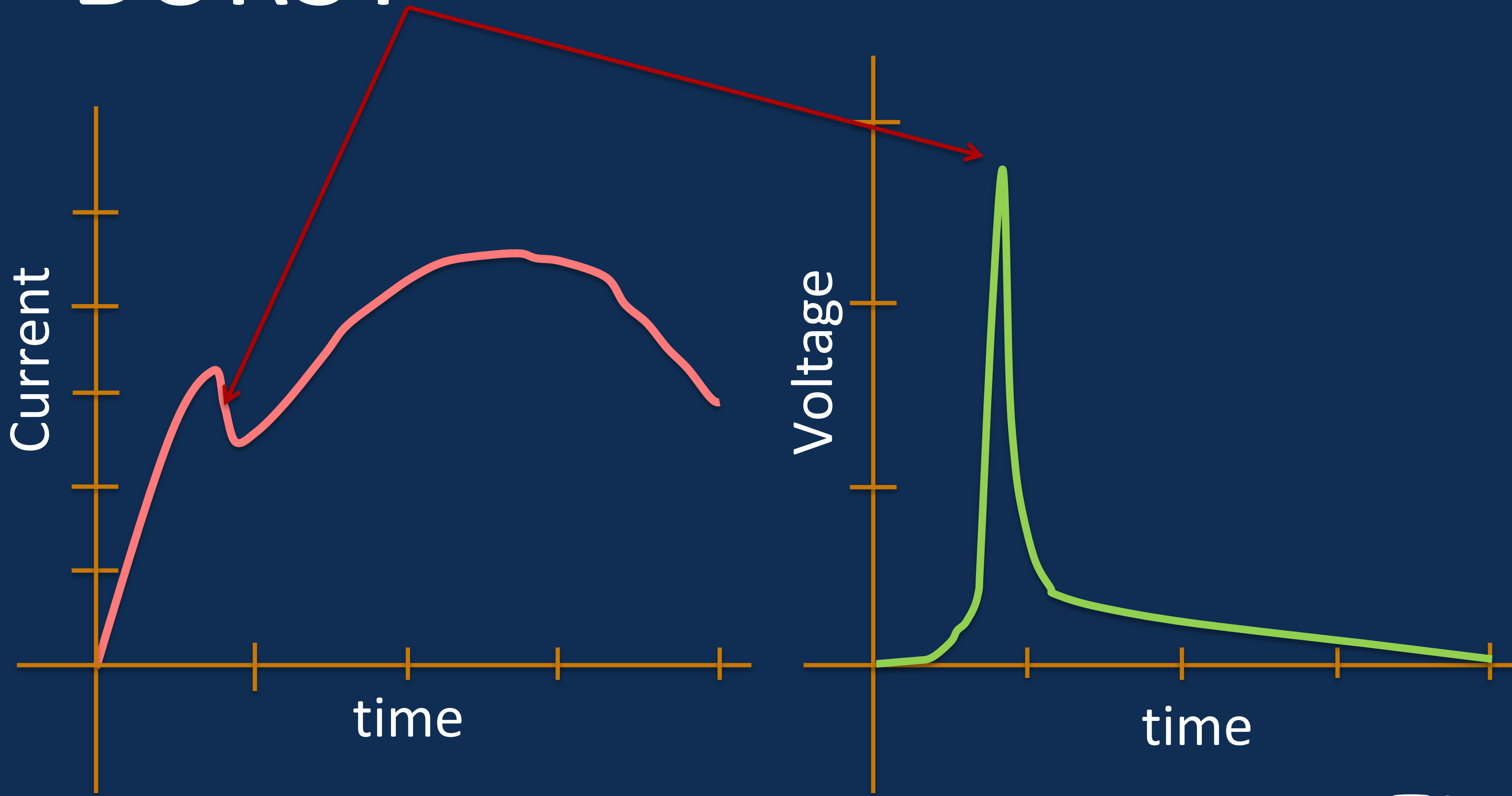
R. J. Reithel & J. H. Blackburn, Exploding Wires v2, p21 (1962)

Phase view of wire evolution



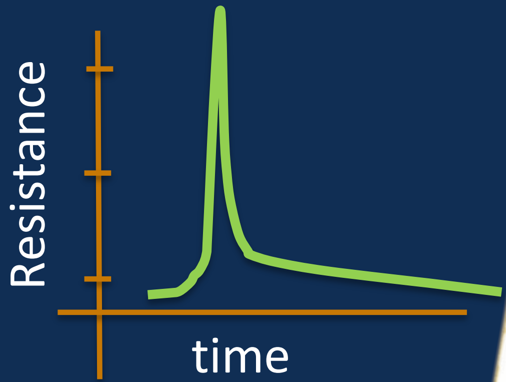
MHD EBW simulations demonstrate

BURST

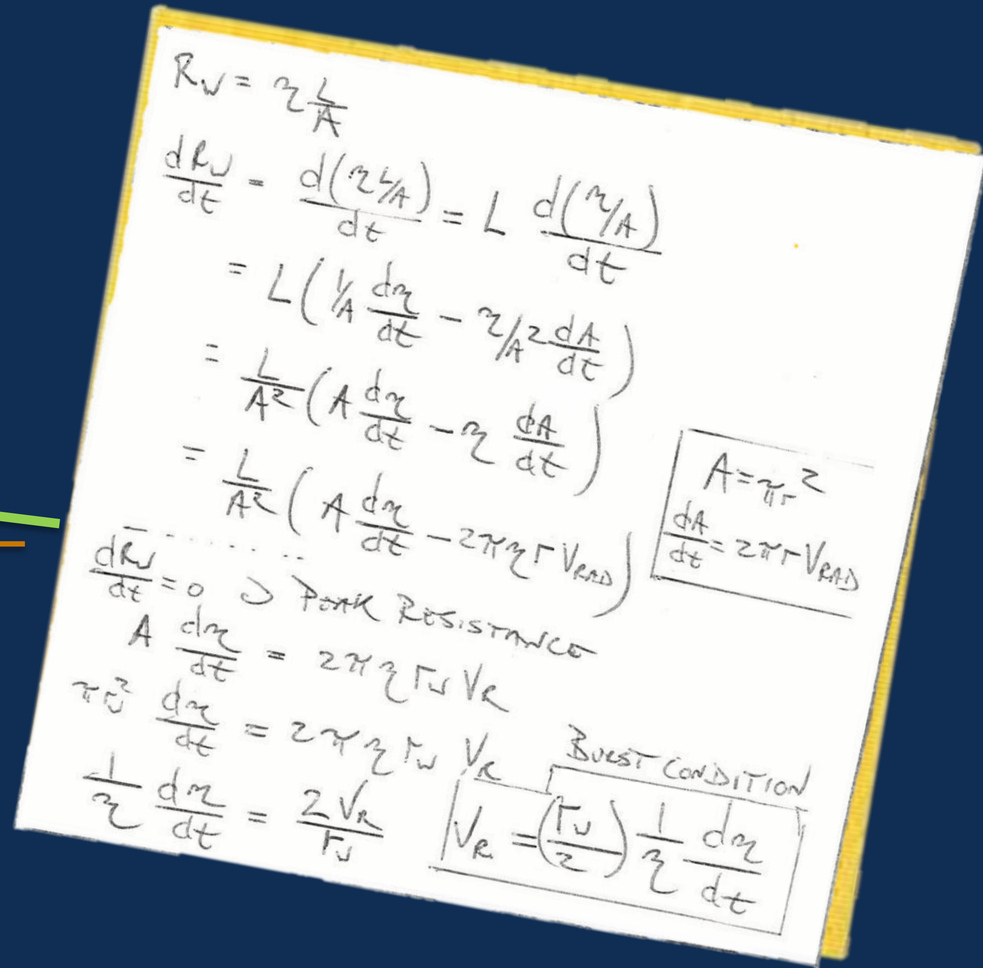


What is "burst"?

Start with the definition of wire resistance



$R_w = \eta\, L / A$



Differentiate w.r.t. time and set equal to zero (resistance maximum at burst)

$V_{radial} = r_w /2 * \{ d\eta/dt * 1/\eta \}$

"Burst" occurs when the radial velocity exceeds the time rate of change of the wire resistivity.

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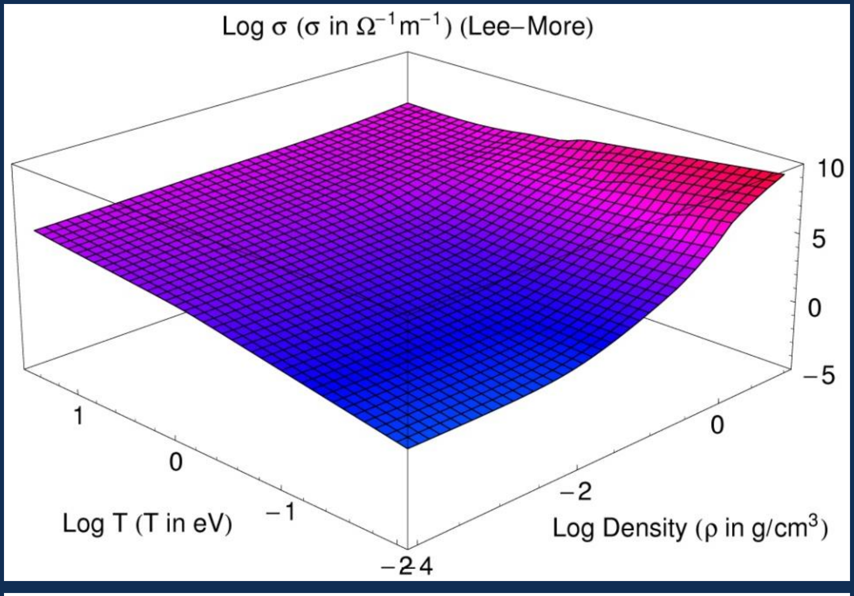
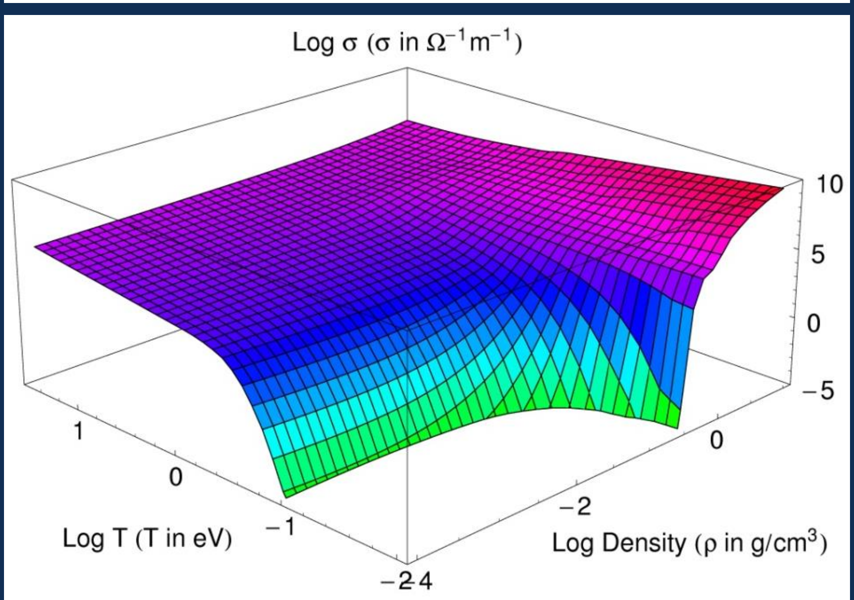
Impact 1: Resistivity Model Accuracy



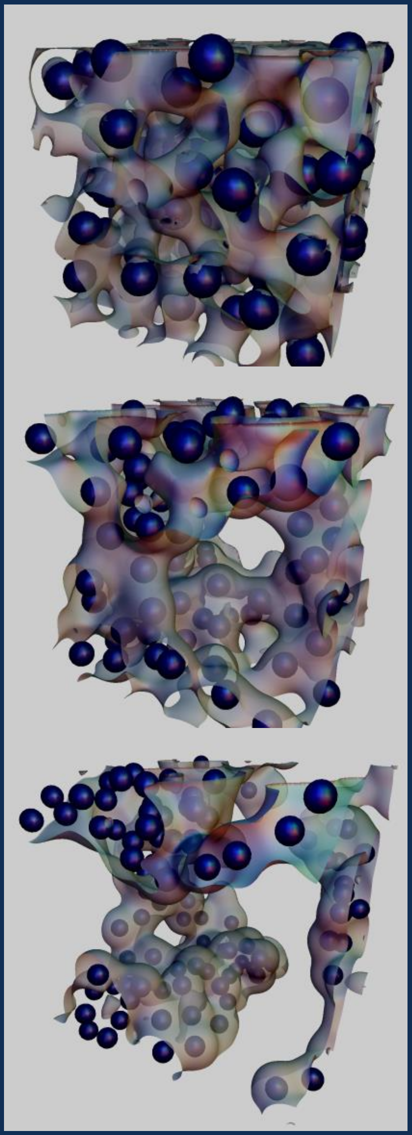


Density functional theory (DFT) based molecular dynamics simulations are used to improve conductivity models

Liquid/vapor phase separation is apparent in the density plot

Pronounced separation into liquid and void (vapor) regions

* M. P. Desjarlais, Contrib. Plasma Phys. **41** (2001) 2-3, 267-270



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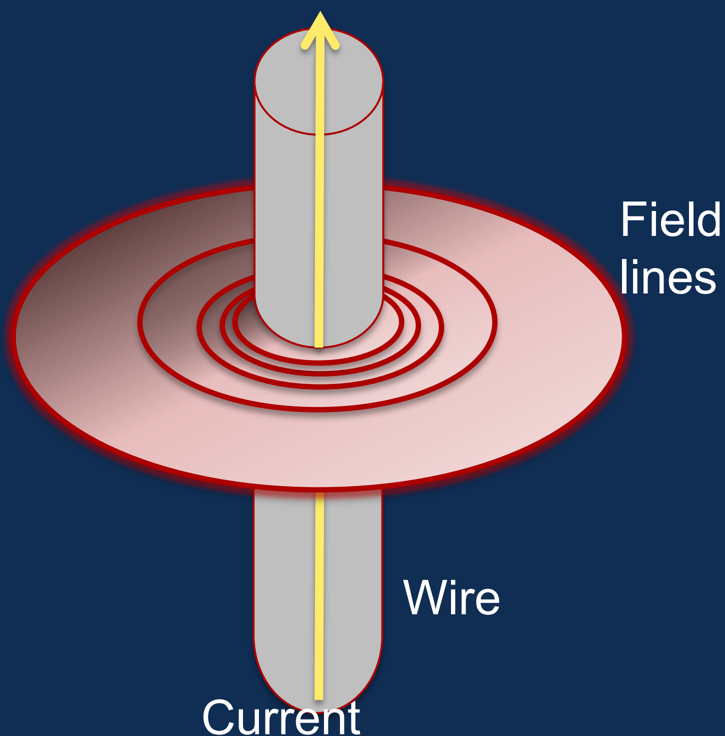
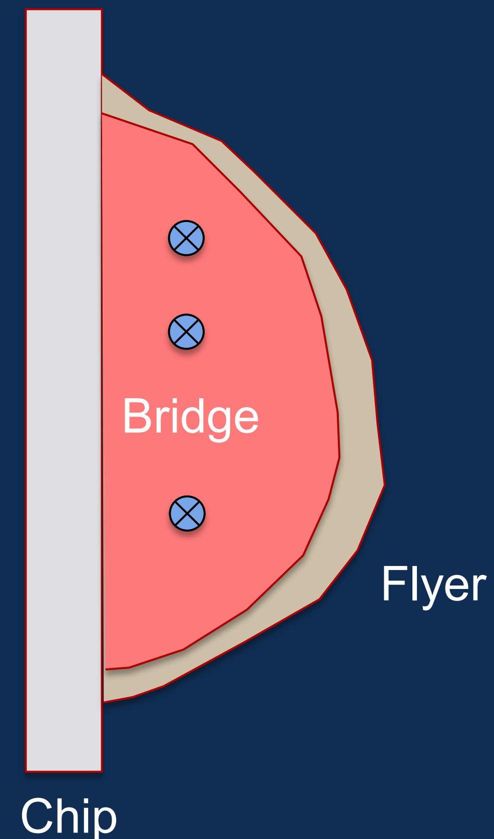
Impact 2: Dimensional accuracy

EBW



Slapper



In principle it should be easier to capture the “2D” area evolution of an EBW than the area evolution of a slapper.

Summary

Provided awareness of what we mean by MHD simulations versus what the community believes is relevant physics
(devil is in the details)

Validation activities are critical to establishing confidence in the approach

Assuming the MHD approximation:

What is burst? It’s when the radial expansion outpaces the resistive change

Resistivity and dimensional accuracy are major players in capturing the physics correctly

EBW Detonator electrical initiation references

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