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Dependence of Electrostatic Field Strength on Voltage Ramp Rates for Spacecraft Materials

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2015 USU Physics Colloquium

Acknowledgements

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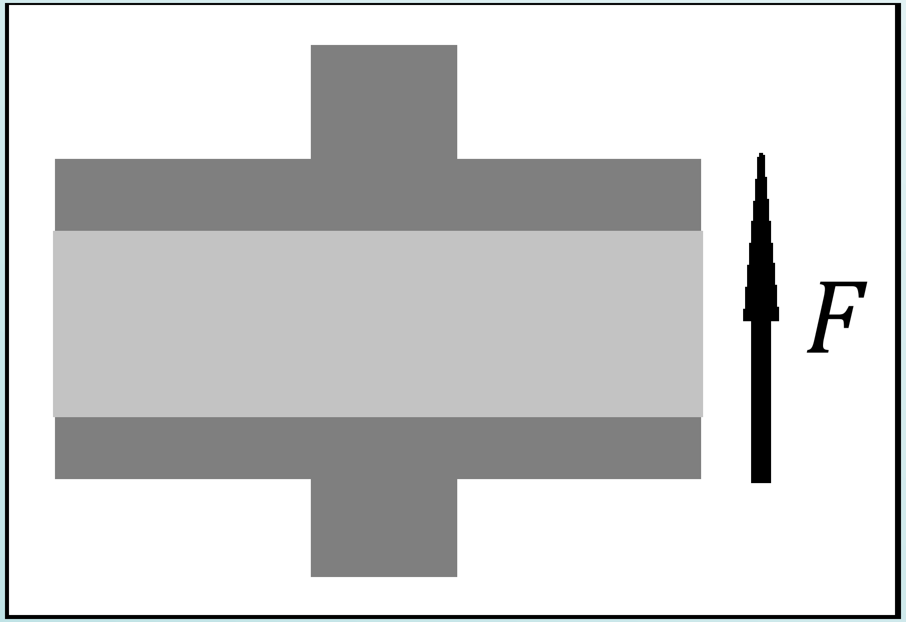
Alec Sim

Charles Sim

Allen Andersen

USU's Materials Physics Group

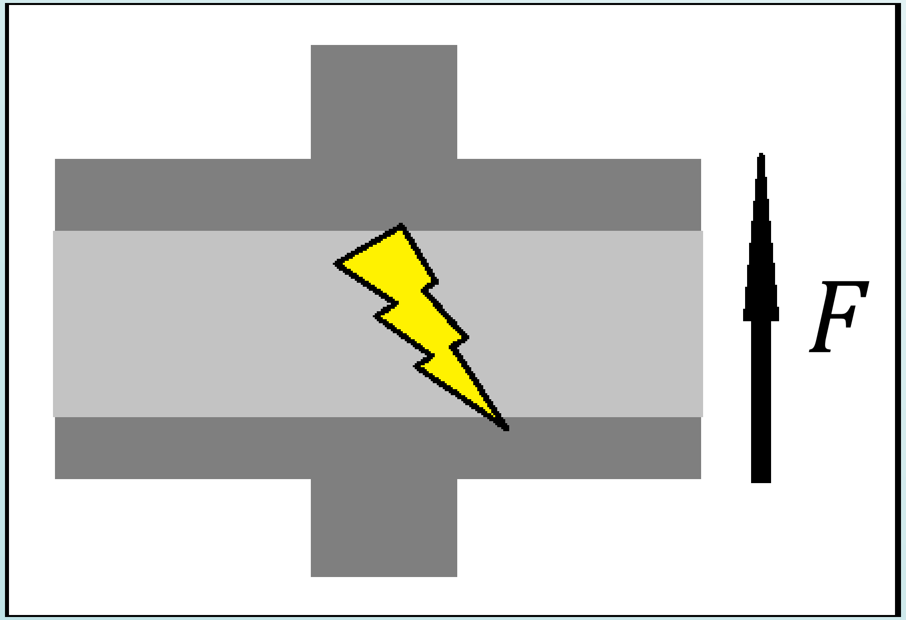
Introduction—What is ESD?



Consider a simple parallel plate capacitor.

- **At low fields current flow is restricted.**

Introduction—What is ESD?



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- At high enough fields or after long times the insulator can breakdown.
- Large currents can flow.

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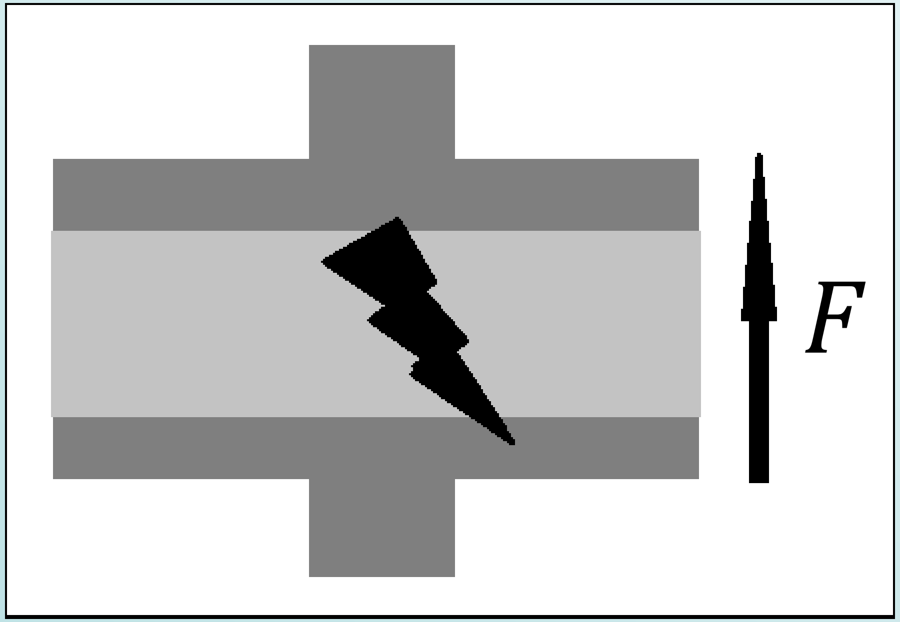


Consider a simple parallel plate capacitor.

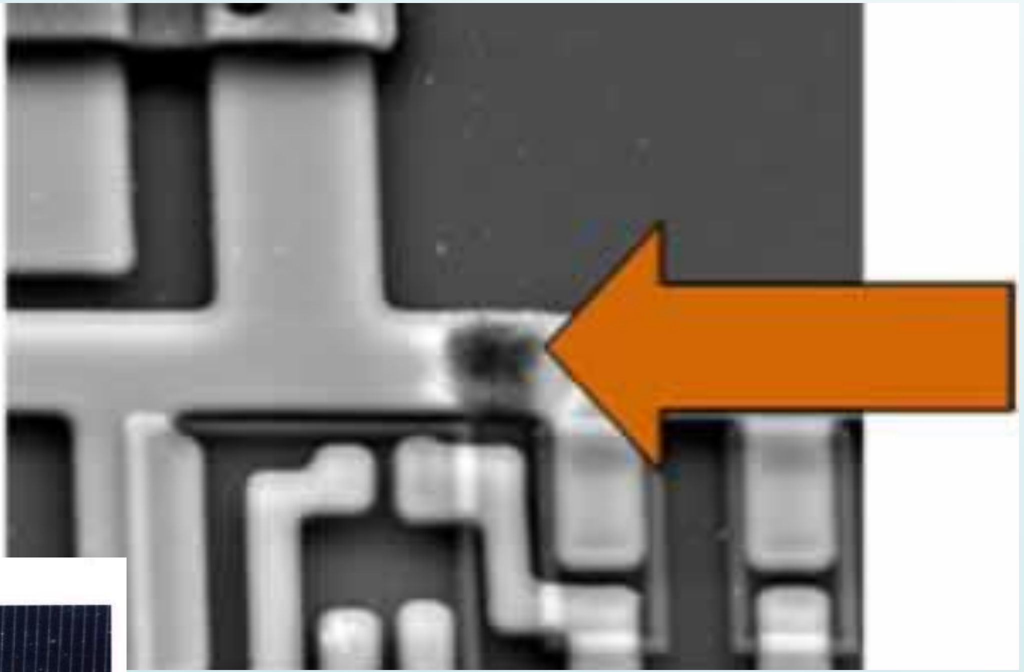
- At low fields current flow is restricted.

- At high enough fields or after long times the insulator can breakdown.
- Large currents can flow.
- Electrostatic discharge (ESD) is a permanent, catastrophic failure of a dielectric material.
- What was an insulator is now essentially a conductor in the system.

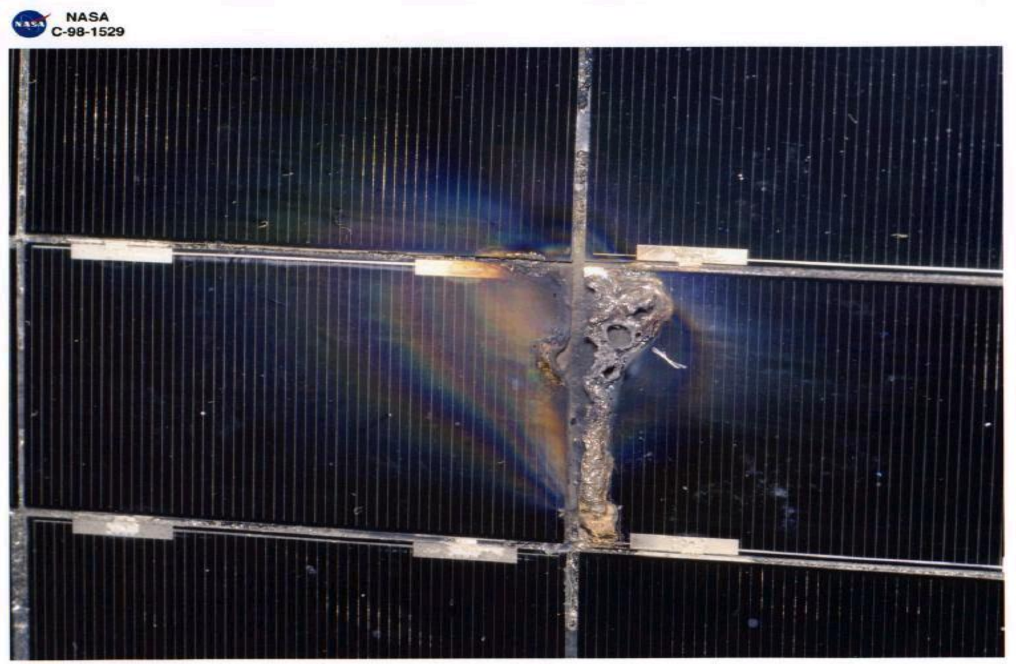
Why should we care about ESD?

ESD is the primary cause of failures attributed to spacecraft interactions with the plasma space environment.

Why should we care about ESD?



Smaller devices=bigger problems



Solar panel damaged by localized charging event

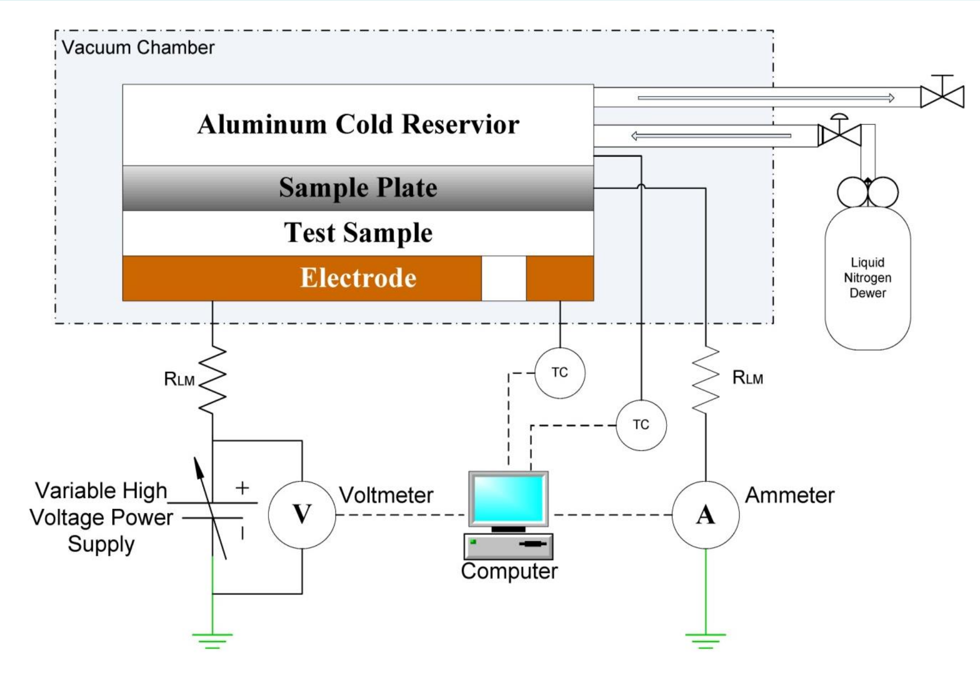
National Aeronautics and Space Administration
Lewis Research Center

Electrostatic field strength is affected by many factors

Important to understand how F_{ESD} varies under different conditions

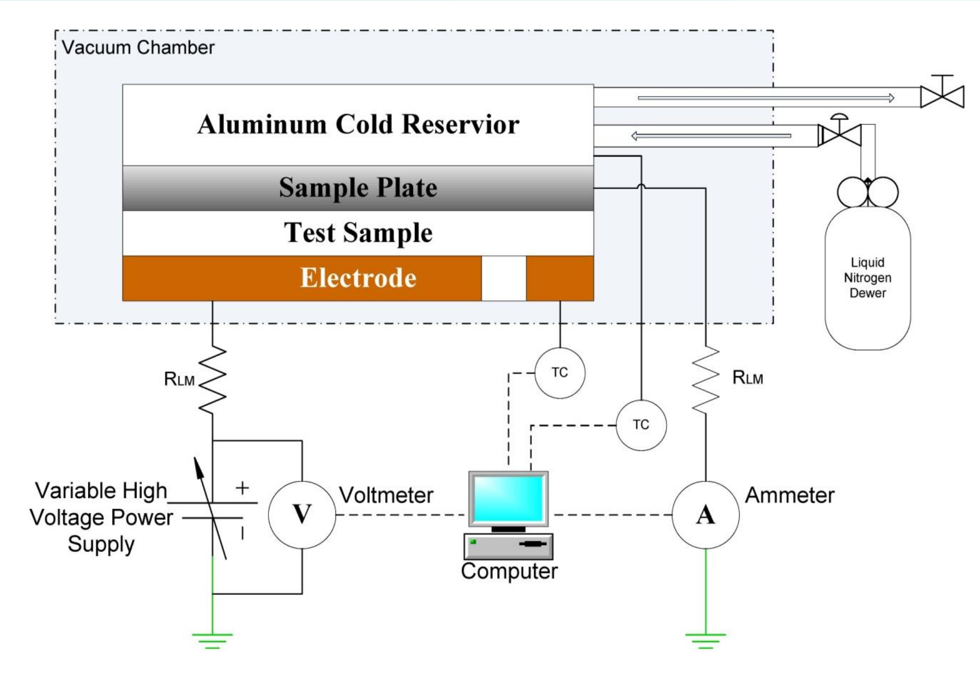
Past work in USU's MPG has looked at F_{ESD} dependence on temperature, voltage ramp rate, duration of applied electric field, etc

ESD Vacuum Chamber



- Simple parallel plate capacitor
- Vacuum ~10^{-6} torr
- Applies up to 30 kV
- 6 electrode carousel

ESD Vacuum Chamber



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ESD Test Assembly:

(A) Adjustable pressure springs,

(B) Insulating layer

(C) Cryogen reservoir,

(D) Thermally conductive, electrically isolating layer,

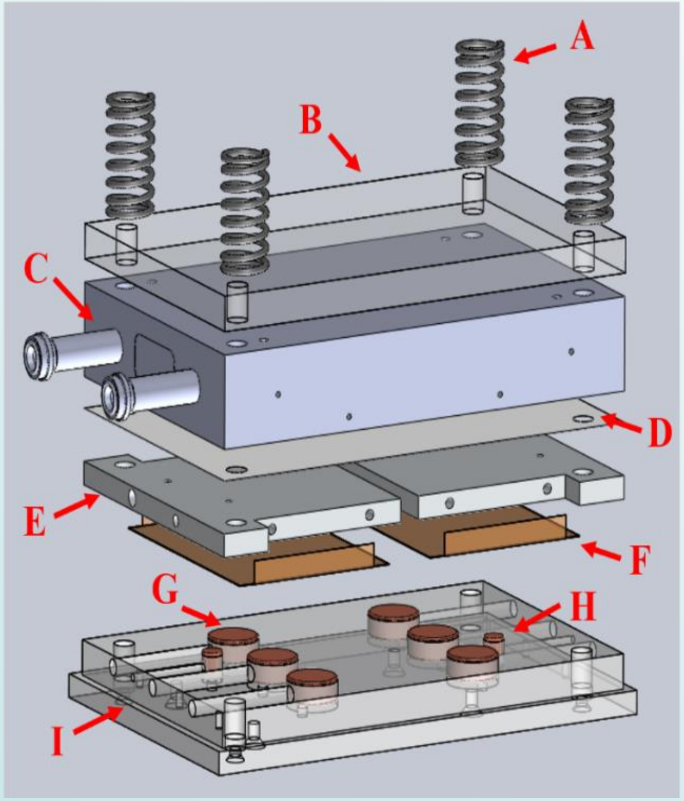
(E) Sample and mounting plate,

(F) Sample

(G) HV Cu electrode

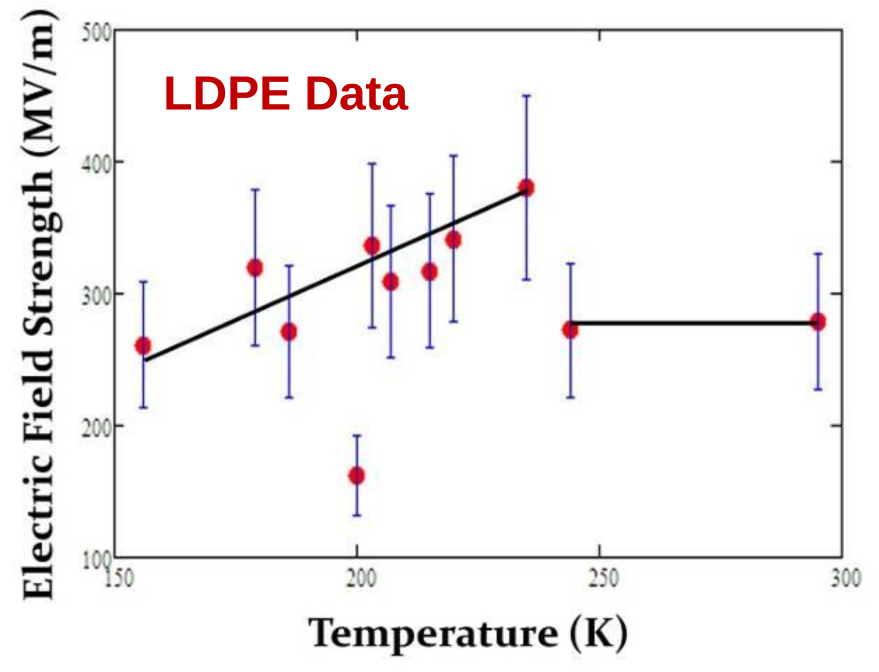
(H) Cu thermocouple electrode,

(I) Insulating base.

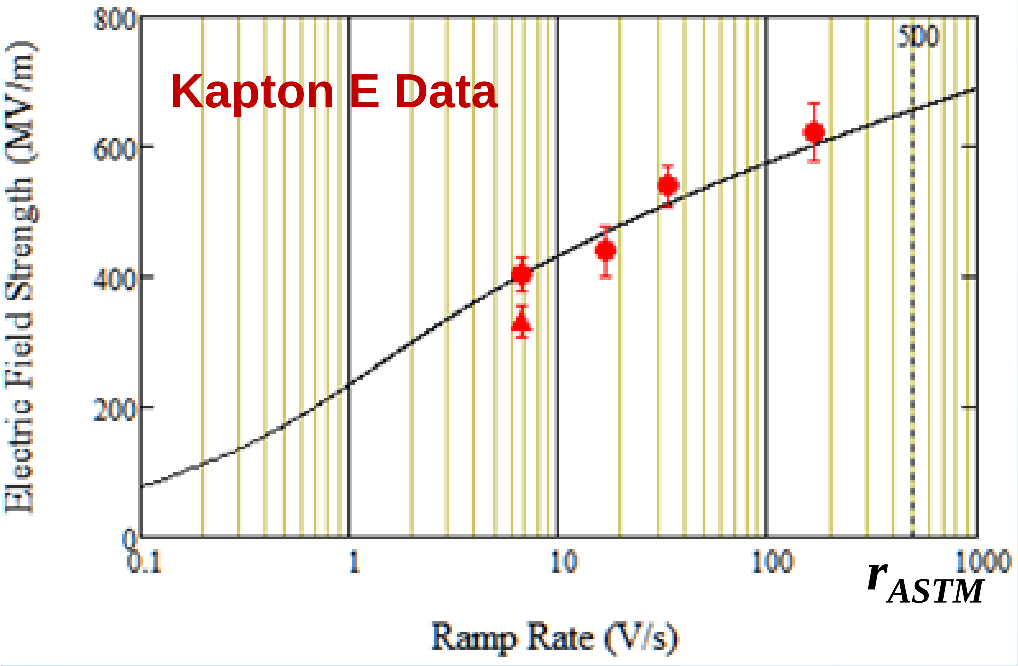


Breakdown Test Dependence on T and dV/dt

F_{ESD} Temperature Dependence



F_{ESD} Ramp Rate Dependence

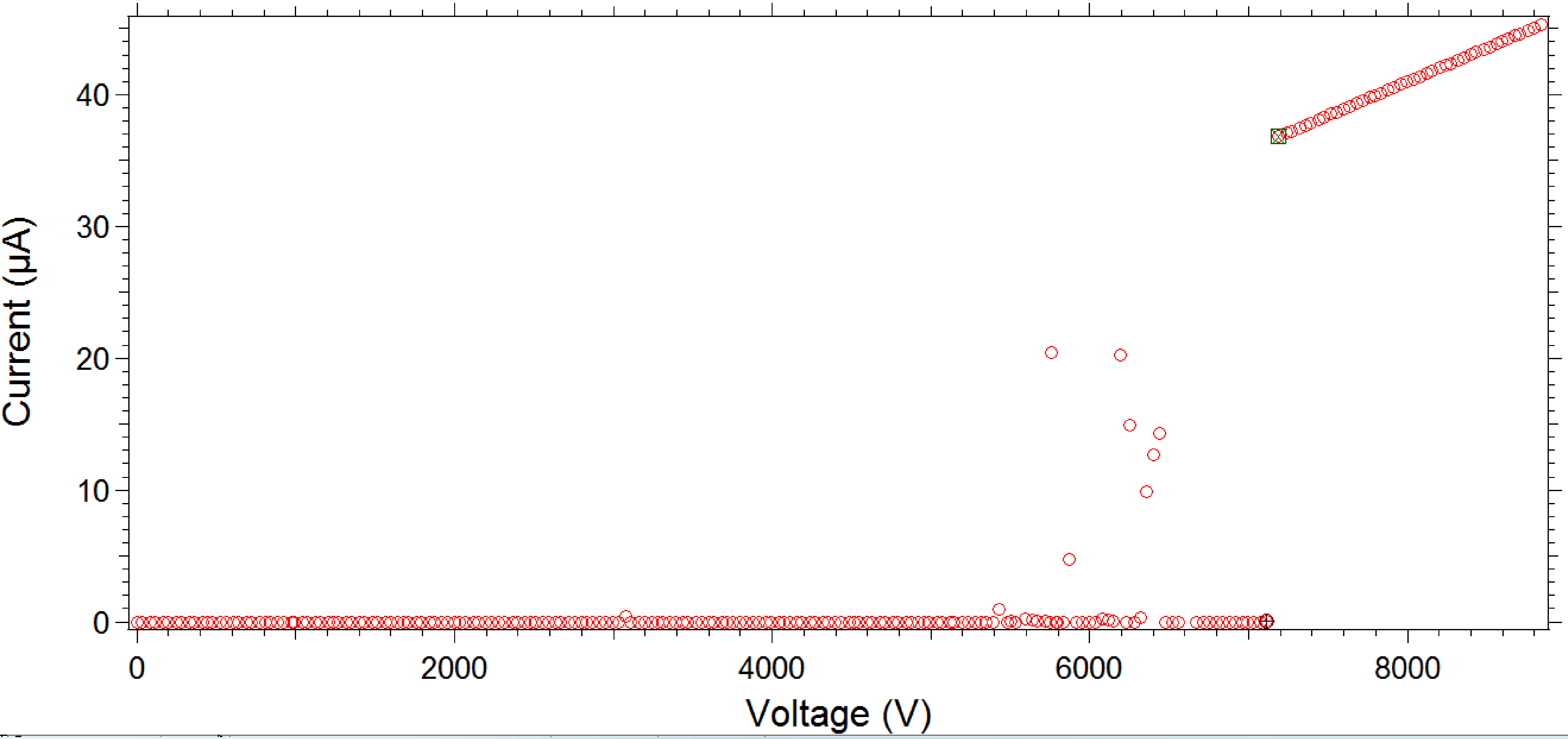


F_{ESD} depends significantly on both temperature and ramp rate.

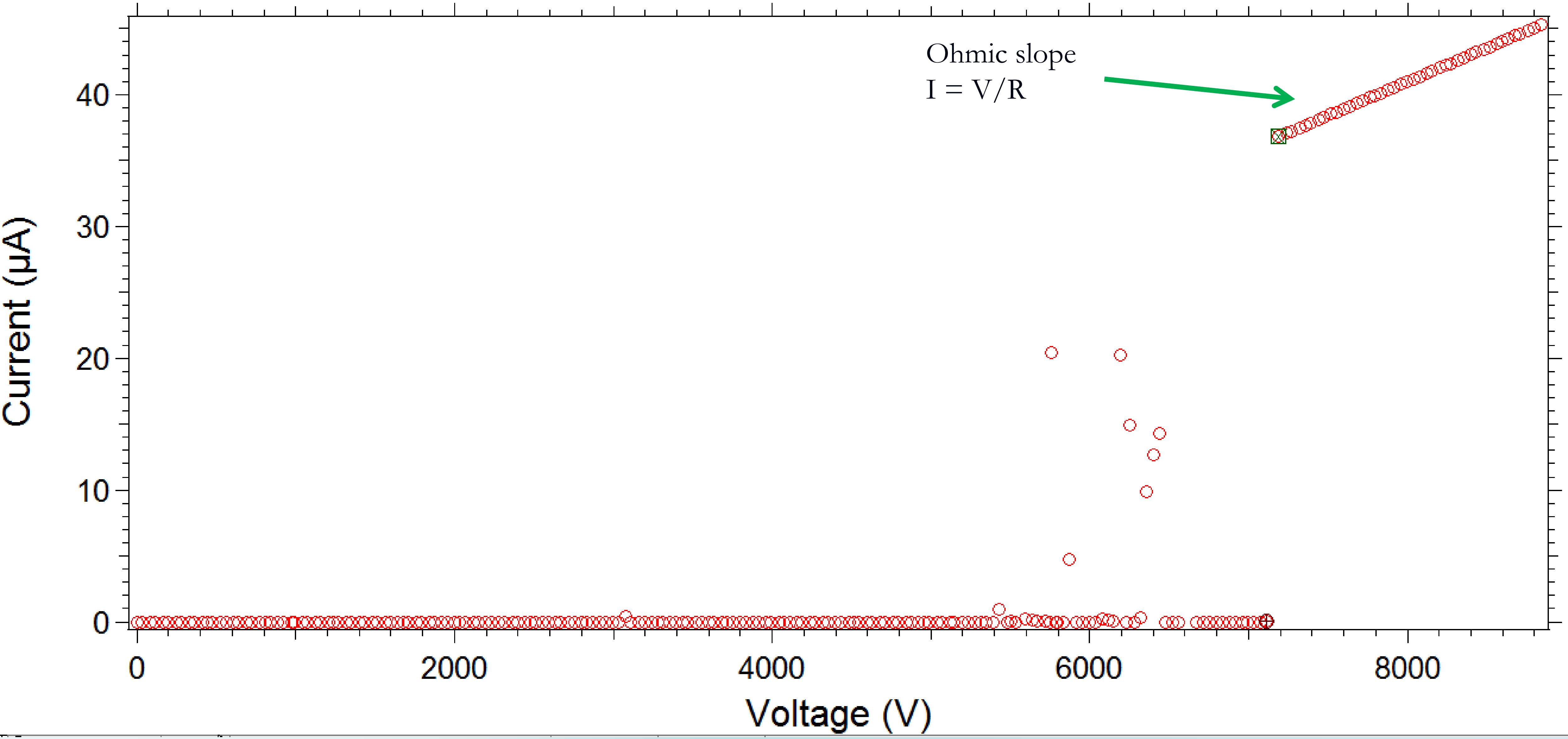
- ASTM D3755 standard tests recommend a 500 V/s ramp rate until breakdown.
- However these tests are not very repeatable and tend to overestimate breakdown strengths for slower ramp rates.
- Slow (even VERY SLOW) ramp rate better model real charging applications.


If you use the recommended ramp rate of 500 V/s to test spacecraft charging
You're gonna have a bad time

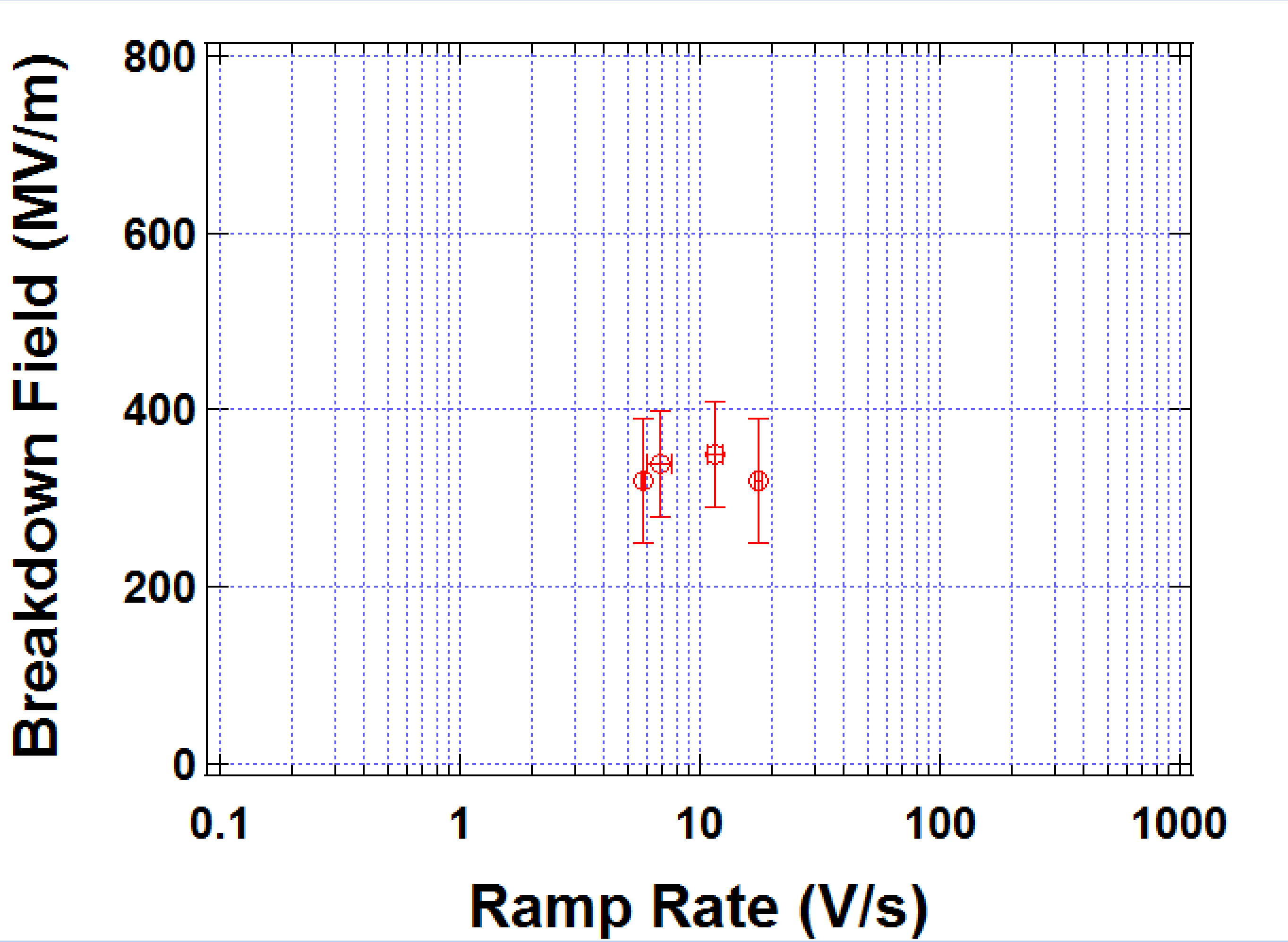
This summer



This summer

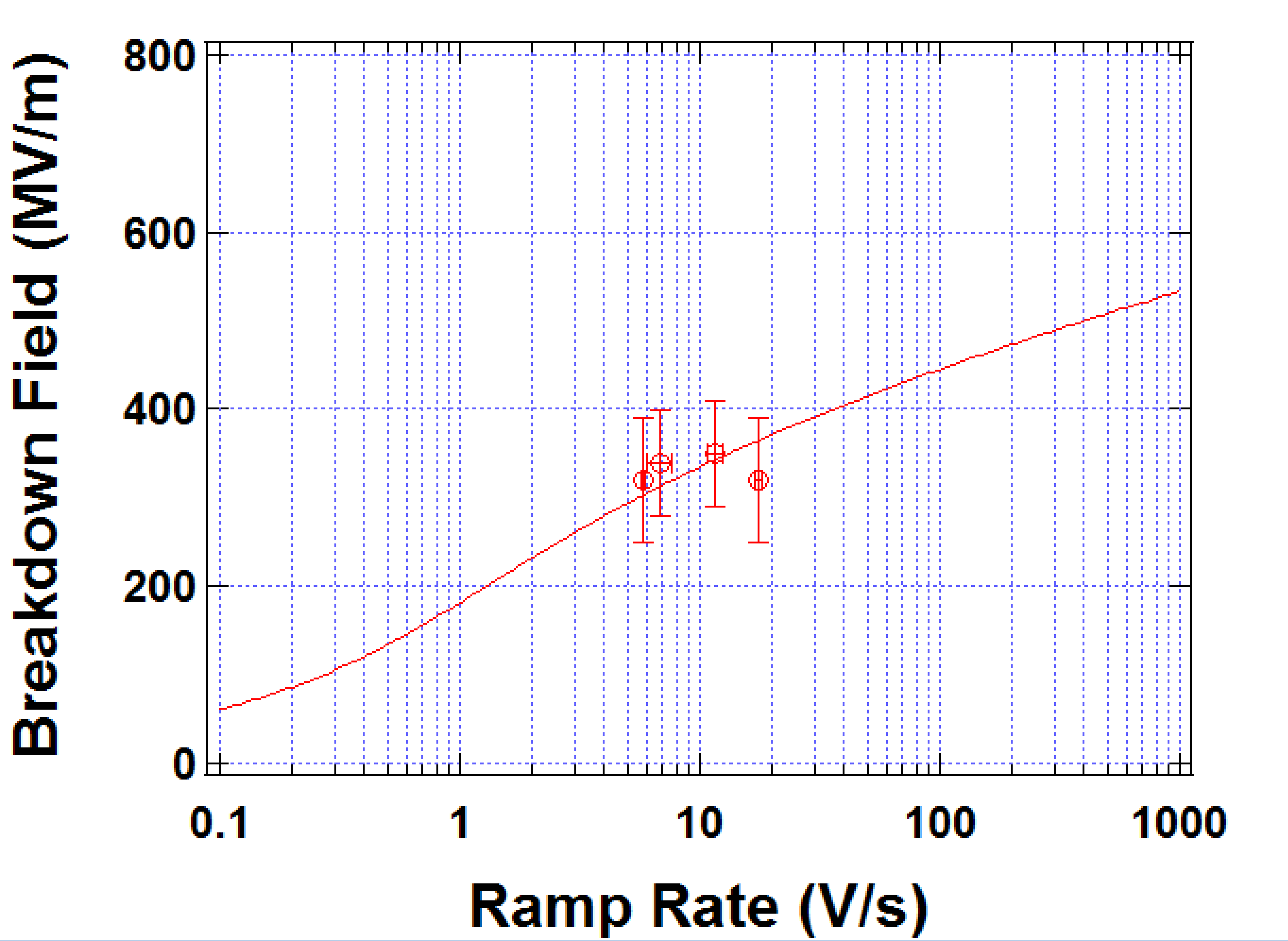

Ohmic slope
I = V/R
Current (µA)
Voltage (V)
0
10
20
30
40
0
2000
4000
6000
8000

This summer



Breakdown Field (MV/m)
800
600
400
200
0
0.1
1
10
100
1000
Ramp Rate (V/s)

This summer



$$F_{ESD}(r) \approx F_{ESD}(r_0)\sqrt{1.1346\ \ln\left(r+\sqrt{1+r^2}\right)}$$

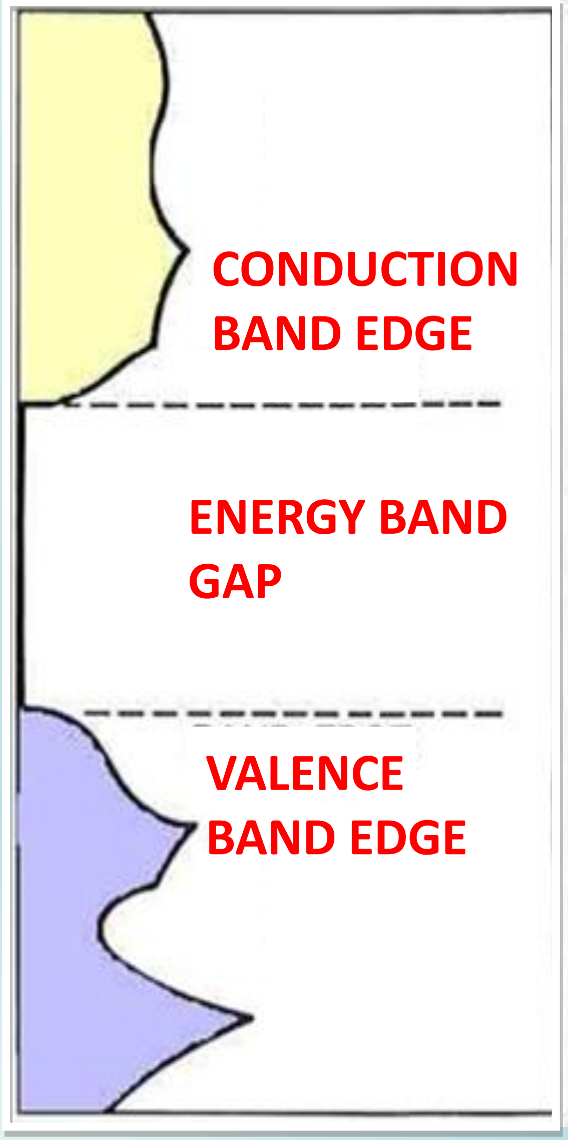
Defect Theory of Highly Disordered Insulating Materials

Empty States

No States

Filled States

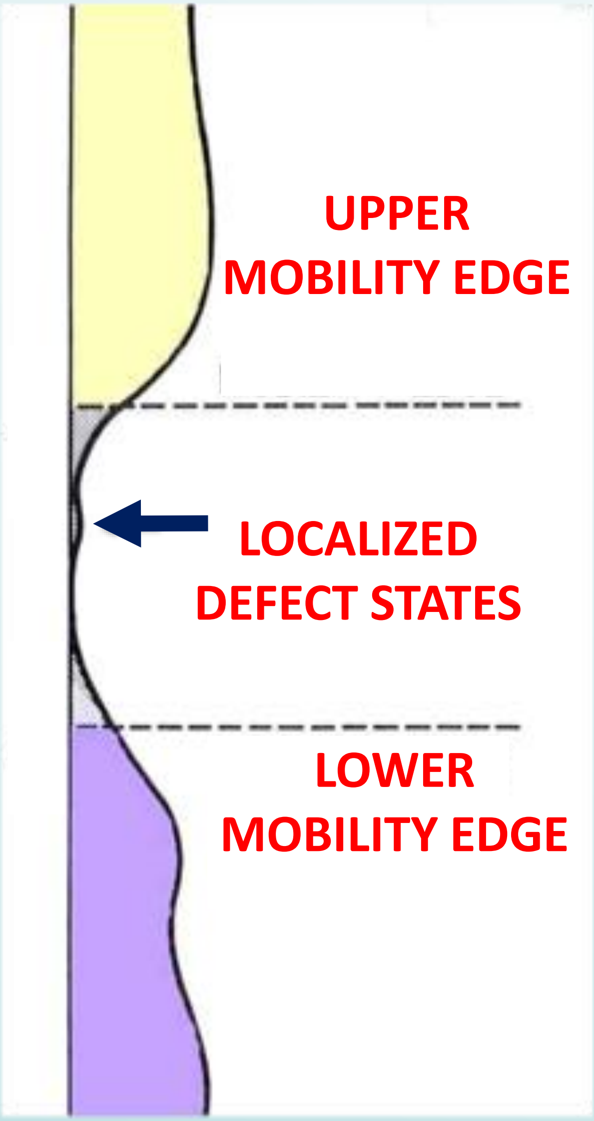
Ordered Materials

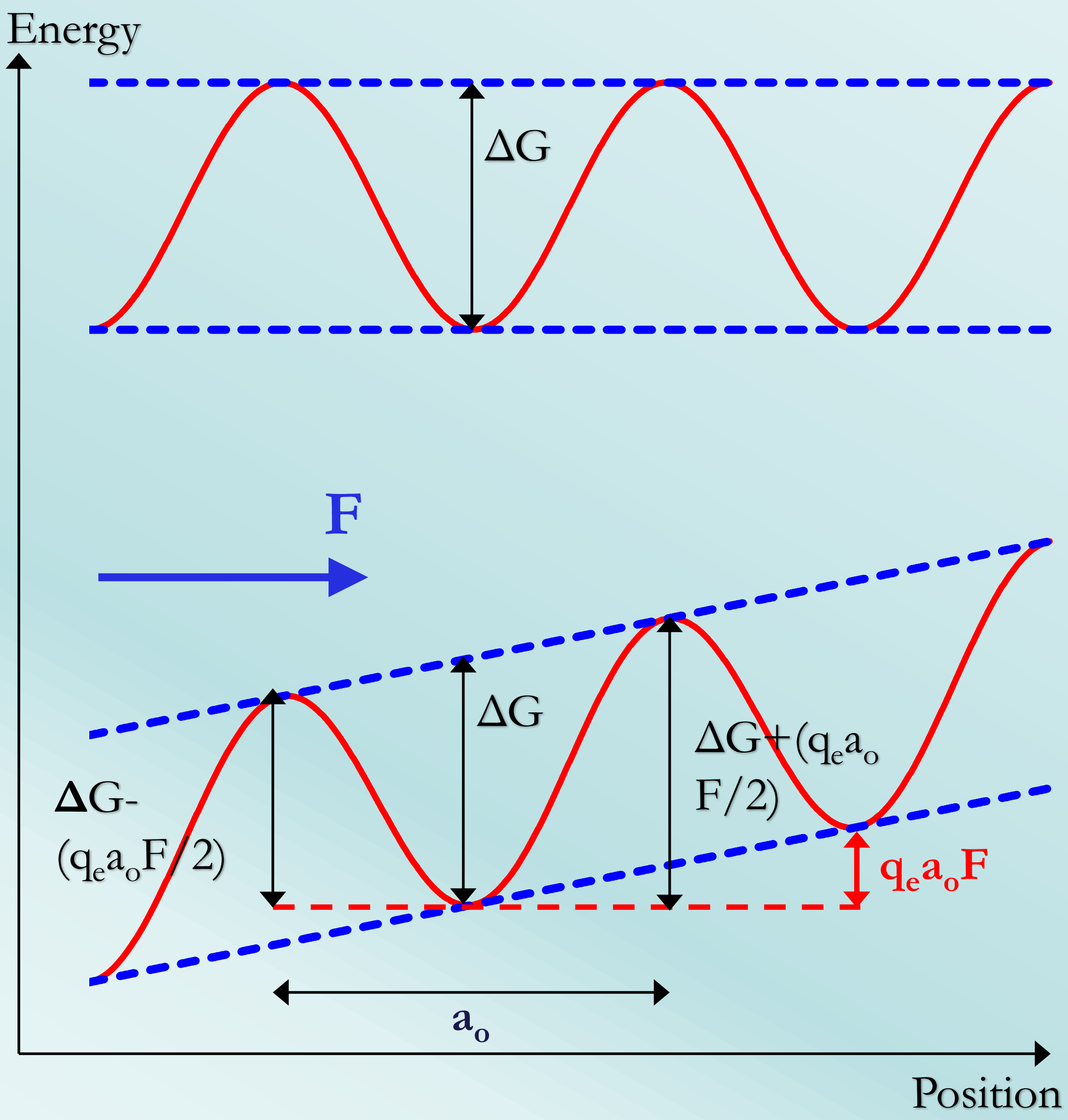


The effect of disorder spatially and energetically introduces localized states in the bad gap.

The density and occupation of defects determine electrical properties.

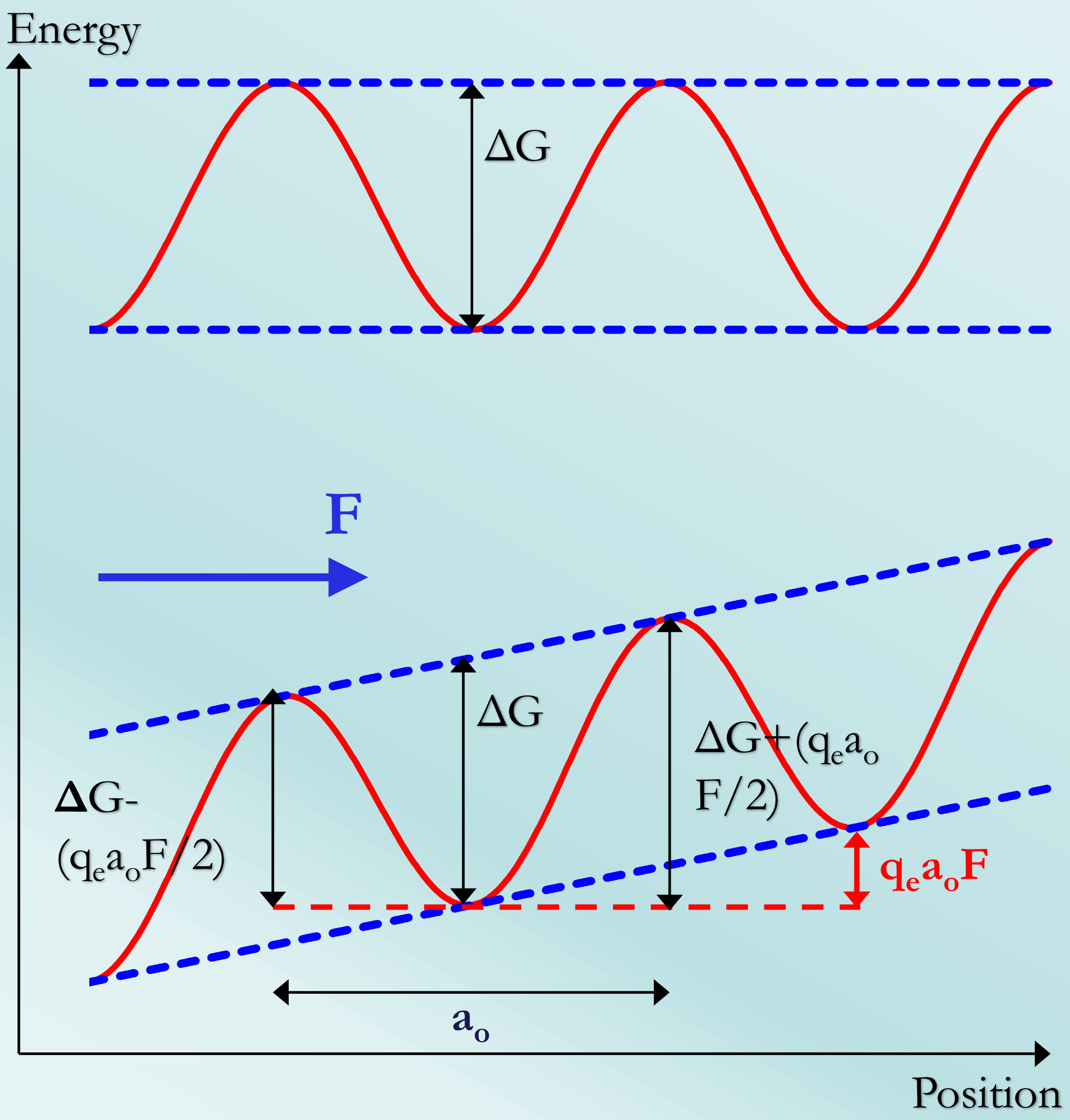
Disordered Materials





Under an applied electric field, charge can ‘hop’ between defect sites. The probability of a transition in a given time step depends upon temperature, well depth, and applied field.

Defect Theory of Highly Disordered Insulating Materials



$$F = qeE$$

$$W = F * a = qeaF$$

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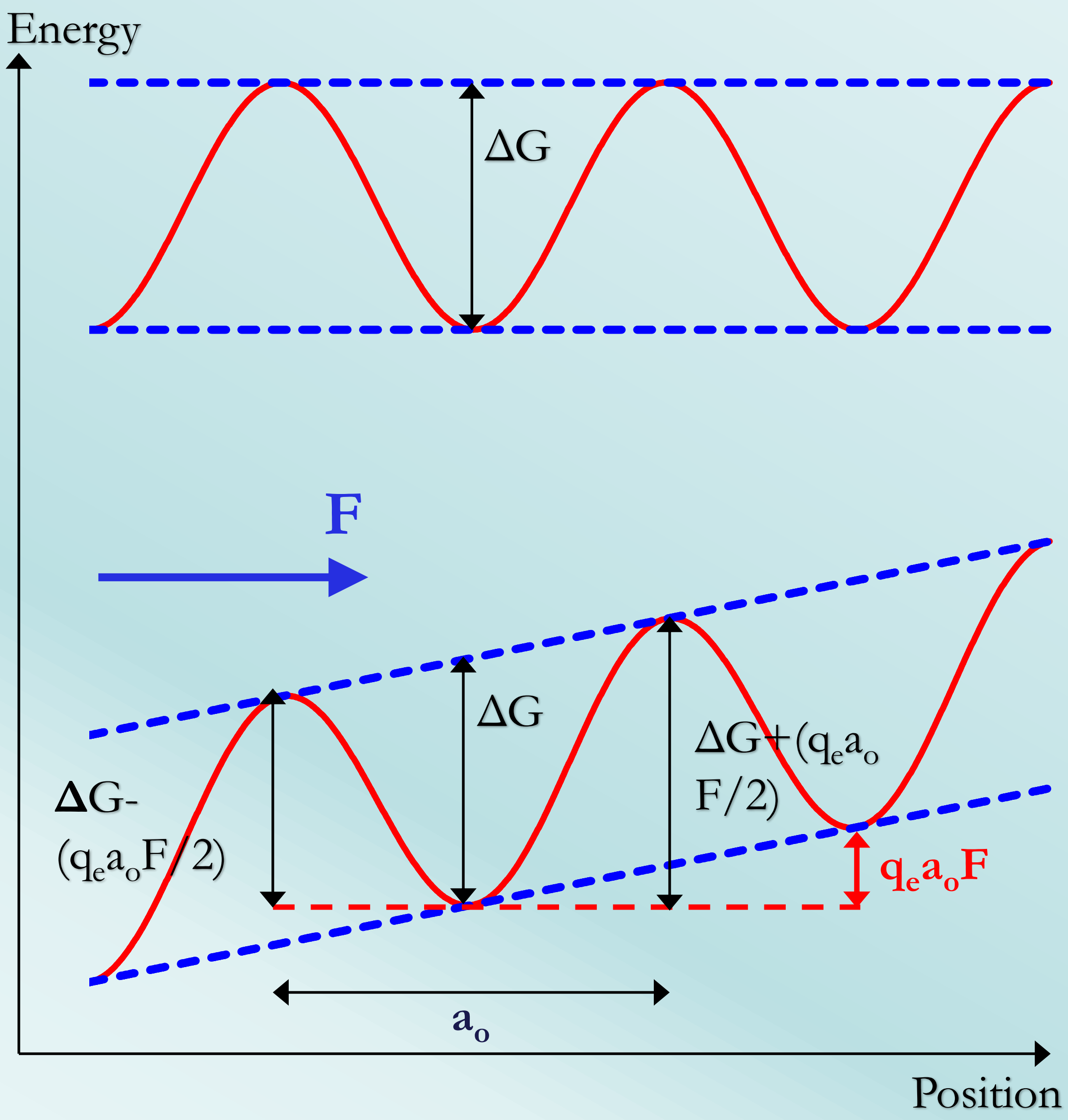

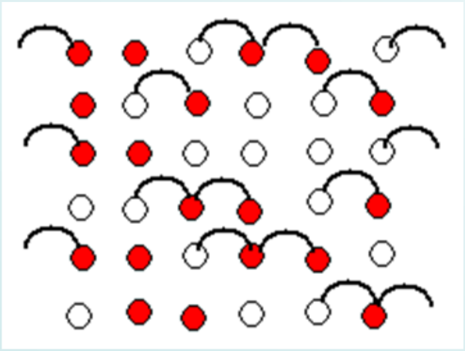

Assumes all depths and hopping distances are the same

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Defect Theory of Highly Disordered Insulating Materials

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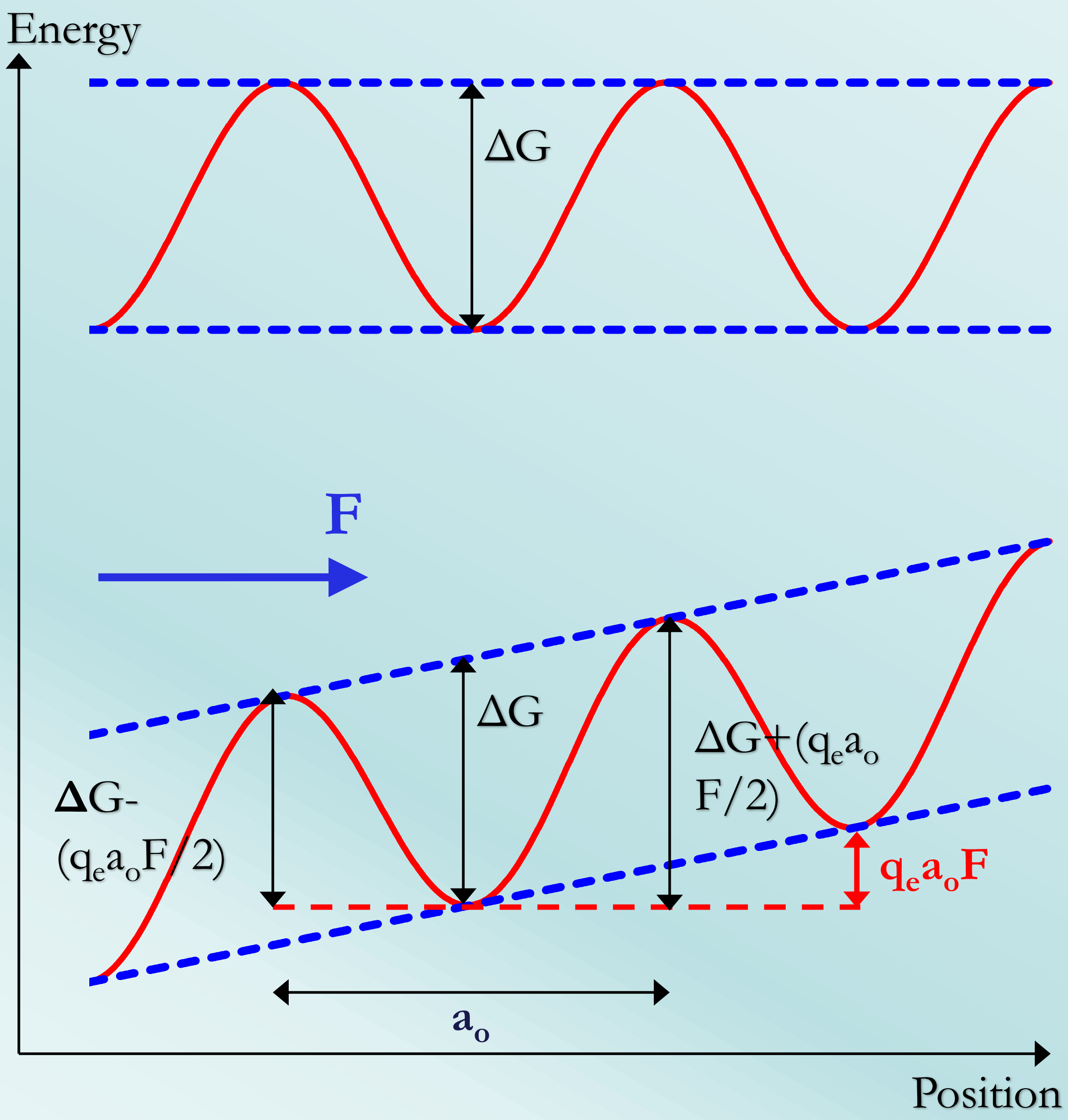

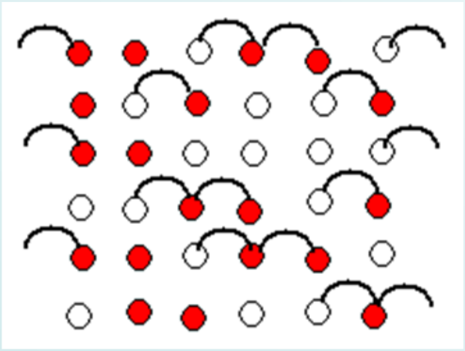

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Under an applied electric field, charge can ‘hop’ between defect sites. The probability of a transition in a given time step depends upon temperature, well depth, and applied field.

$$F = qeE$$

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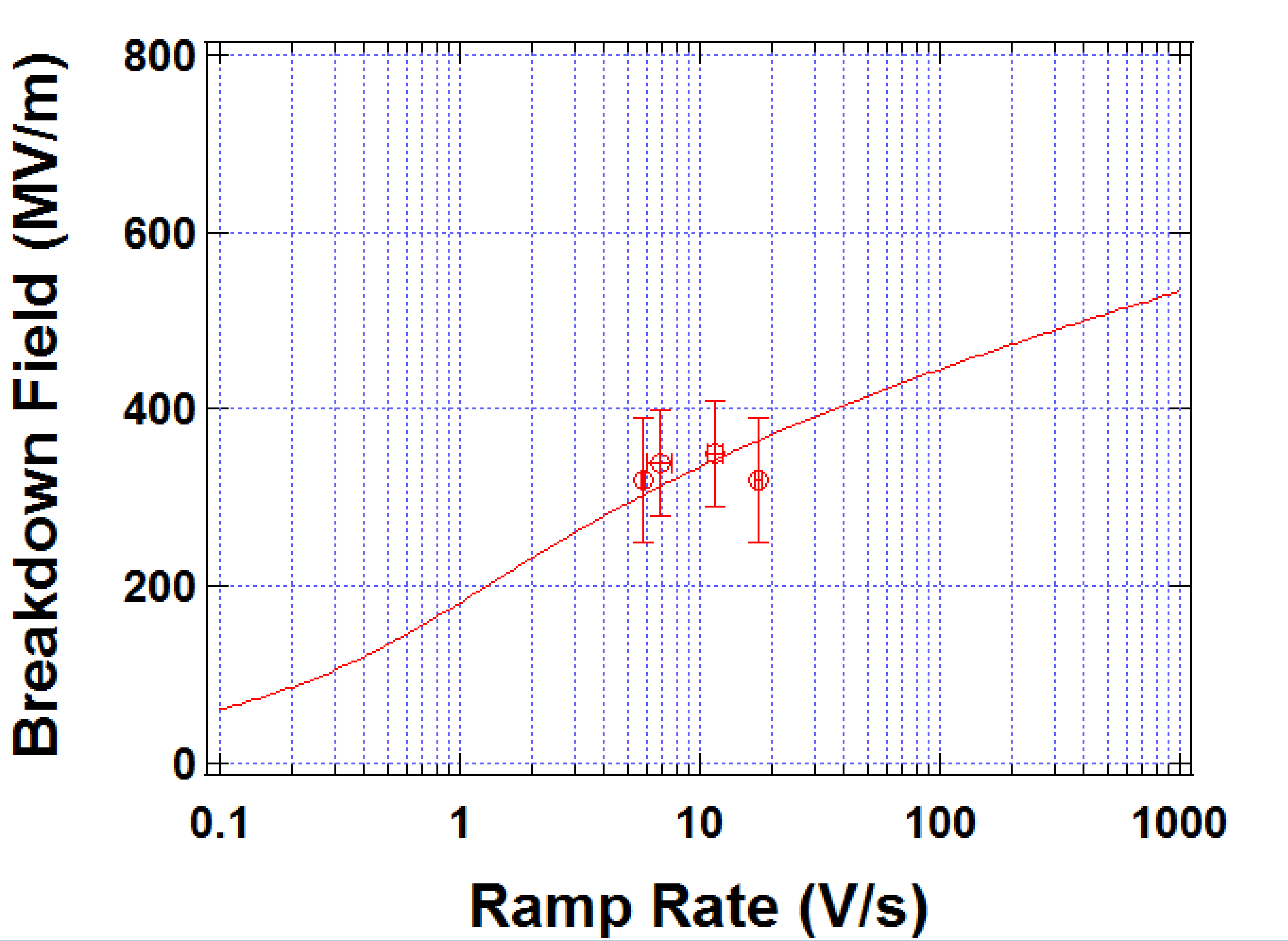
$$P_{def}(F,T,\Delta t) = \left(\frac{2k_BT}{h/\Delta t}\right) \exp\left[\frac{-\Delta G_{def}}{k_BT}\right] \sinh\left[\frac{\varepsilon_0\varepsilon_r F^2}{2k_BTN_{def}}\right]$$

Utah State University



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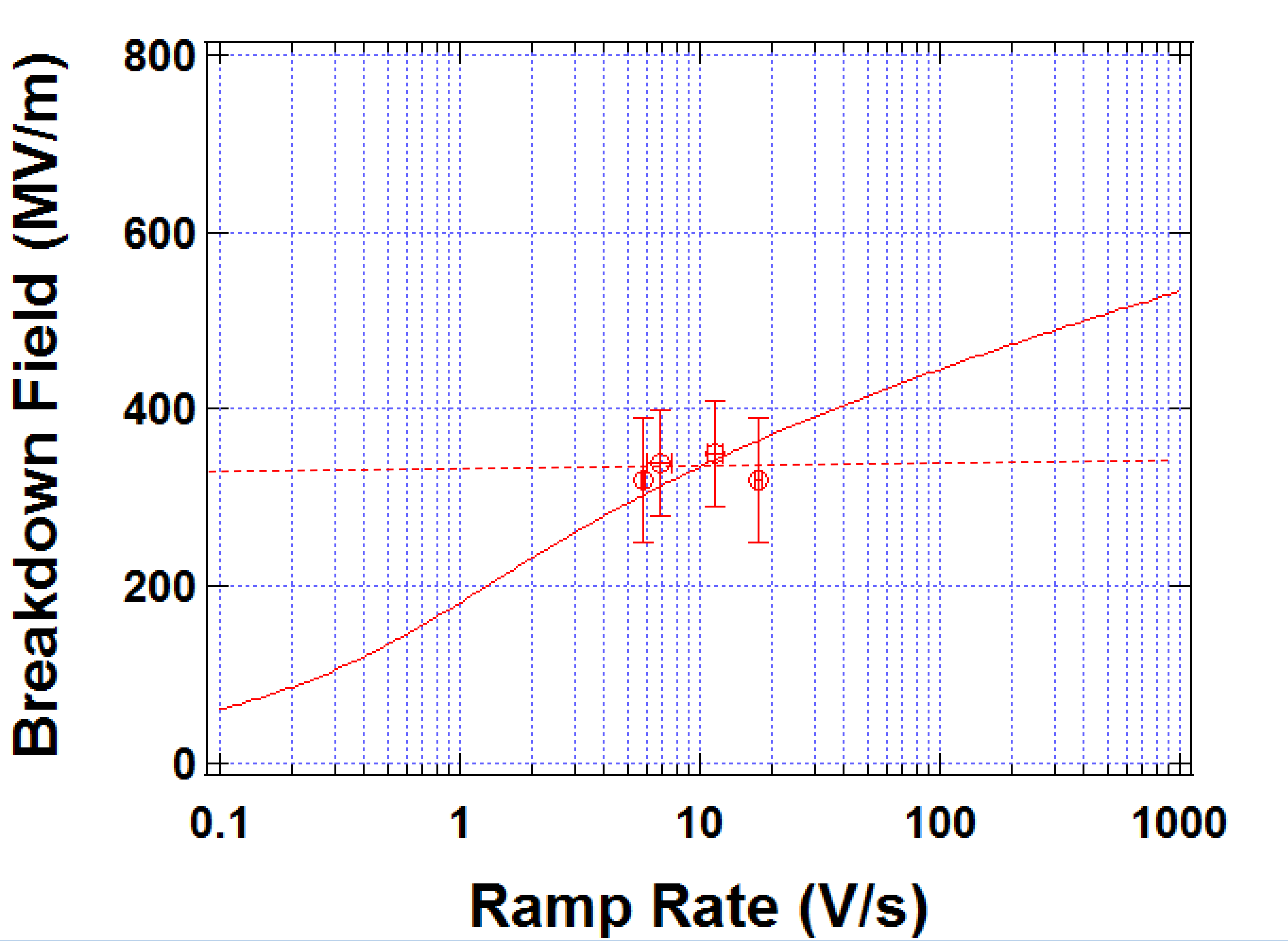

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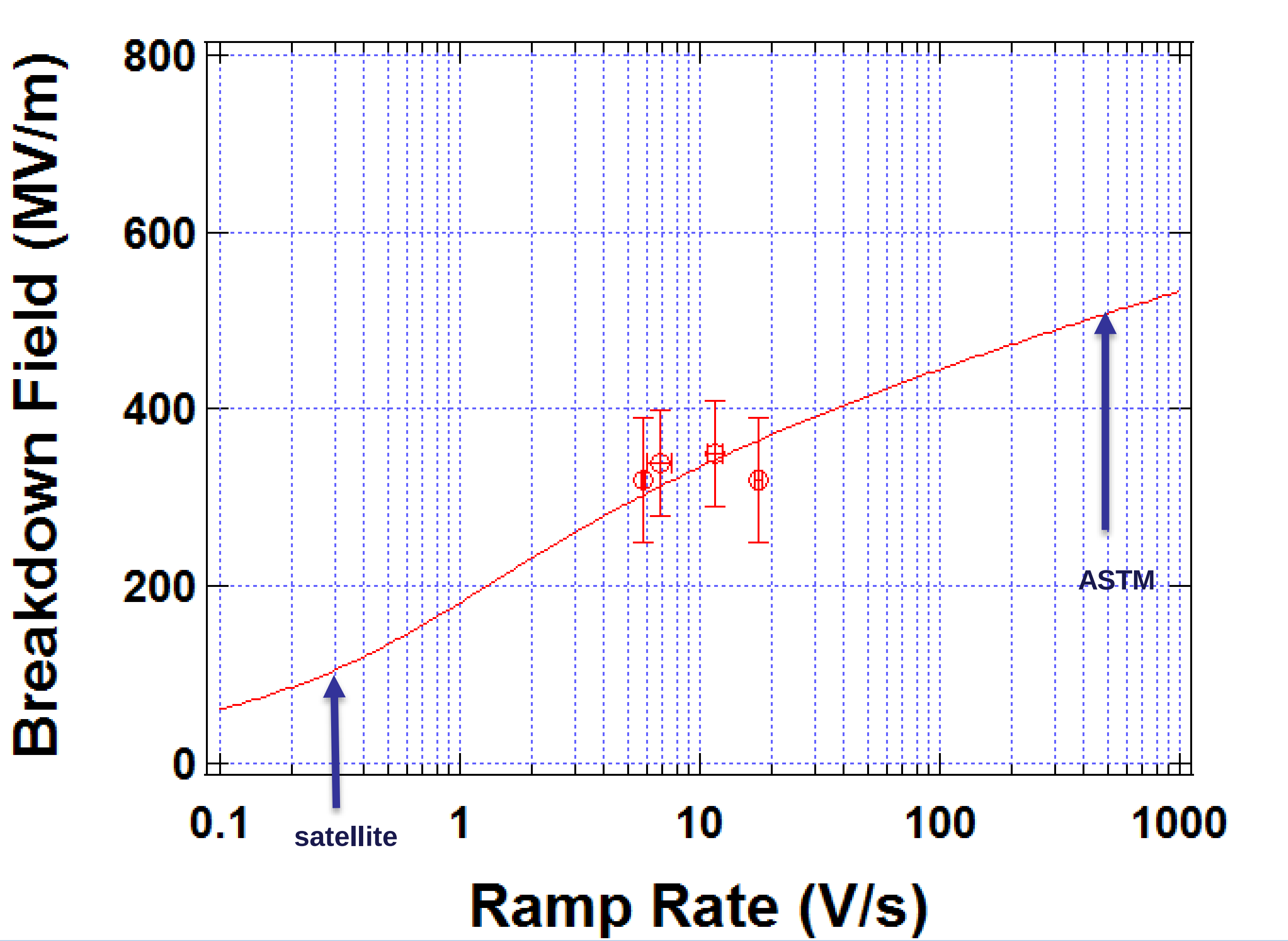
Future Work



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Future Work

- Look into ramp rates on extreme ends of graph
- Expand ramp rate tests already done on Kapton/LDPE
- Begin testing temperature dependence of all three

References

Allen Andersen and JR Dennison, "Electrostatic Discharge in Solids," Utah State University Physics Colloquium, Utah State University, Logan, UT, October 8, 2013.

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