# Arc Suppression Coatings for Spacecraft Cabling and Electrodynamic Tether Applications

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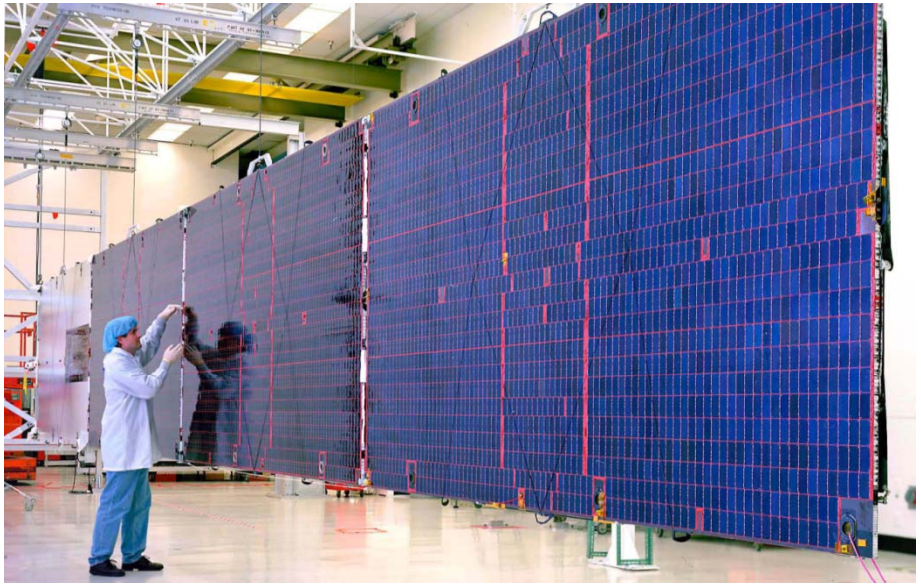
# Agenda

- Motivation
- Background on arcing processes
- Candidate materials
- Proof-of-concept experiments
- Experimental results
- Summary

# Arc suppression coatings are needed for space applications

- Applications include space tethers, solar arrays, exposed cable bundles on satellites

An electrodynamic tether tug



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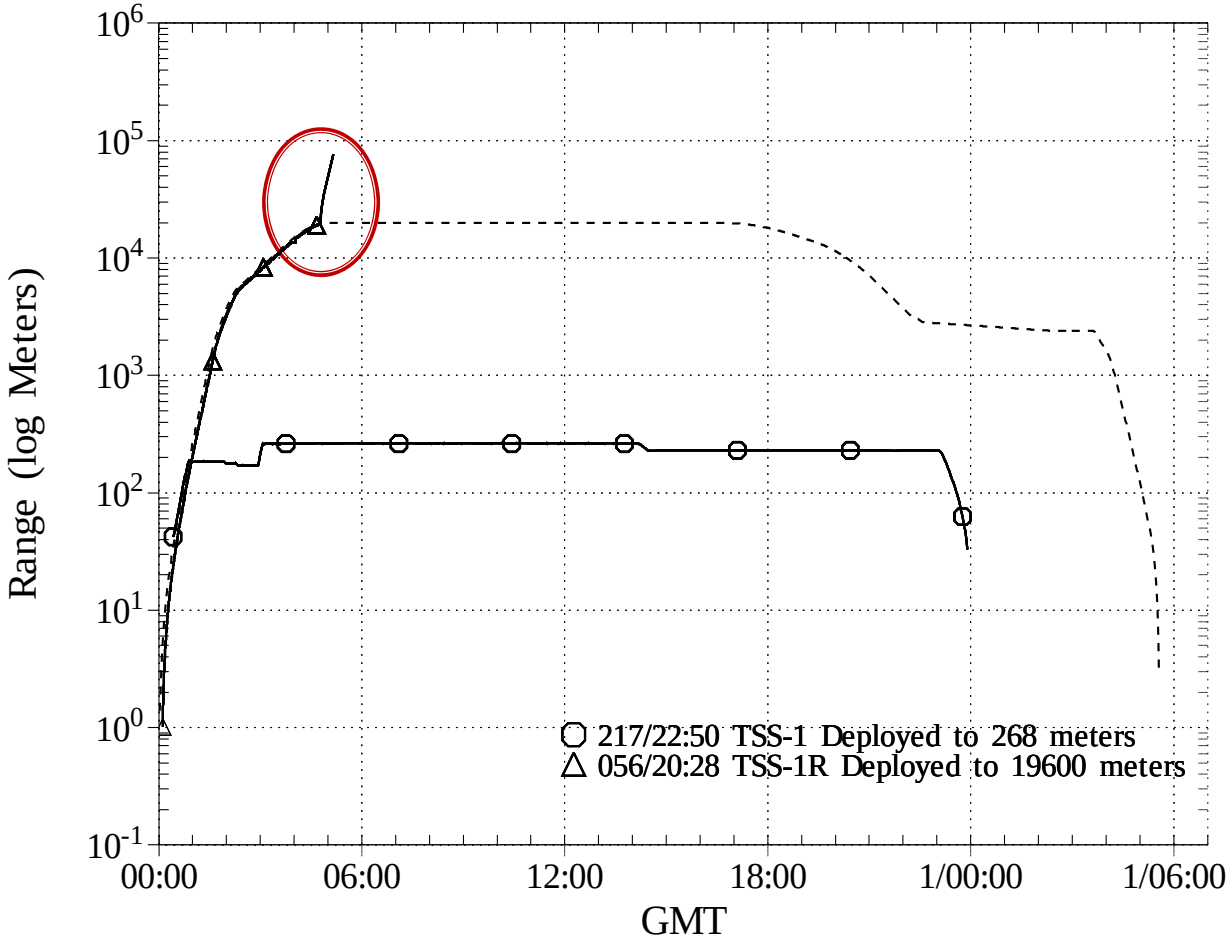
# Arcing can be catastrophic to electrodynamic tether systems




TSS during deployment

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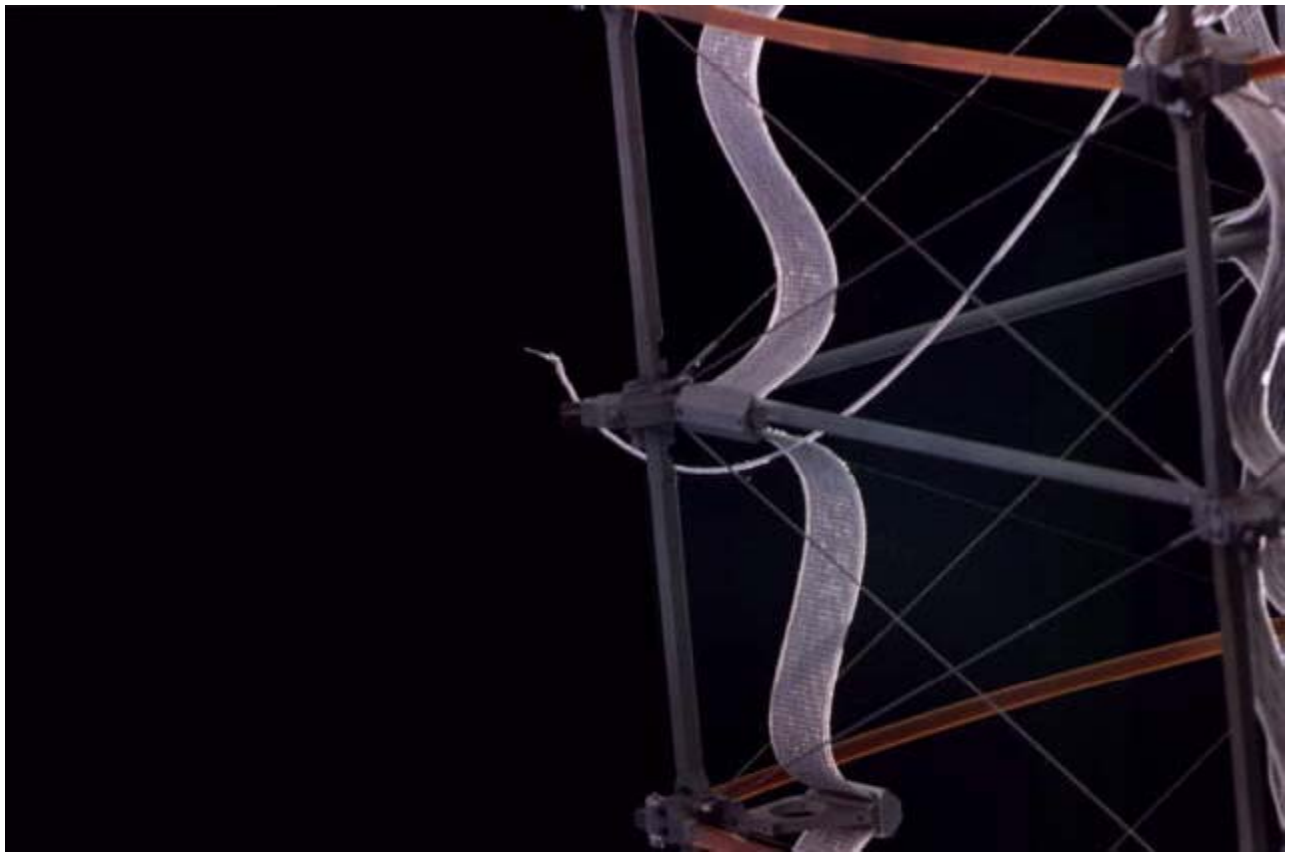
# Arcing can be catastrophic to electrodynamic tether systems



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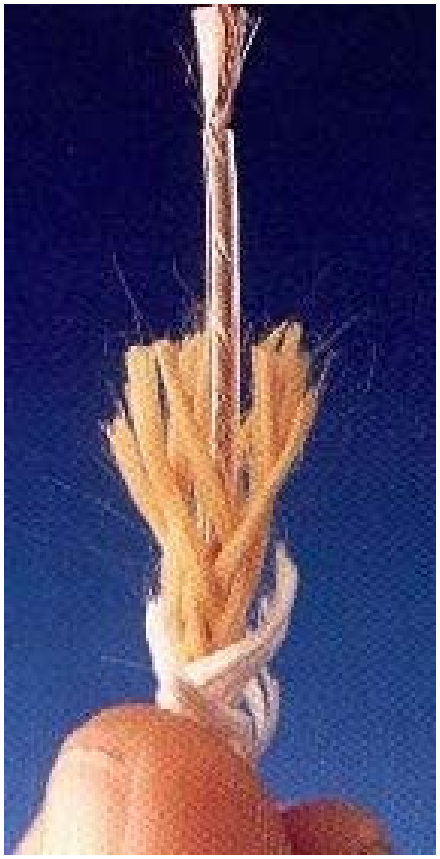
# Newer tethers coat metal directly to reduce trapped gases



TSS Tether

- Partially mitigates against arc sustainment
- Switching schemes can be used to minimize large voltage changes
  - Method was to be used on ProSEDS
- Coatings can also provide other desired properties, such as absorption/ emission

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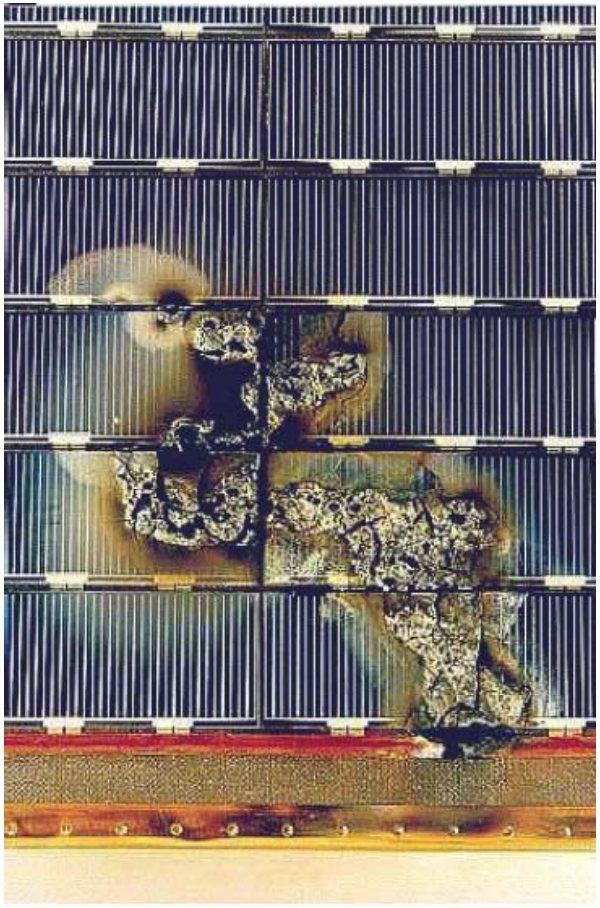
# Triple-point junctions provide locations for arcing



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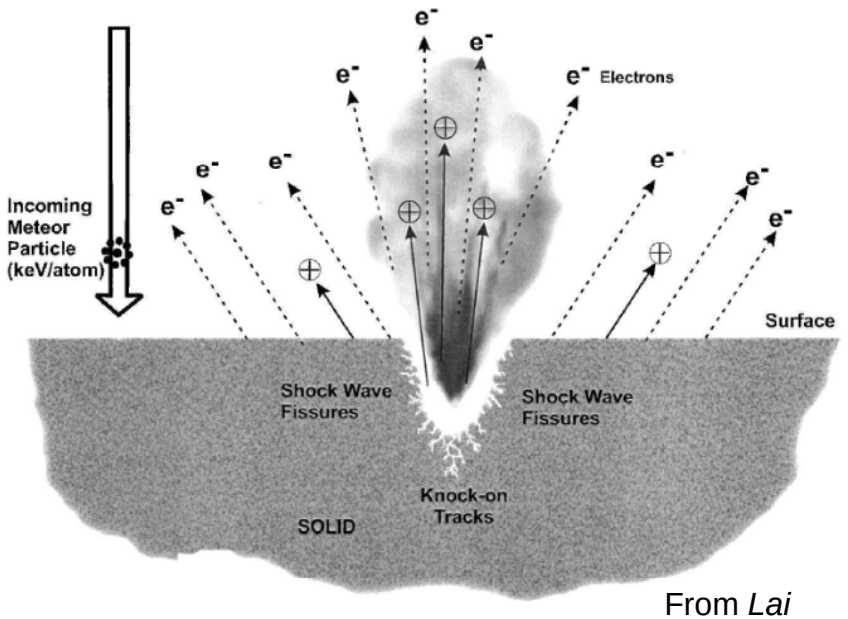
# Plasma and neutral gas are generated by the hypervelocity impact of particle on solid surface, providing mechanisms for arcing

- Two mechanisms occur for both insulated and bare (i.e., conducting) surfaces:
  - 1: generation of plasma cloud due to energy released
  - 2: ionization of material ejected as neutral gas
- For insulated case, once underlying conductor is exposed, third mechanism possible:
  - 3: development of arc due to "triple point"




From *Lai*

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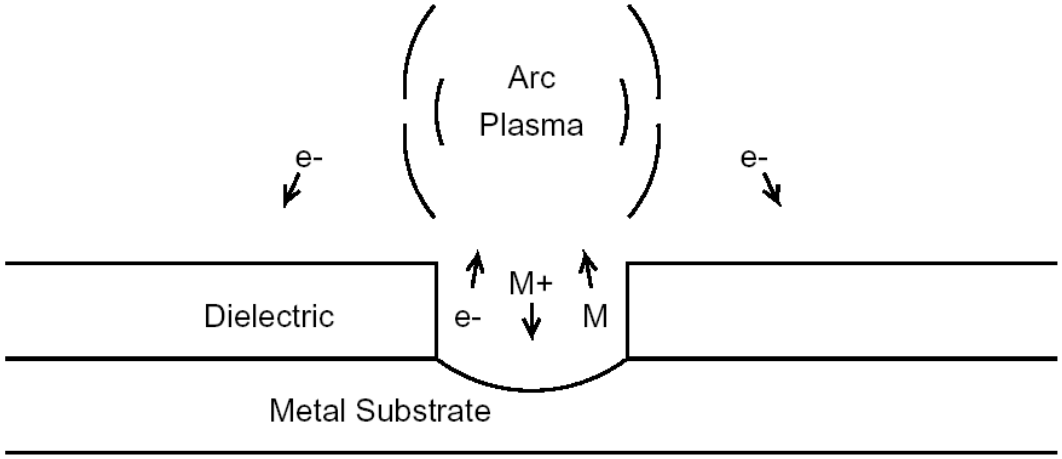
# Arcs can sustain themselves via "snap over" and "triple point"

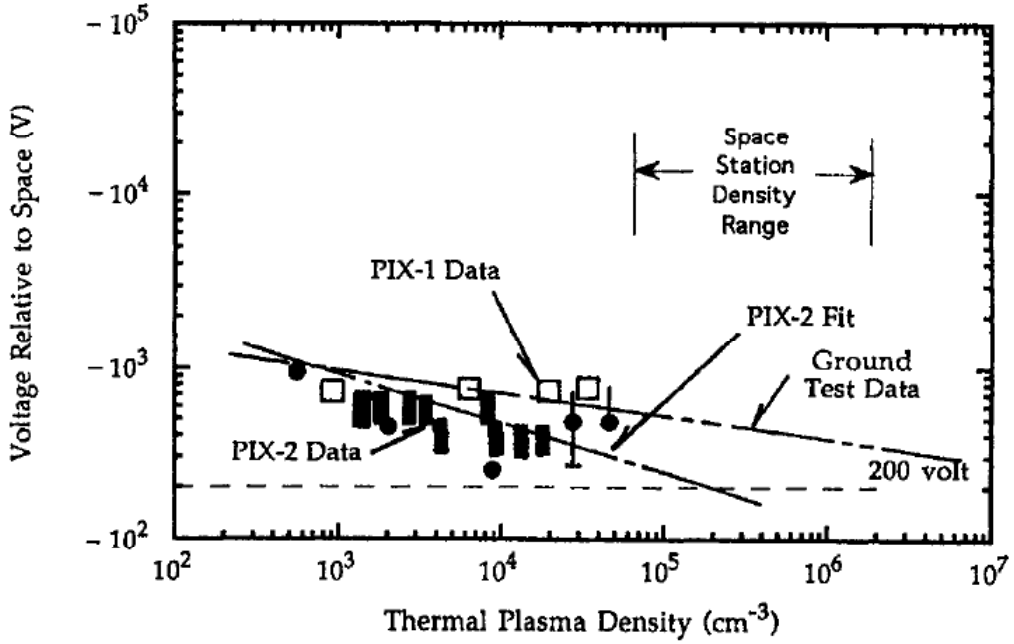
- Once begun, arc tends to collect electrons on the dielectric surface and focus ions back to metal surface or conductive arc surface




From *Snyder*

# Voltage breakdown is function of local plasma density

- Voltage limit between bare (or breached) conductors is <1000 V for almost all near space conditions
- For LEO satellites and proposed EDT systems (i.e., 200–500 km), limit on order of 300 V or less
- Hence, once a breach occurs, it is important that any continual arcing that eats away at insulation be stifled

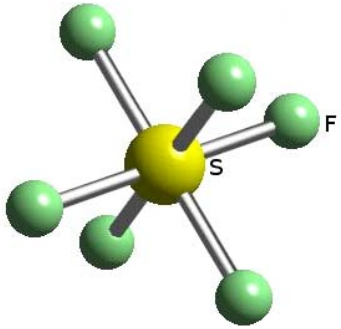



From *Latham*

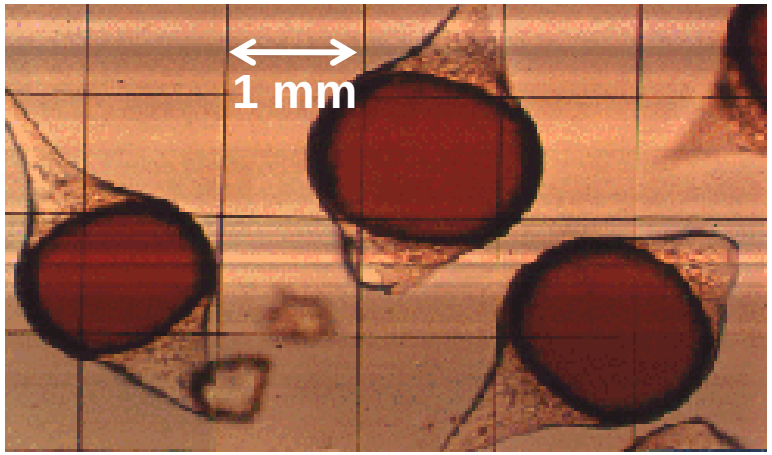
# We have investigated the use of arc suppressing gas or materials in coatings

- Performed proof-of-concept experiments to show that the presence of an electronegative gas could reduce prevalence of or, ideally, eliminate any arcing
- Researched other candidate materials
- Suggested methods for incorporation in coatings

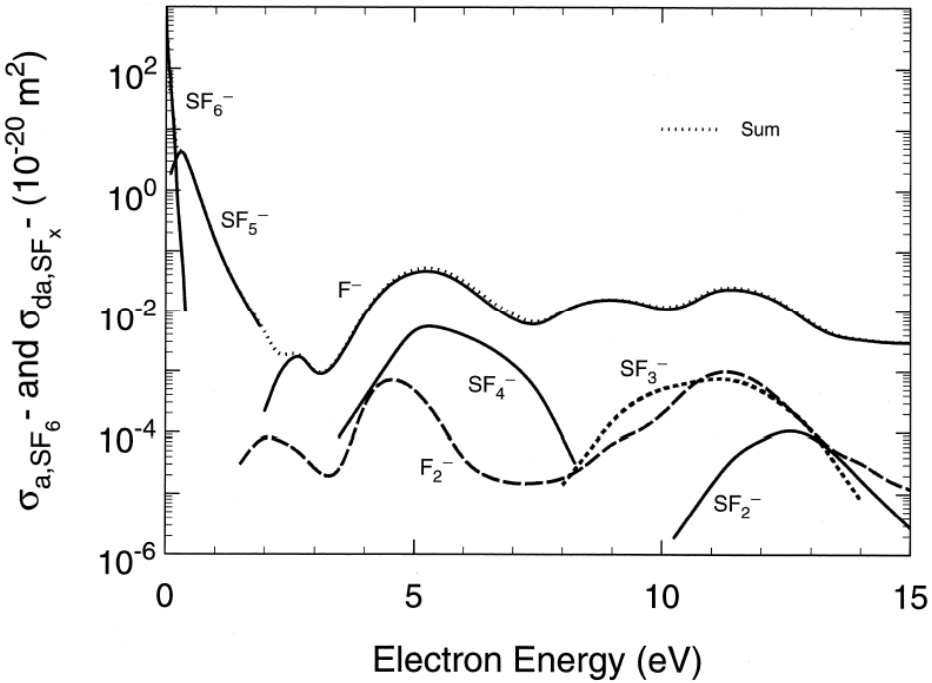
# Sulfur hexafluoride could be microencapsulated in coatings




$SF_6$ is highly electronegative




microencapsulated materials




Recommended cross sections for formational ions and suggested representing sum of all shown cross sections [from *Christophorou and Olthoff*, 2001]

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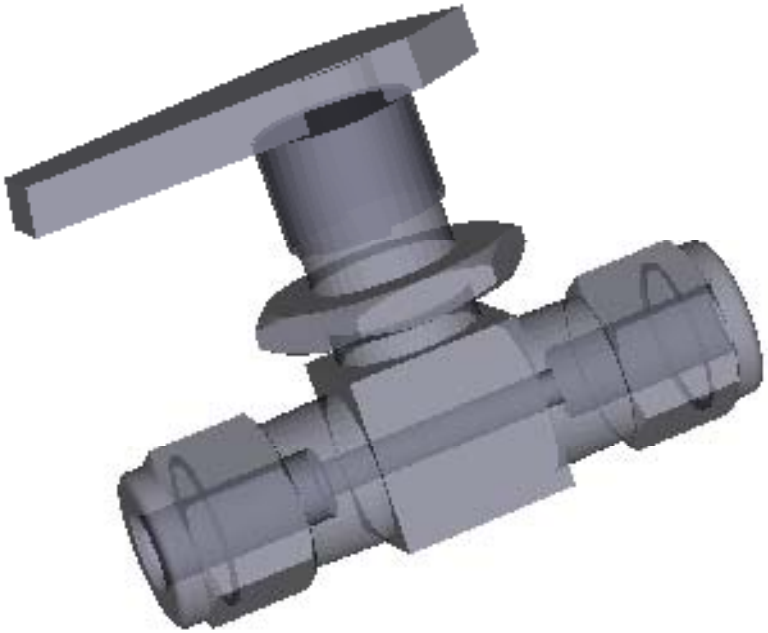
# Cavities were used as analog of microencapsulation

- Could defined trapped volume
- Simpler to use experimentally



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# Cavities were filled with $SF_6$, air, and left open

| Cavity | Gas | Pressure |
|---|---|---|
| 1 | ambient | ambient |
| 2 | air | 1 atm |
| 3 | $SF_6$ | 1 atm |
| 4 | $SF_6$ | 1 atm |
| 5 | $SF_6$ | 1 atm |

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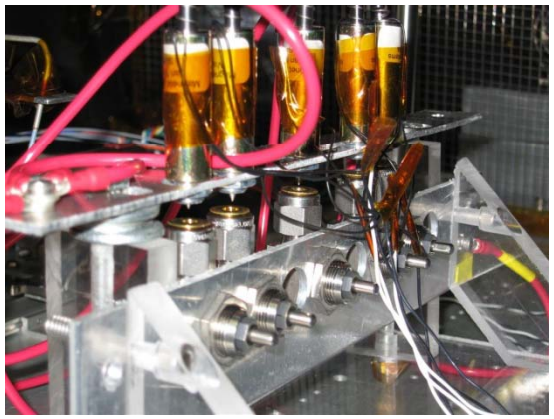
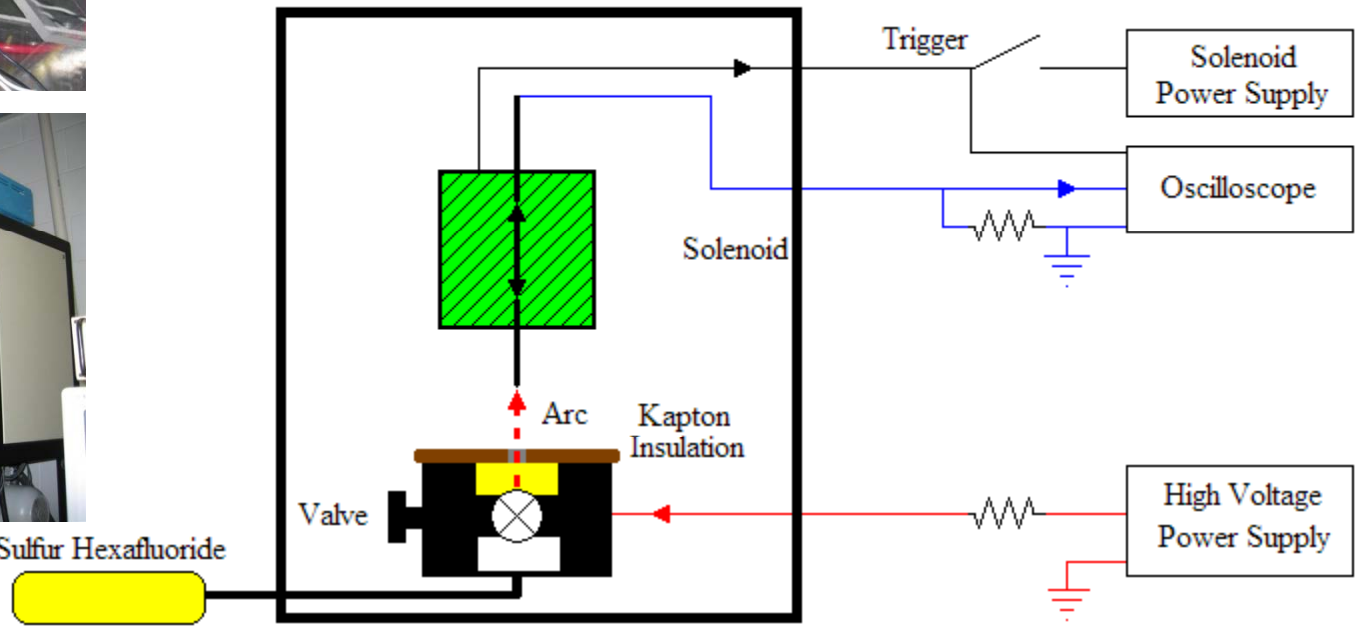
# Experimental apparatus was built and tests performed in vacuum environment



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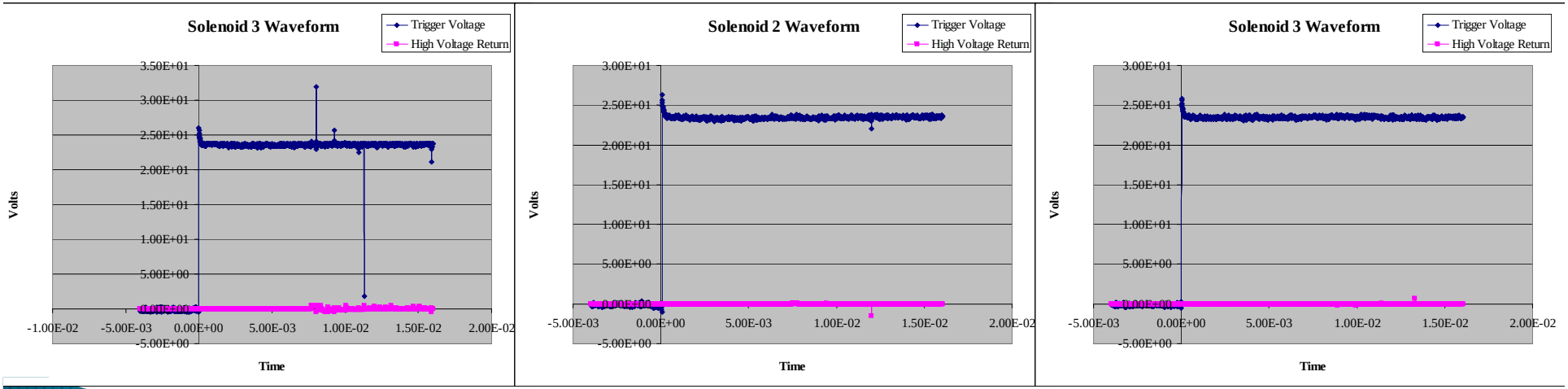
# Experimental results show that technique is feasible

- Presence of electronegative material nearby HV conductor with breached insulation can mitigate initial arc
- Arc mitigation depends on quantity of suppressant available and, even when available only in quantities that do not eliminate arc, it reduces severity of arc event and increases time before arc onset

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# Other candidate materials should be investigated

- Nanoparticles are interesting, e.g., Buckminster fullerenes “buckyballs” (most prevalent is of form $C_{60}$) with atomic structure that imparts unique properties: electrically insulating, highly electronegative, can be polymerized, can be sublimed, and can be dissolved
- Electron absorbing/adhering nanoparticles, such as simple elements like copper or nickel
- Variable conductivity silicon nanoparticles

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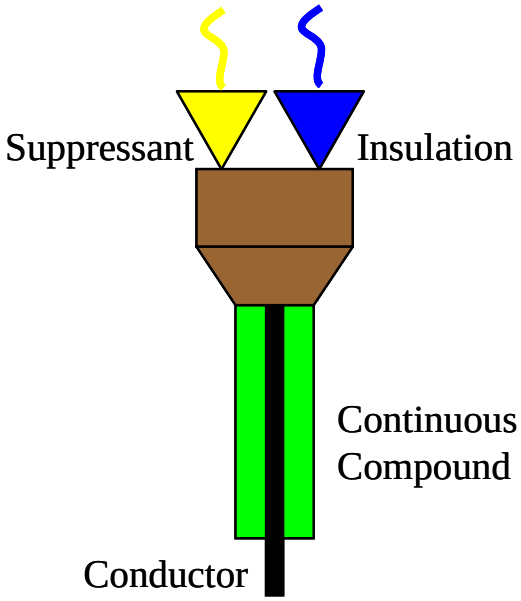
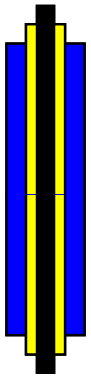
# Several potential methods could be used to incorporate insulating material (blue) and suppressant (yellow)

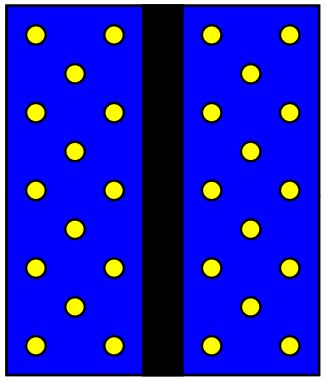



Adding suppressant directly within chemistry of existing coatings—figure shows two materials mixing together to form new material



Suppressant Layer Under Proven Insulation

Separate coating that would be applied as an interior layer



Encapsulated Suppressant Mixed Into Insulation

Mixing in chemically isolated encapsulated pockets of suppressant

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# Summary

- Arc suppression coatings are needed for space applications
  - Critical for EDTs
- Physics of impact and arc mechanisms are difficult to mitigate
- We have investigated use of arc suppressing gas or materials in coatings
- Experimental results show that technique is feasible
- Much more development work is needed