REVEALS Activities in Exploration, Graphene-based Antistatic Coatings Real-time & 2D Meta-material Radiation Detectors

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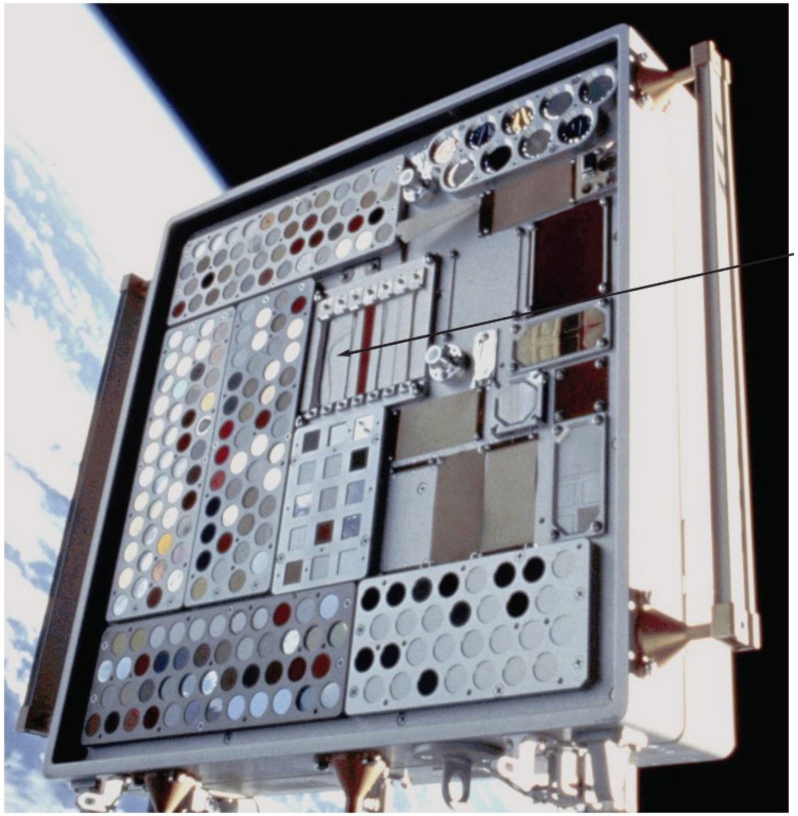
REVEALS Program and What We Do…



Finckernor, NASA Tech. Rep., 2017, 2003

- NASA SSERVI Overview
- REVEALS Research Center
- Research Into Volatile Formation
- Motivating Risk Factors of Space
- Active Dosimetry
  - Existing Technology
  - New Design
- Radiation Attenuation
- Radiation Shielding Material Design Considerations
- Development of New Composite Materials

SSERVI
SOLAR SYSTEM EXPLORATION RESEARCH
VIRTUAL INSTITUTE
Formerly the NASA LUNAR SCIENCE INSTITUTE

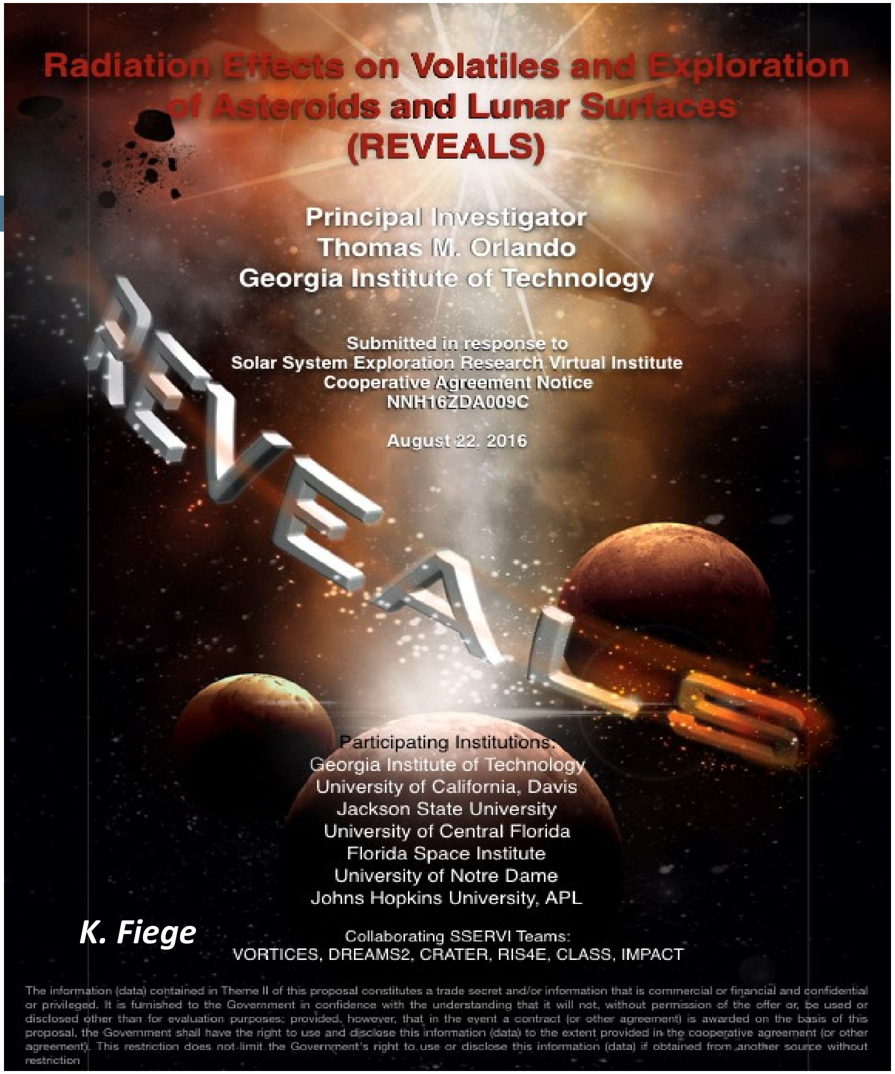
CLASS – Center for Lunar & Asteroid Surface Science

IMPACT

VORTICES – VOlatile Regolith Thermal Investigations Consortium for E

DREAM2 – Dynamic Response of the Environments at Asteroids, the Moon, and moons of Mars

RIS4E – REMOTE IN SITU AND SYNCHROTRON STUDIES FOR SCIENCE AND EXPLORATION



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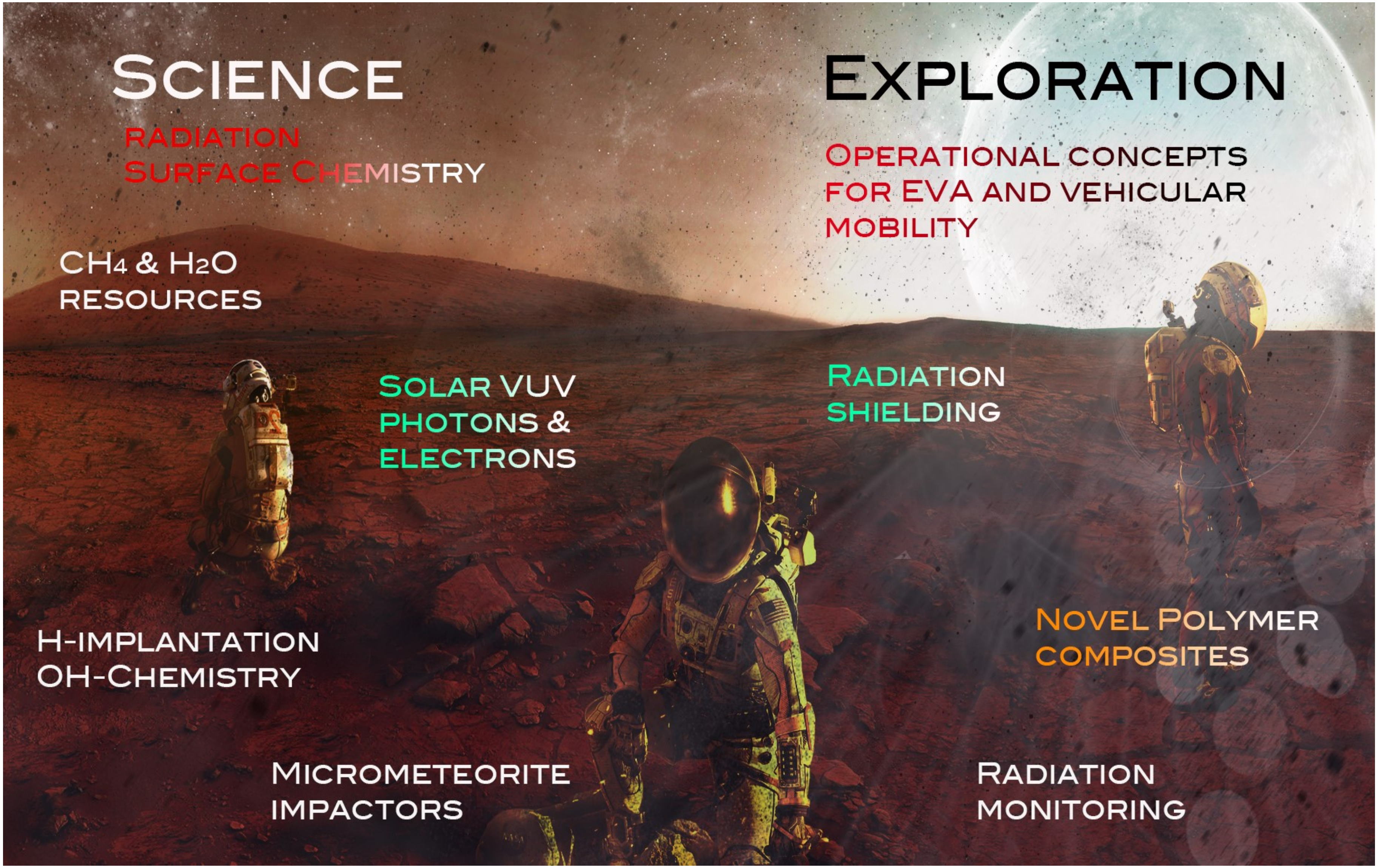
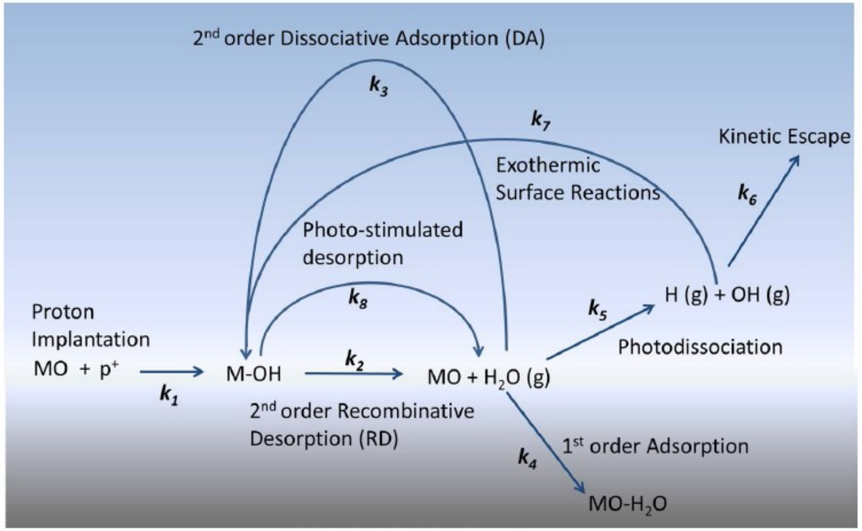

Science
Radiation
Surface Chemistry
Exploration
Operational concepts
for EVA and vehicular
mobility
CH4 & H2O
resources
Solar VUV
photons &
electrons
Radiation
shielding
H-implantation
OH-Chemistry
Novel Polymer
composites
Micrometeorite
impactors
Radiation
monitoring

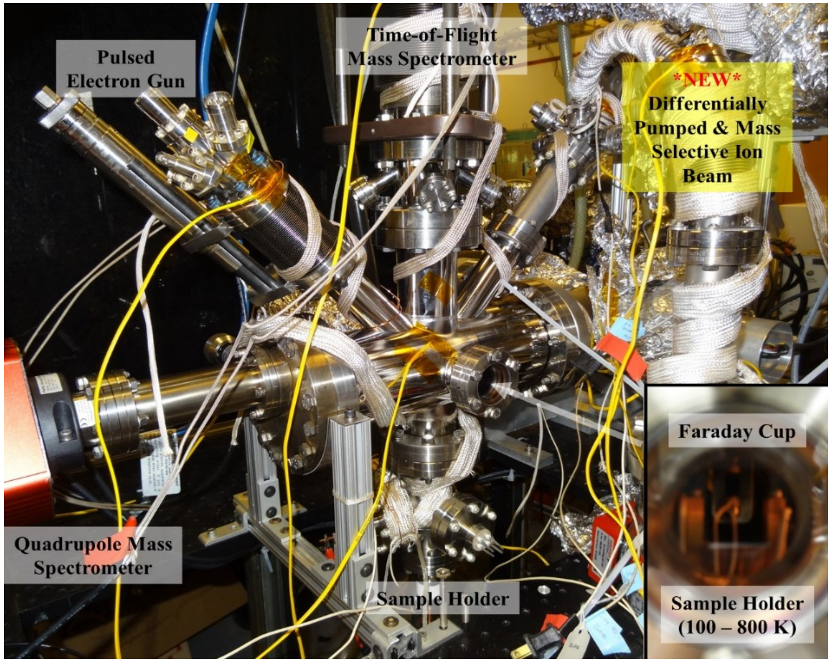
Radiation Effects on Volatiles and Exploration of Asteroids and Lunar Surfaces (REVEALS) Research Mission: To understand radiation effects on the chemical evolution of volatiles and develop human protection technologies that enable the long-term exploration and habitation of airless bodies within our solar system.

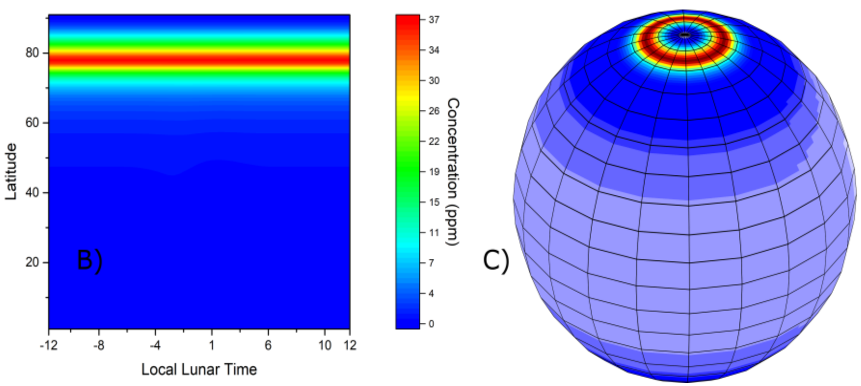
Theme I - Volatile (water) formation from radiation and micrometeorite interactions with airless bodies

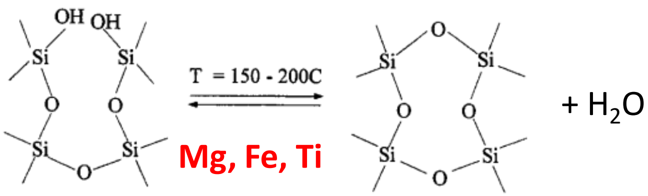
Theme II - New materials for radiation shielding and real-time dosimetry monitoring systems.

Solar wind proton interactions with regolith and water formation mechanisms

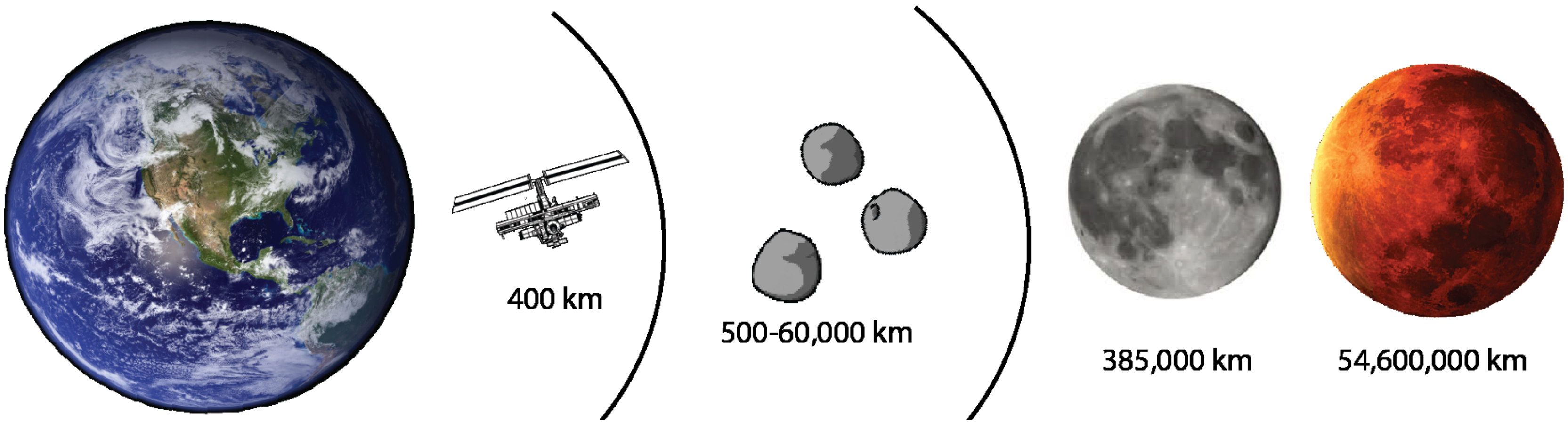






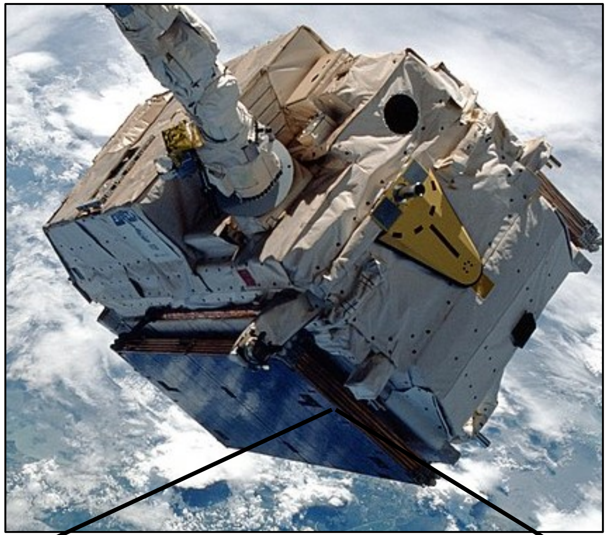


Radiation Monitoring and Shielding - Risk Factors of Space

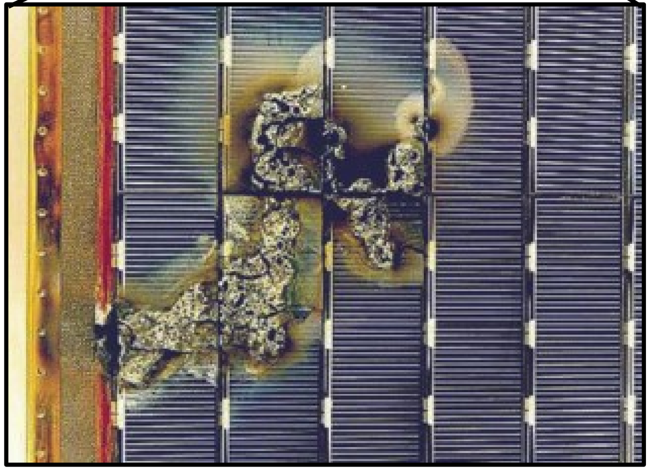


NASA, Types of Radiation, 2018
Finckernor, NASA Tech. Rep., 2017, 2003

Risk Factors of Space: Static Charging

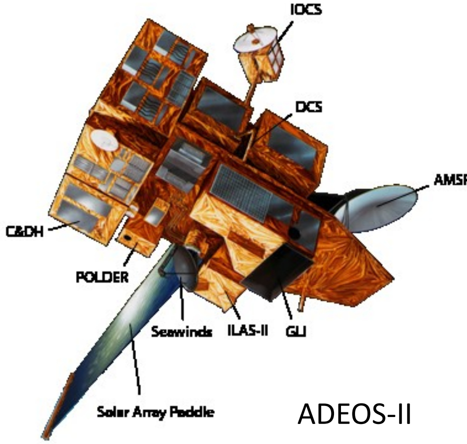


EURECA STS-57



- Examples:
  - Galaxy 15 – telecommunications satellite – 1 year delay
  - Advanced Earth Observing Satellite 2 (ADEOS-II) - destroyed
  - EURECA STS-57 – Solar cell damage
- Effects:
  - Electric shock
  - Instrument error
  - Equipment failure

Commercial anti-static coatings ≈100 MΩ



ADEOS-II

Personal Dosimeters

1) Novel Capabilities in Terrestrial Personal Radiation Dosimeters Yet Unused in Space

- Currently used NASA personal dosimeters (ISS): **Passive dosimeters**
  * **To be returned to ground** upon mission completion for analysis
  * **No in-flight exposure information**
  * Integral exposure information over entire mission, **no time resolution**

2) Technology Need for Exploration Mission 2 and Beyond

- **Requirements**: Need for wearable **personal <u>active</u> dosimetry**, capable of:
1) Measuring **time resolved** and time integrated absorbed dose
2) Operating for 30 days without being charged or requiring data download
3) Being read out by the crew via a **display on the dosimeter**

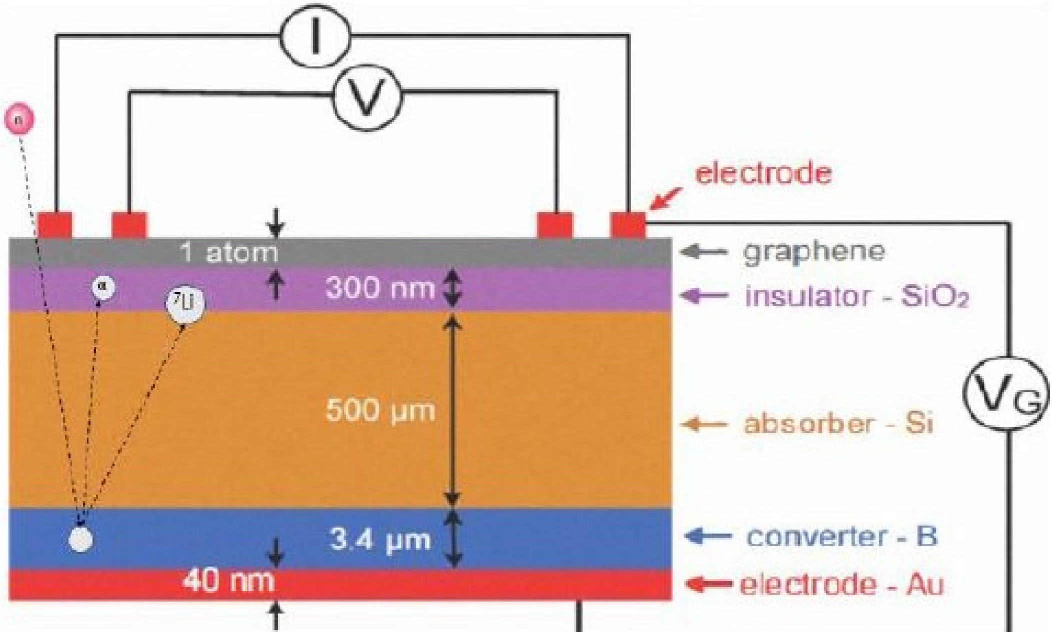
Requirement not met with existing NASA radiation hardware (passive dosimeters)

..maybe new materials/devices are required?.

9/21/2016 Martin Leitgab, NASA Space Radiation Analysis Group

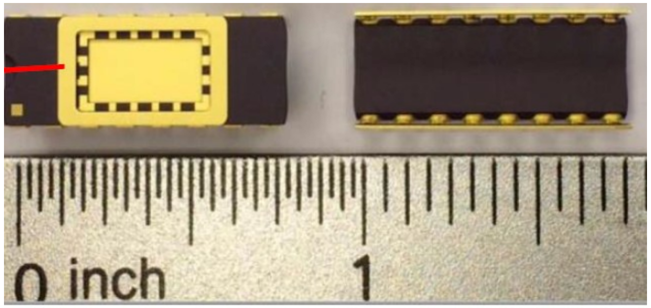
New Dosimetry Approach:

Operation: Changes in local electric fields arising from neutron capture impair e^- mobility in graphene layer allowing neutron flux to be observed by monitoring changes in resistance across the graphene layer.



Key Benefits:

- Small in size
- Cumulative and real-time dose measurements
- Only requires power during resistance measurement
- Mission-scale lifetimes



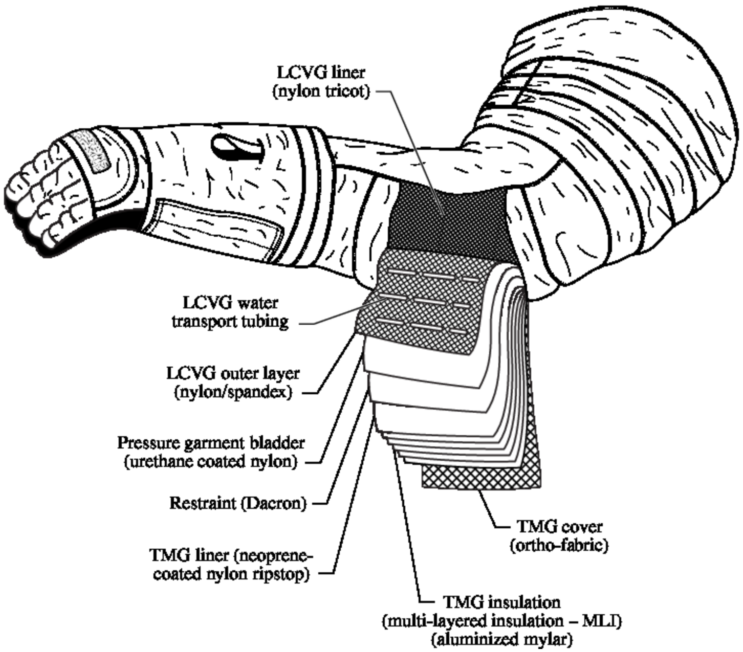
Radiation Attenuation

1) Absorb radiation
- Radiation-induced radical formation
- Quench or stabilize through resonance
- Short-term approach
- Heavy metals, polysulfones

Wiki Commons

2) Maximize H content
- Best at slowing particle-based radiation
- Limit degradation through robust chemistry
- Best long-term approach
- Water, polyethylene, LH2

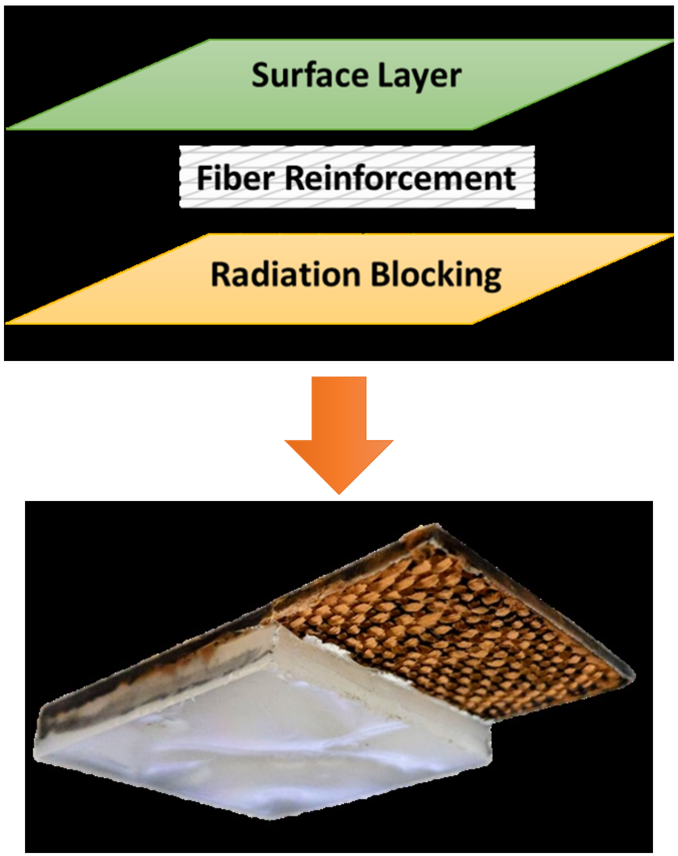
Multi-Functional Composites: Design Considerations



- Most polymers are insulating, which builds **static charge**!
- Must withstand **micrometeoroid impact**
- Provide mechanical reinforcement
- **Radiation Effects**
  - **UV exposure** in the presence of atomic O is devastating to polymer fibers (and most organic materials)
  - **Solar Particle Events** and **Neutrons** can initiate degradation through more sophisticated pathways due to radical generation.
  - **Galactic Cosmic Rays** are extremely difficult to stop but aren't the leading cause of damage due to small size and low frequency

Wilson et al., NASA 20040065987, 2003

Ultimate Goal – Multilayer Composite



1) Surface Layer
- Dissipate static charge
- Radiation attenuation
- Impact resistance
- UV resistance

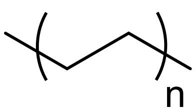
2) Fiber Reinforcement
- Mechanical Properties
- Radiation attenuation

3) Radiation Attenuation Layer
- Maximize Radiation attenuation
- Tunable thickness

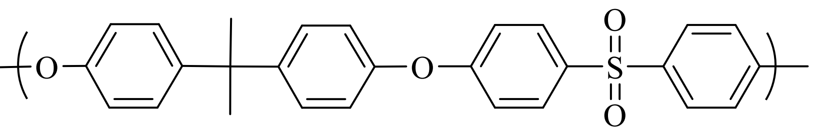
Realizing Conductive Radiation Shielding Materials

Thermoplastics

- Scalable chemistry
- Range of performance tunability
- Radiation attenuators
- Versatile fabrication
- Not generally conductive



Polyethylene



Polysulfone

Graphene

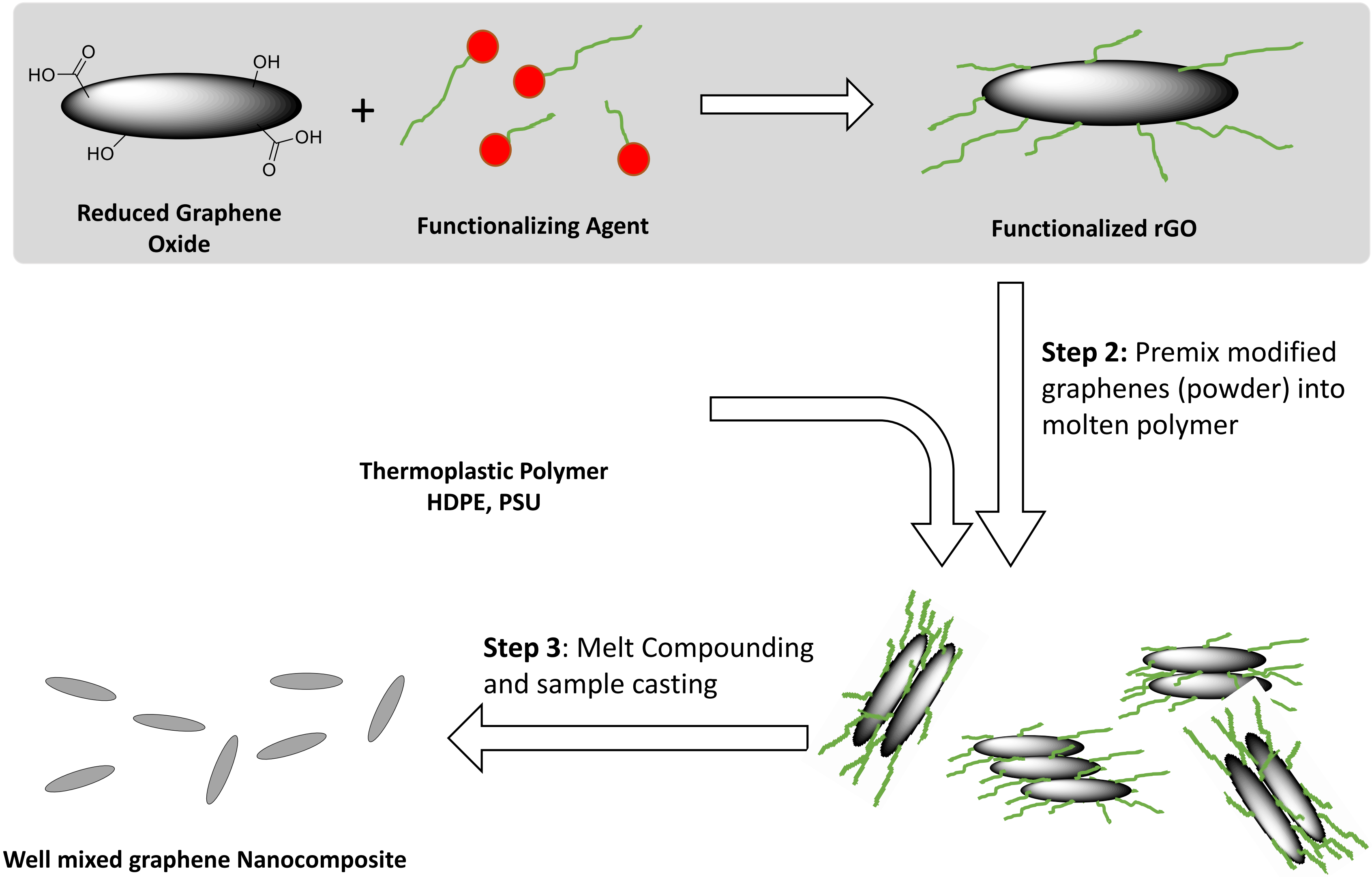
- Simple chemistry
- High conductivity
- Excellent mechanical properties
- Not readily miscible

Reduced graphene oxide

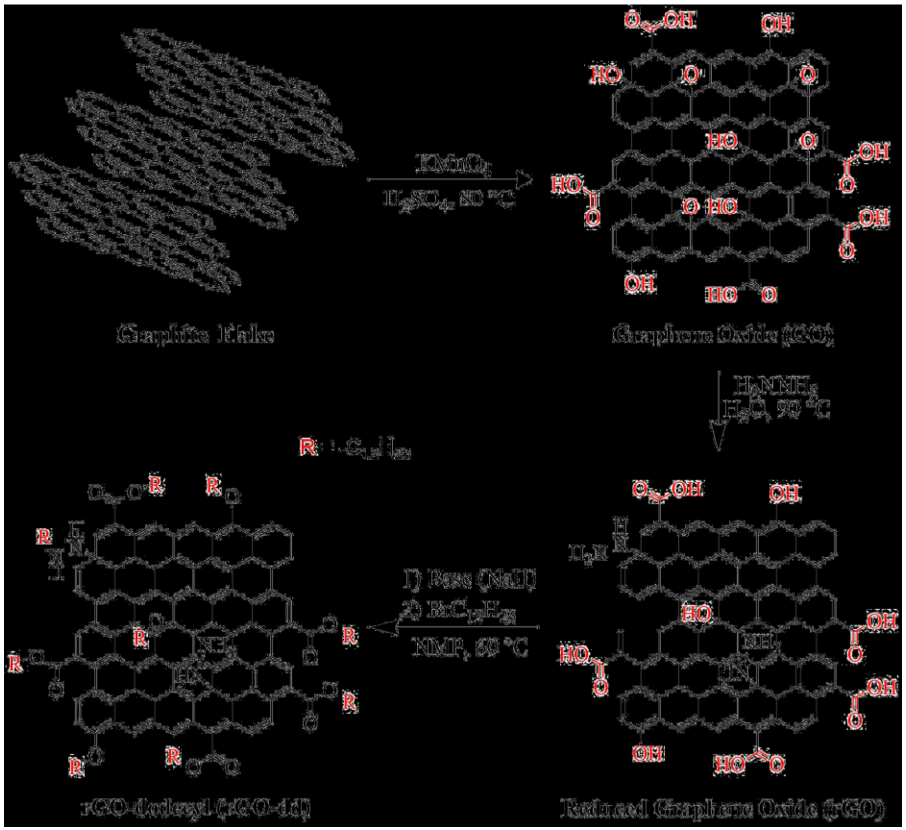
Melt Compounding HDPE-rGO Composites

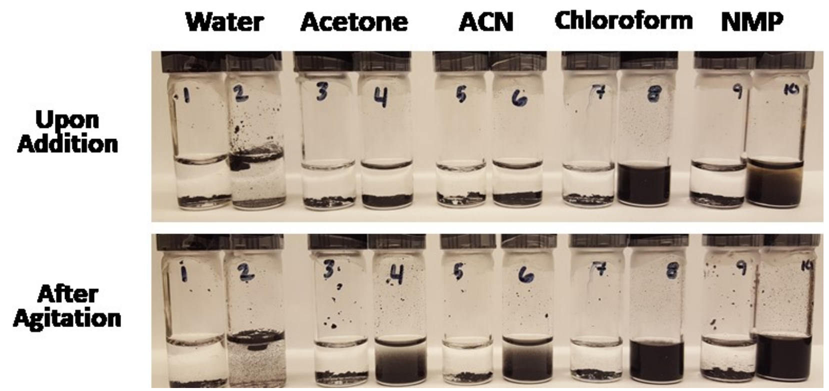
Approach: Synthesize chemically modified reduced graphene oxides to enhance miscibility in a polyethylene matrix to confer electrical conductivity and enhanced mechanical properties.

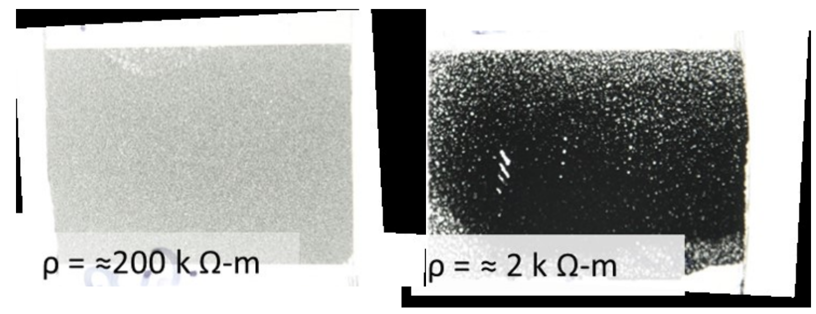
Composite Formation Process



Synthesis & Properties of Modified rGO

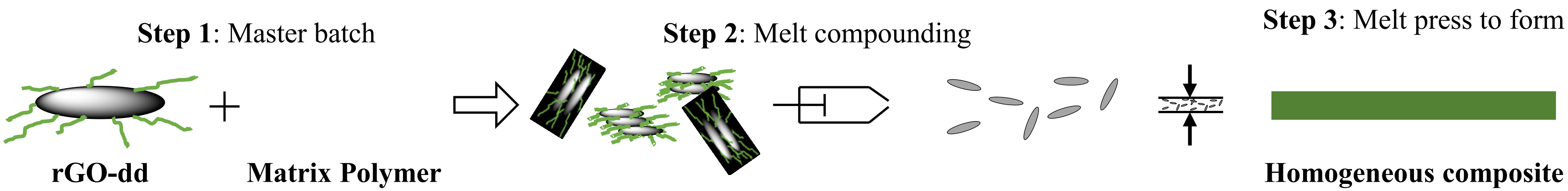


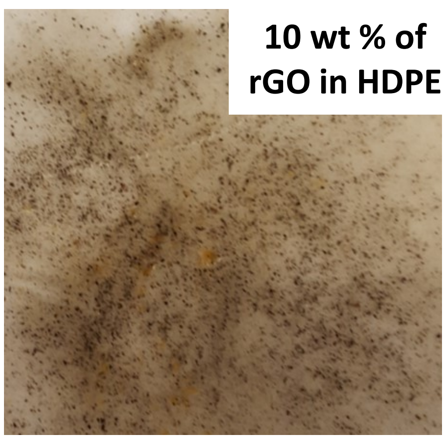




Material	t [mm]	ρ [Ω-m]	σ [S cm^{-1}]
Graphite	0.20	3.4×10^{-6}	2940
GO	Insulator		
rGO	0.14	1.3×10^{-5}	750
A-rGO	0.17	3.0×10^{-5}	340

Melt Compounding

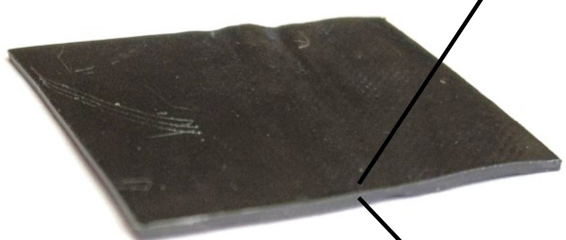




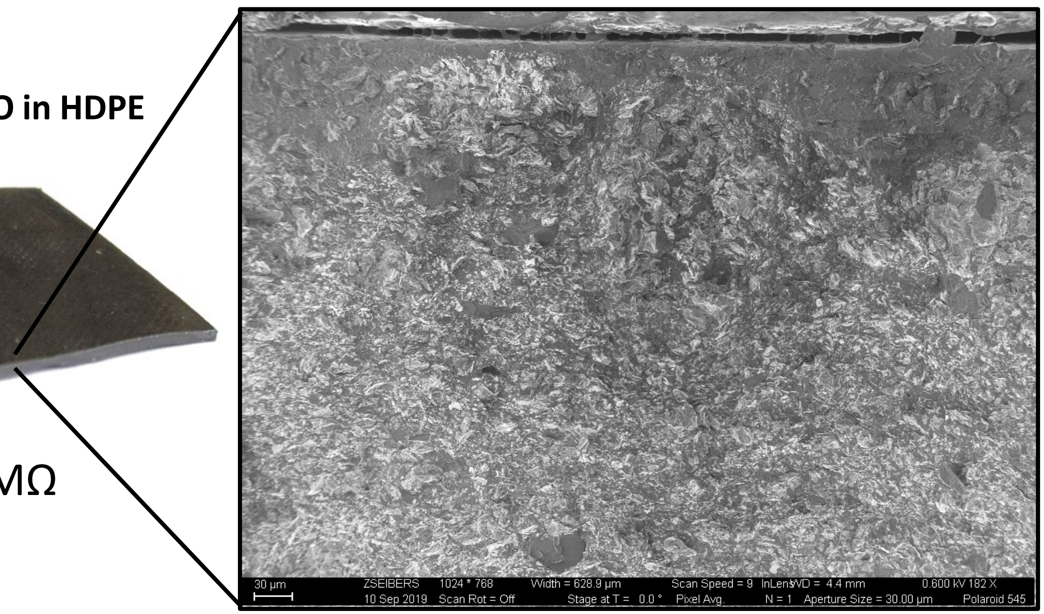
10 wt % of rGO in HDPE

Not Conductive

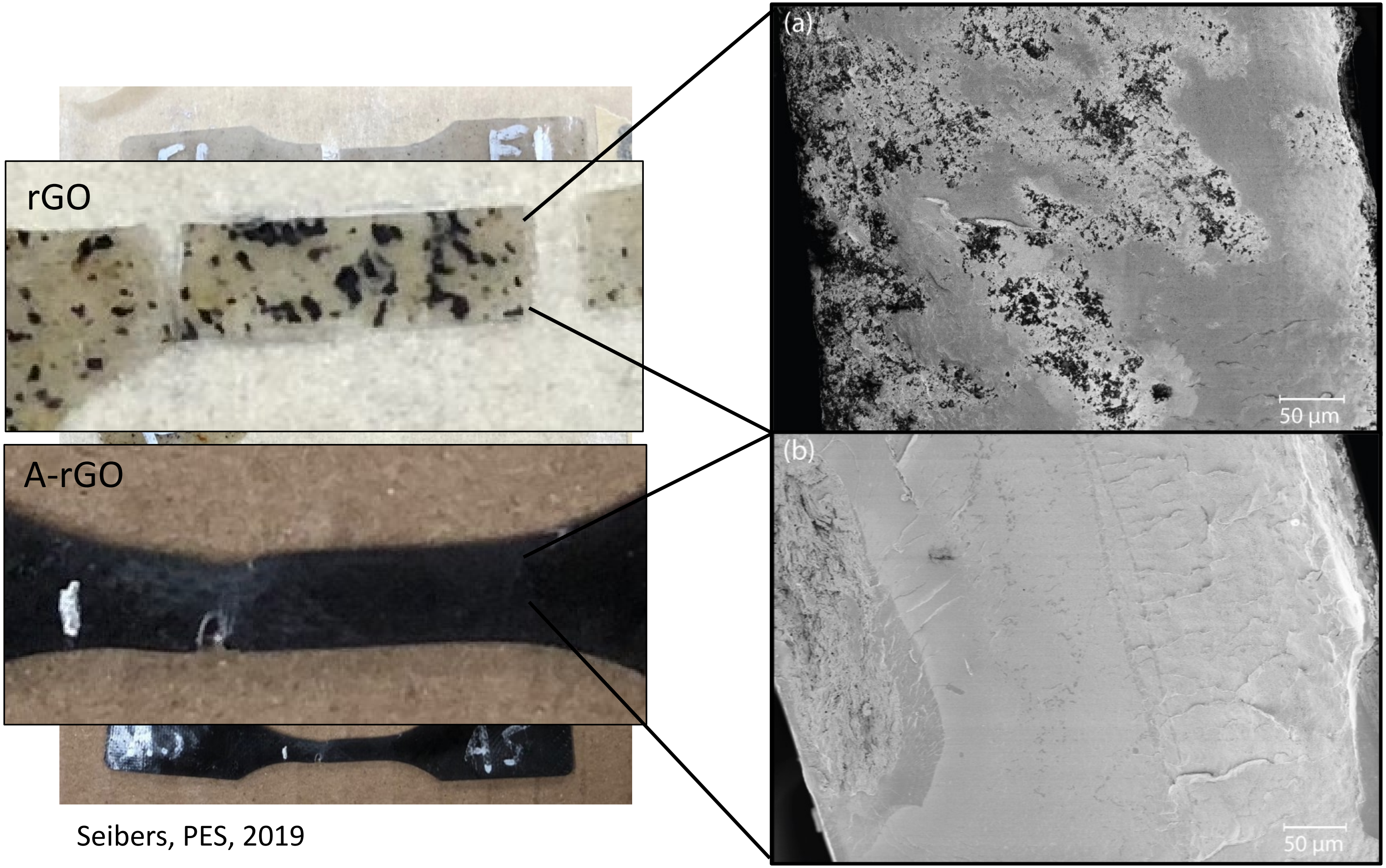
10 wt % of A-rGO in HDPE



$R_S \approx$1-10 MΩ



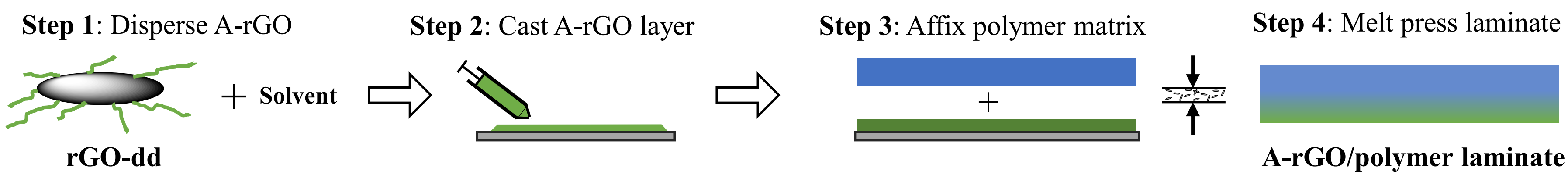
Dispersion and Failure Mode



Seibers, PES, 2019

Melt Lamination

Melt Lamination



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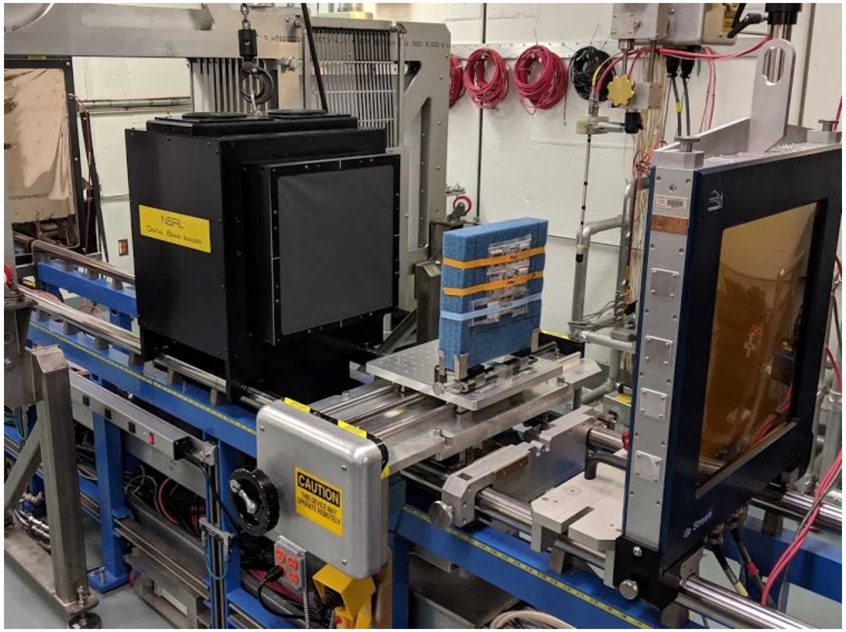
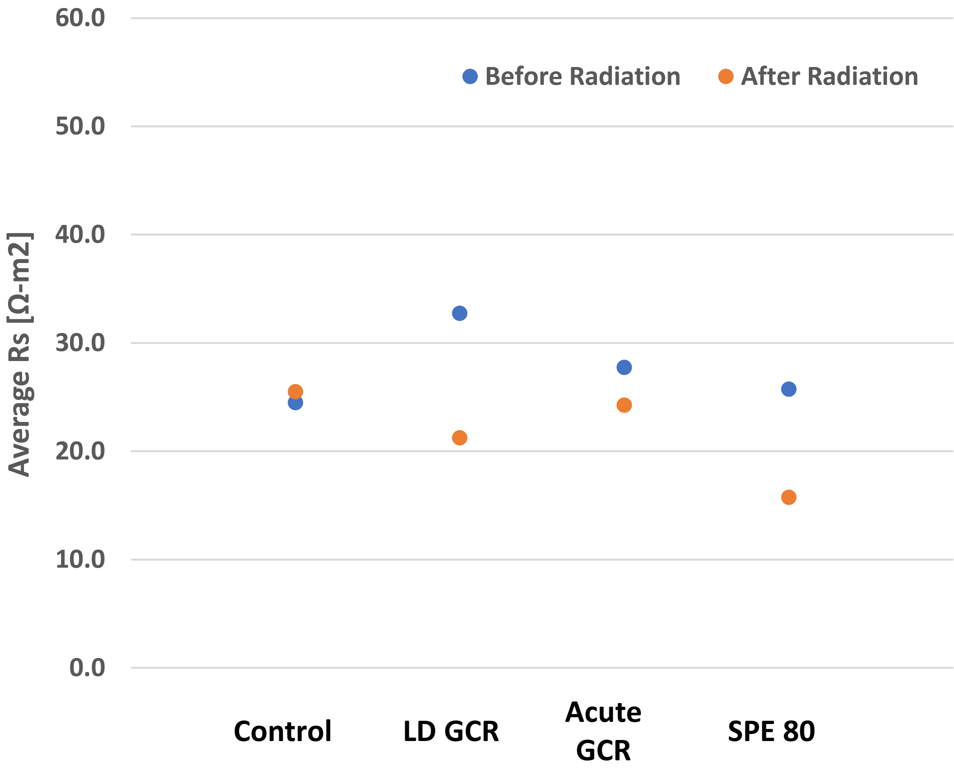
rGO	0.14	1.3 x 10^{-5}	750
A-rGO	0.17	3.0 x 10^{-5}	340
Laminate	--	2.6 x 10^{1}	
10% in HDPE		1-10 x 10^{6}	

Simulating Space Radiation at NSRL

- Galactic Cosmic Ray at low and acute dose rates to 80 cGy
- Solar Particle Event 80 cGy

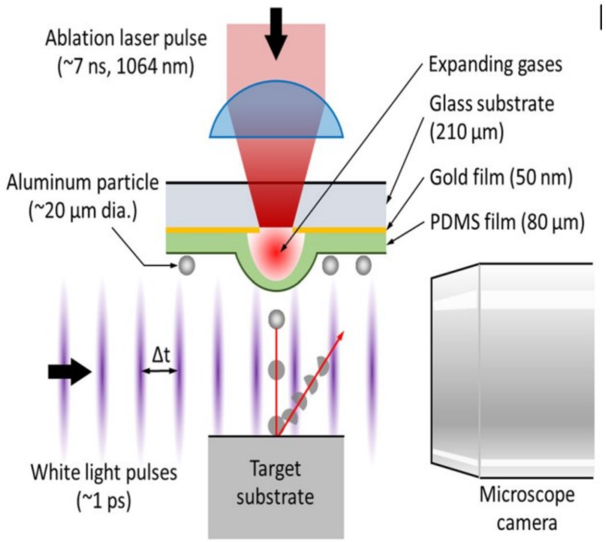




Key Takeaways

$R_S \approx 10\ \Omega$

- Developed facile synthetic strategy to increase the miscibility and processability of rGOs
- Demonstrated multiple manufacturing methods to suit different application-specific needs
- Simulated radiation exposure appears to have no significant effect on graphene material



Moving Forward

- Continue exploring the durability of composite materials to space hazards including radiation exposure and micrometeoroid impact
- Incorporate graphenes into fiber-reinforced multi-layer composites
- Implant active dosimetry devices directly into composite

Acknowledgements

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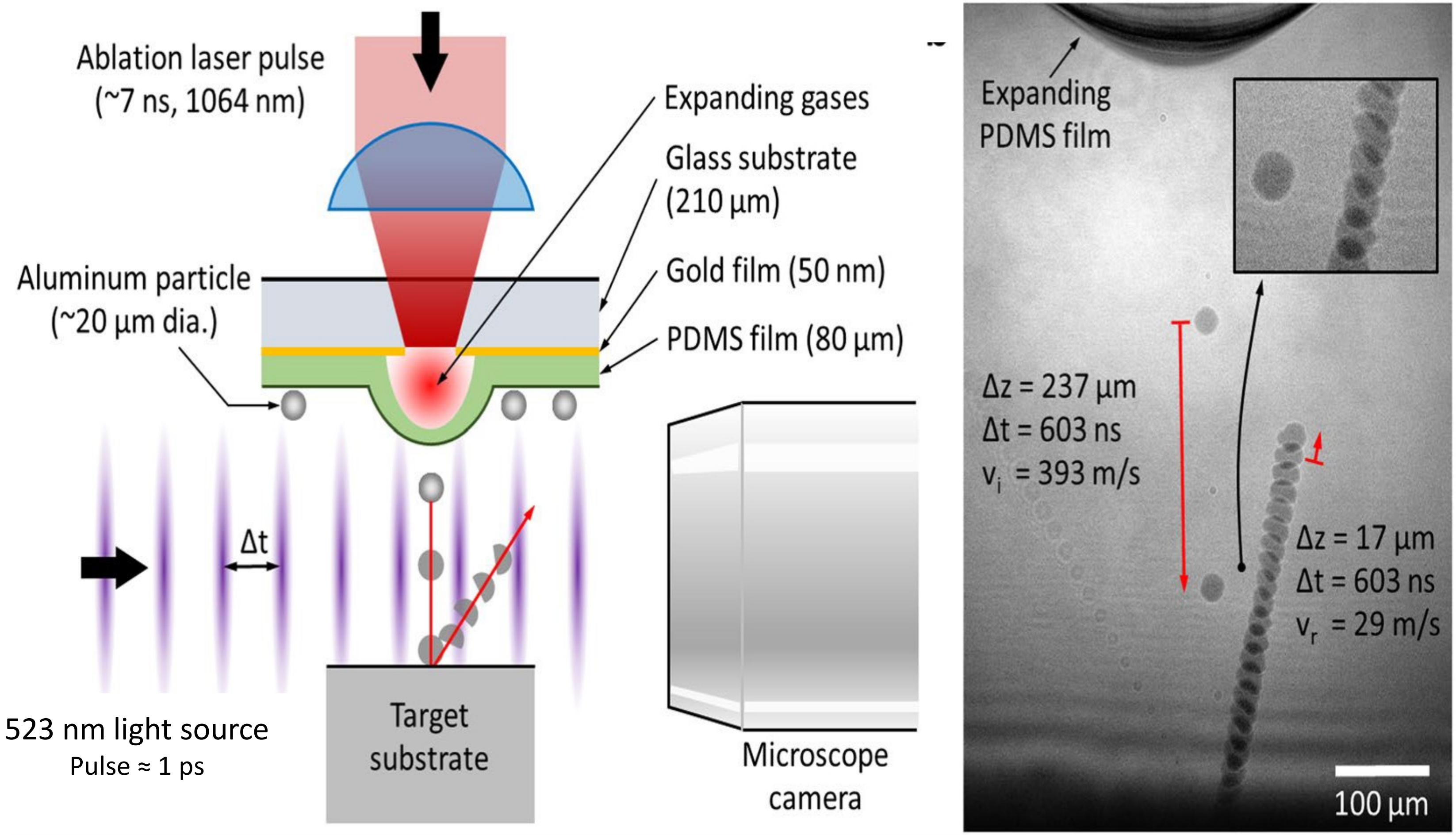
Simulating Micrometeorite Impact Events



Xie et al. Sci. Rep. 2017, **7**, Article number: 5073.