

Constraints on Relativistic Runaway Electron Avalanches on Mars from Long-Term In Situ Electron Measurements during Dust Events

WRMISS 2026

Jan Leo Löwe, S. Löffler, D. Matthiä, R.F. Wimmer-Schweingruber, S. Khaksarighiri, D.M. Hassler, B. Ehresmann, J.Guo, T. Berger, C. Zeitlin, G. Reitz

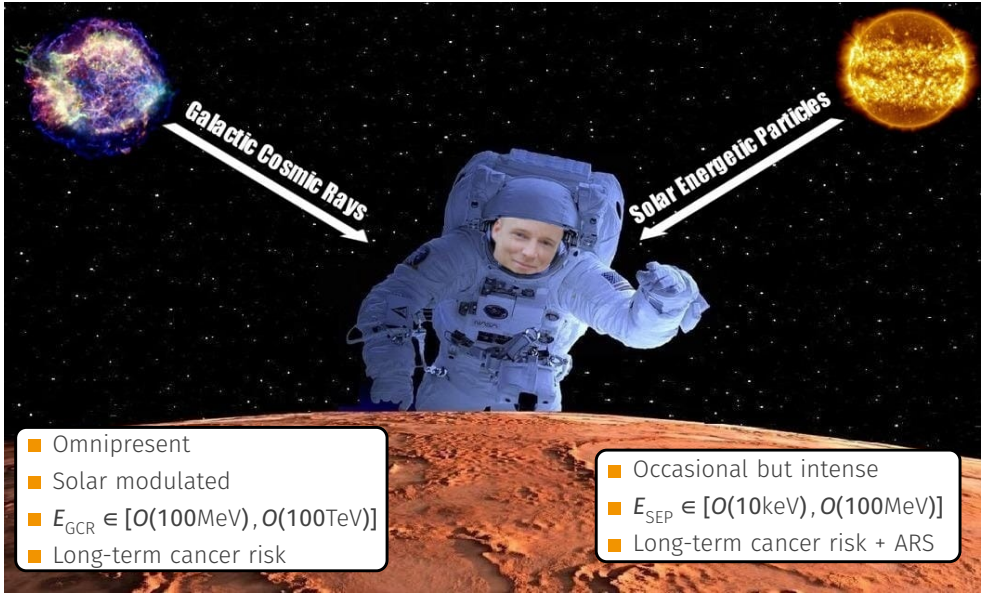
2. September 2026

CAU Kiel: Extraterrestrial Physics

Radiation Environment in Deep Space



Radiation Environment in Deep Space

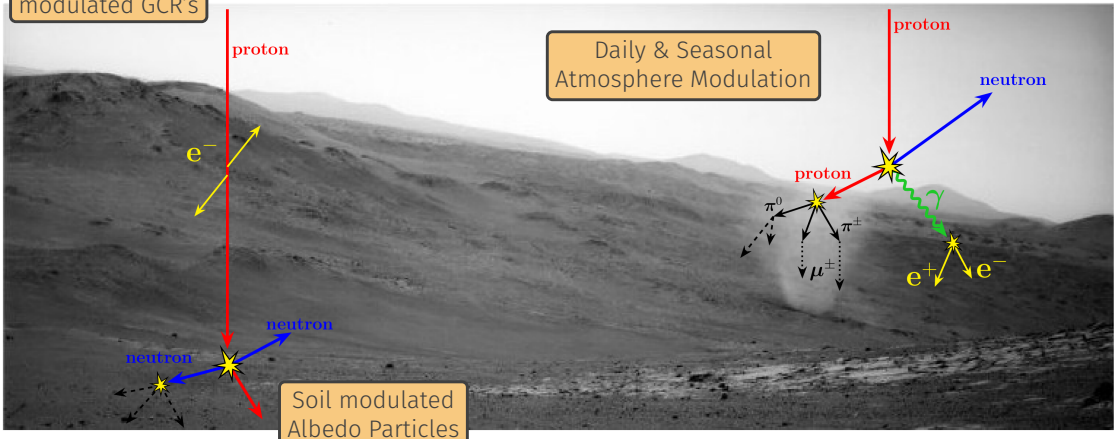


Radiation Environment on Mars

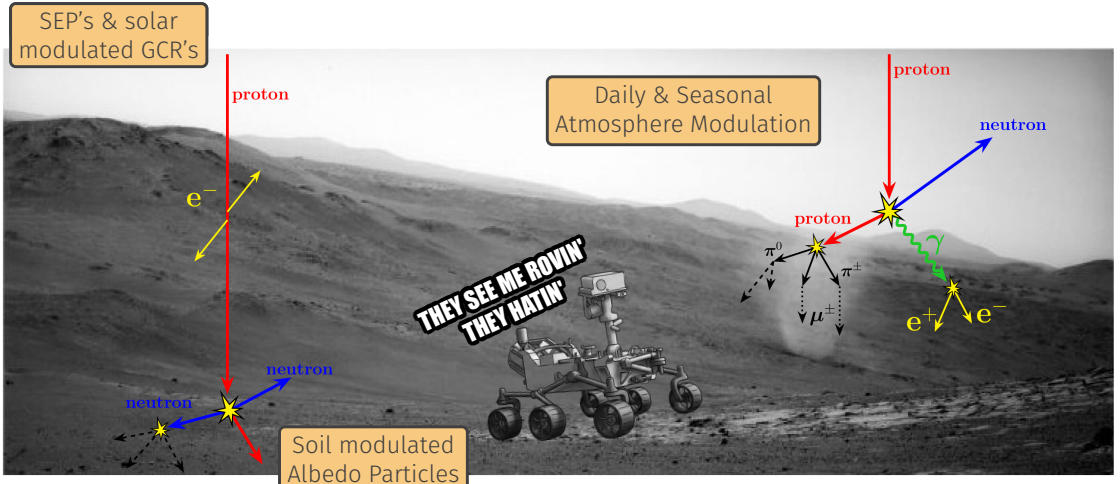
SEP's & solar modulated GCR's



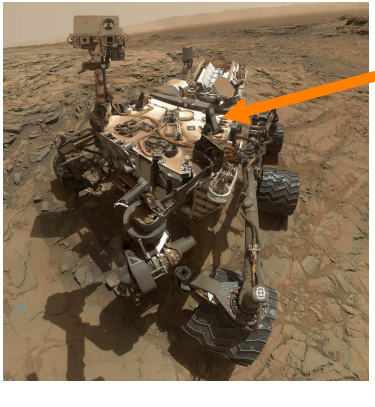
Radiation Environment on Mars

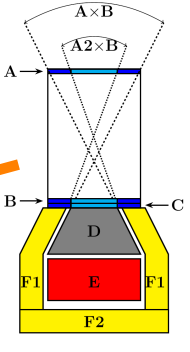


Radiation Environment on Mars



Radiation Environment on Mars



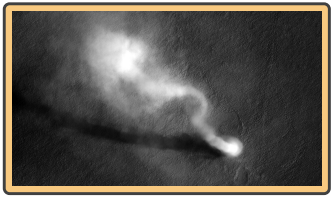


Dust Activities on Mars

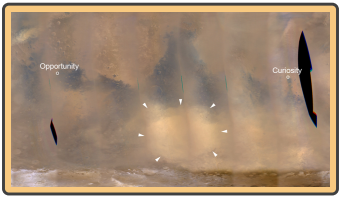
Images Credit:
NASA/JPL-Caltech/MSSS



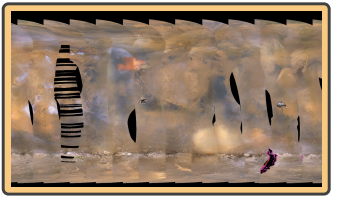
Dust Devils



Regional Dust Storm



Global Dust Storm

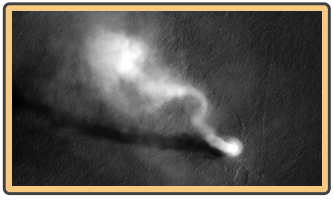


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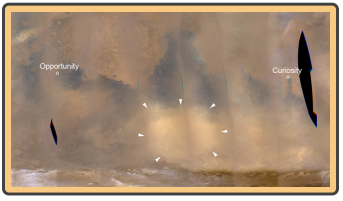
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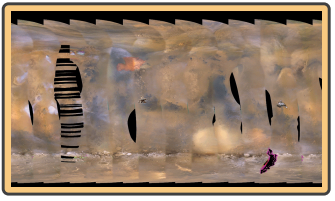
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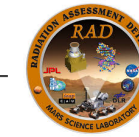
Global Dust Storm



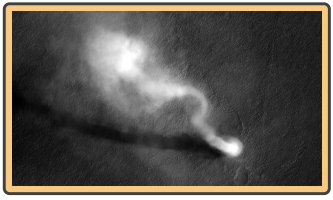
- Independently of season
- Observed at nearly all locations
- Diameters: 0.1-1 km
- **Heights: Up to 5-10 km**
- Lifetimes: 5–30 minutes

Dust Activities on Mars

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Dust Devils



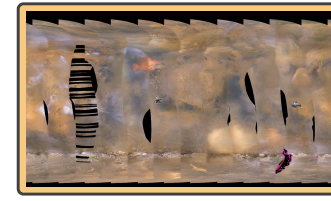
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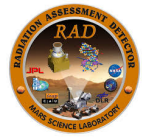
- Coalescence of smaller local storms
- Common seasons: southern spring & summer
- Covered areas: ≥ 1.6×10^6 km^2
- Heights: Up to 40 km
- Lifetimes: 10-20 days

Global Dust Storm

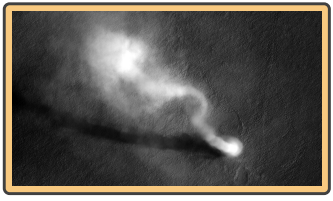


Dust Activities on Mars

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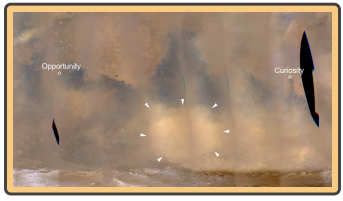


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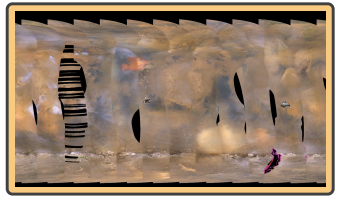
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Regional Dust Storm



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Global Dust Storm



- Planet-encircling
- Rare (Last event 2018)
- Heights: Up to 60 km
- Lifetimes: Weeks - Months

Dust Activities ⇔ Radiation Environment


Calbuco Volcano


Calbuco Volcano (Chile), 2015


Sakurajima Volcano


Sakurajima Volcano (Japan)


Taal Volcano (Philippines), 2020

’Lightning’ on Mars



’Lightning’ on Mars



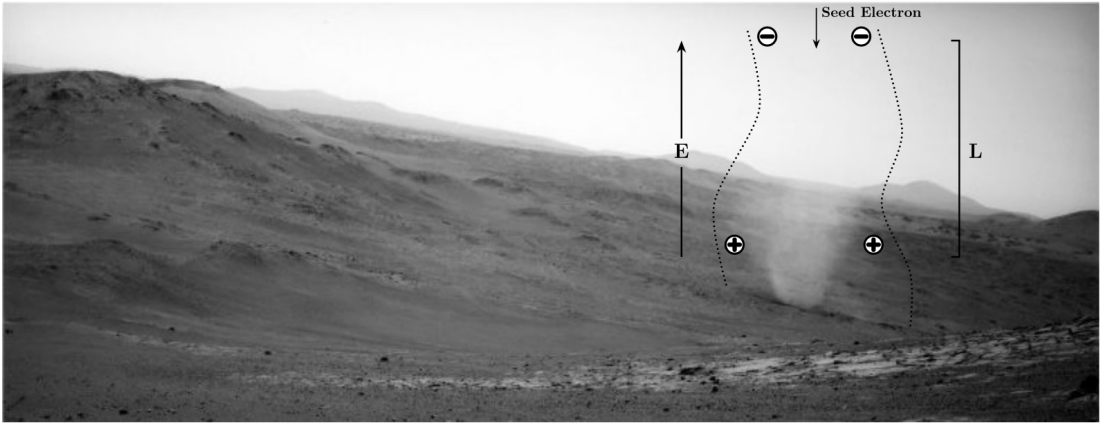
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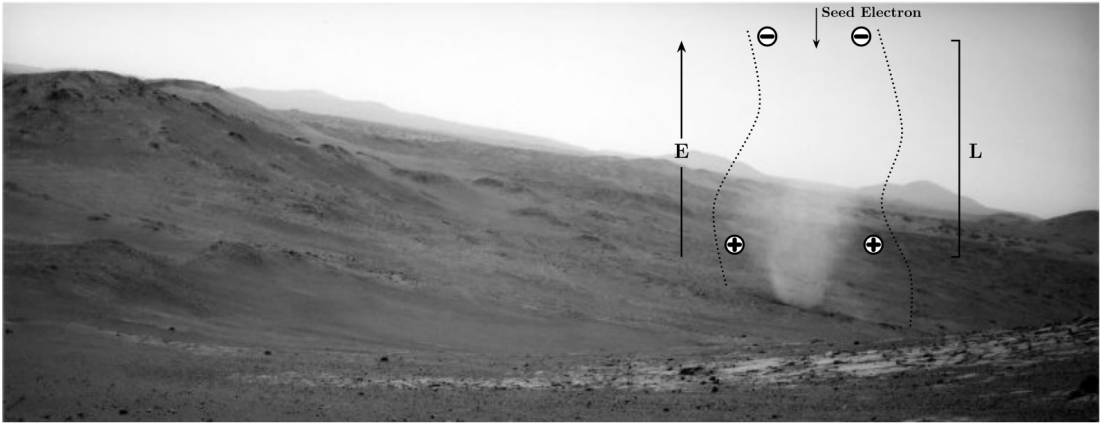
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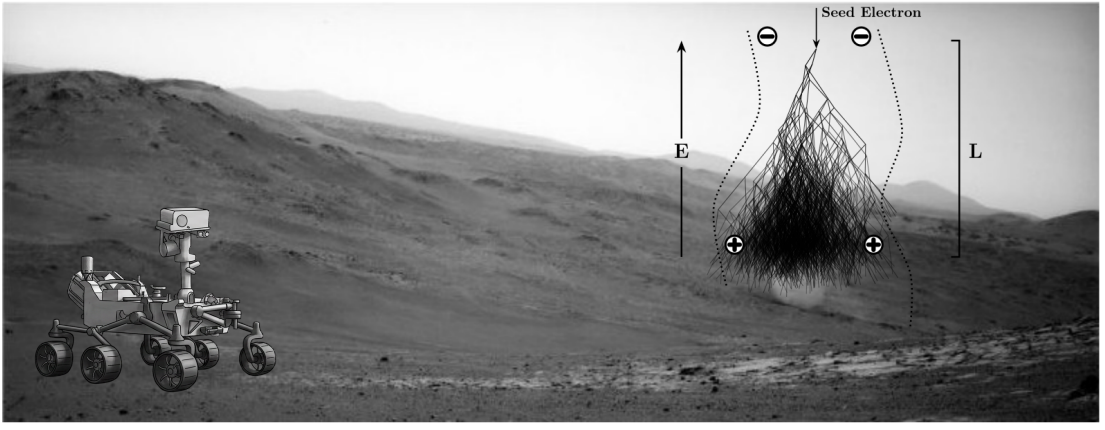
Relativistic Runaway Electron Avalanches



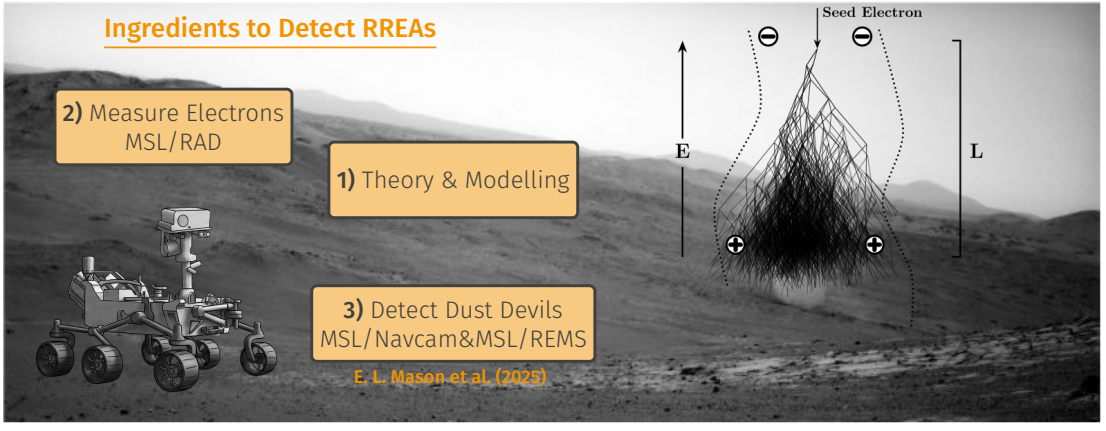
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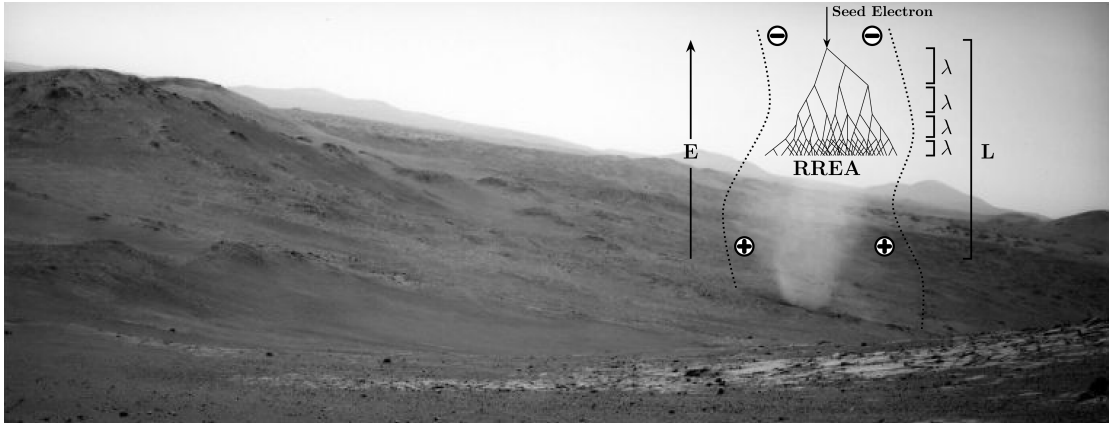
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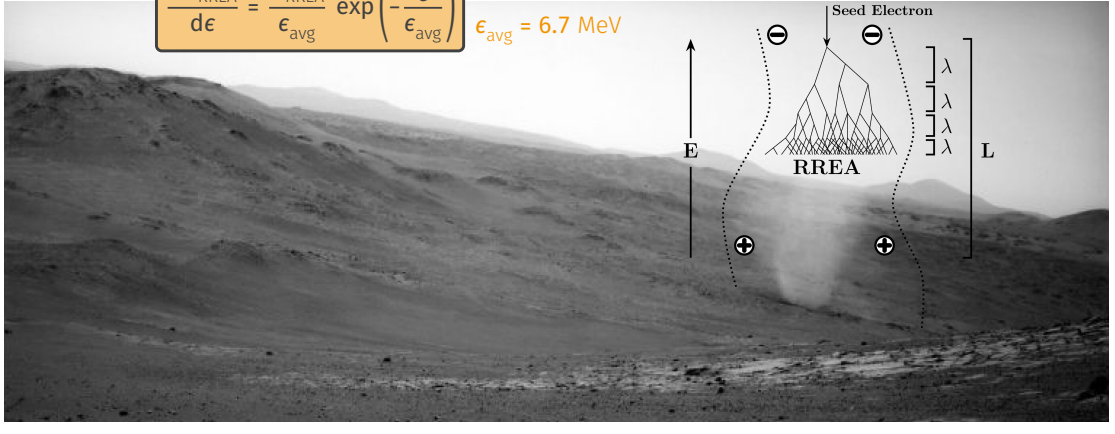
1) RREA: Theory & Modelling



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$$\frac{dN_{RREA}}{d\epsilon} = \frac{N_{RREA}}{\epsilon_{avg}} \exp\left(-\frac{\epsilon}{\epsilon_{avg}}\right)$$

ϵ_{avg} = 6.7 MeV



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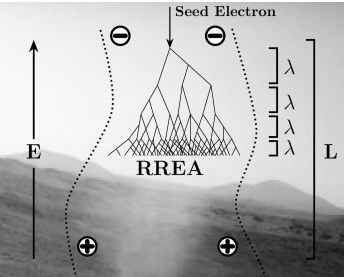
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L [km]	n	N_0 [cm^{-2}s^{-1}]
0	1	1.52
1.03	0.91	1.46
2.16	0.82	1.37
4.12	0.69	1.29
6.48	0.56	1.22
8.39	0.47	1.16
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$$N_{RREA} = N_0 \exp\left(\frac{L}{\lambda}\right)$$

$$\lambda = \frac{\Gamma}{(E - E_{thr} \cdot n)}$$

$E_{thr} \approx 4.94 \times n$kV/m
$\Gamma \approx 6795 \pm 3$kV



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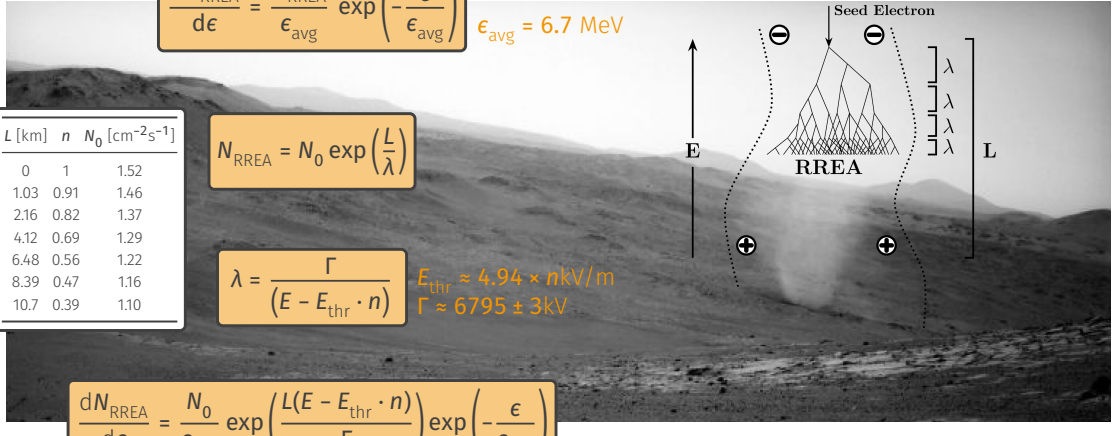
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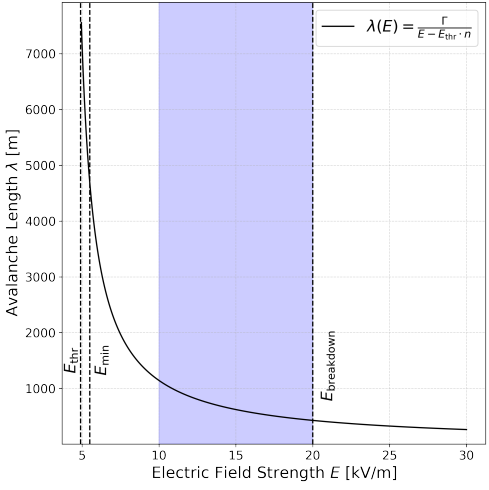
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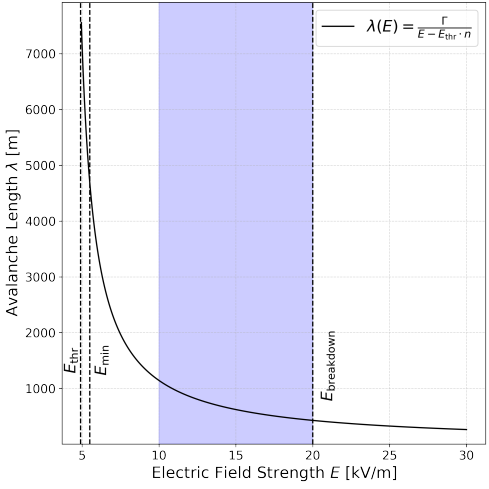


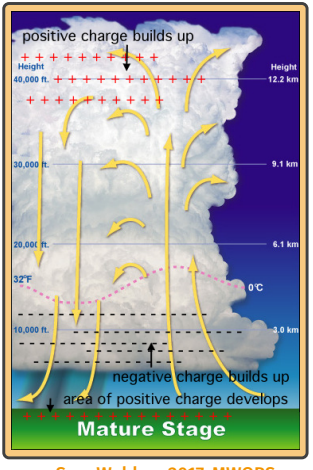
$$\frac{dN_{RREA}}{d\epsilon} = \frac{N_0}{\epsilon_{avg}} \exp\left(\frac{L(E - E_{thr} \cdot n)}{\Gamma}\right) \exp\left(-\frac{\epsilon}{\epsilon_{avg}}\right)$$

1) RREA: Theory & Modelling



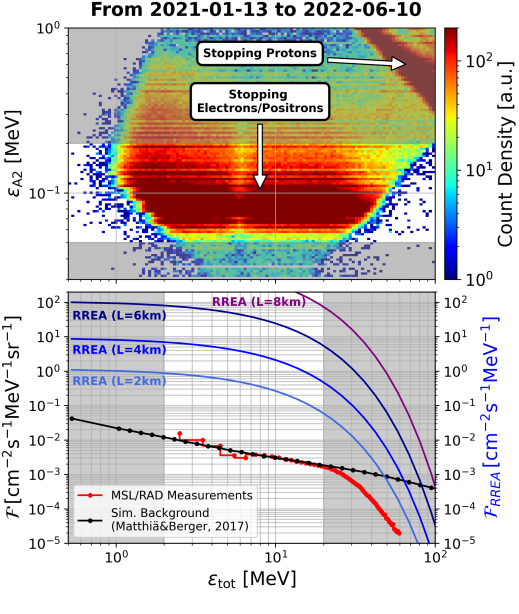
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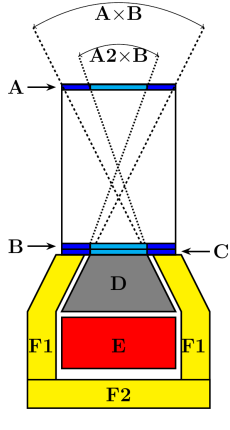




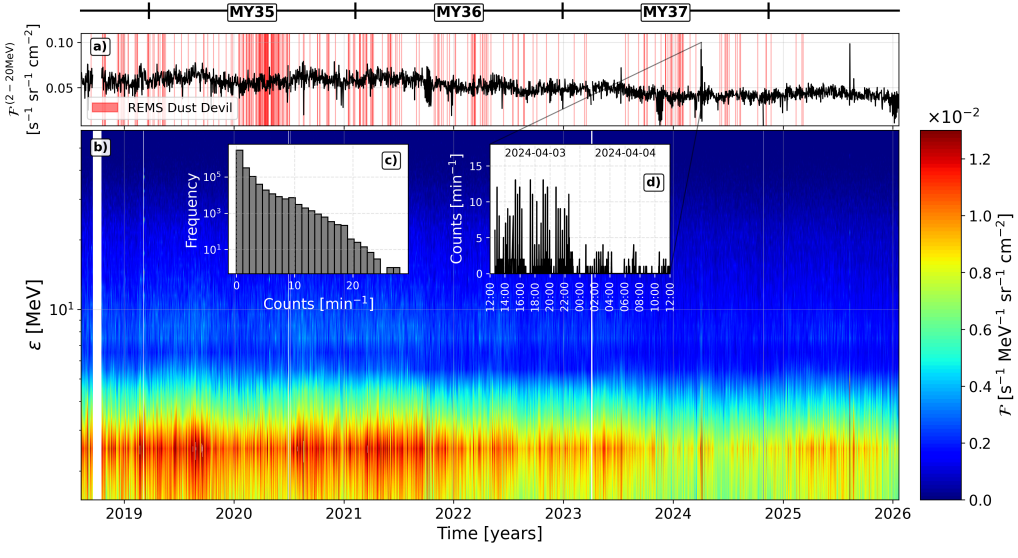
Sam Webber, 2017, MWOBS

2) RREA: Measure Electrons





2+3) RREAs During Dust Devils?



Interpretation

Results indicate that none of the at least 287 dust activity events that passed over the Curiosity rover between August 2018 and 21 March 2025 produced RREAs.
Moreover, no RREA signatures were identified in the overall 7.5-year MSL/RAD dataset.

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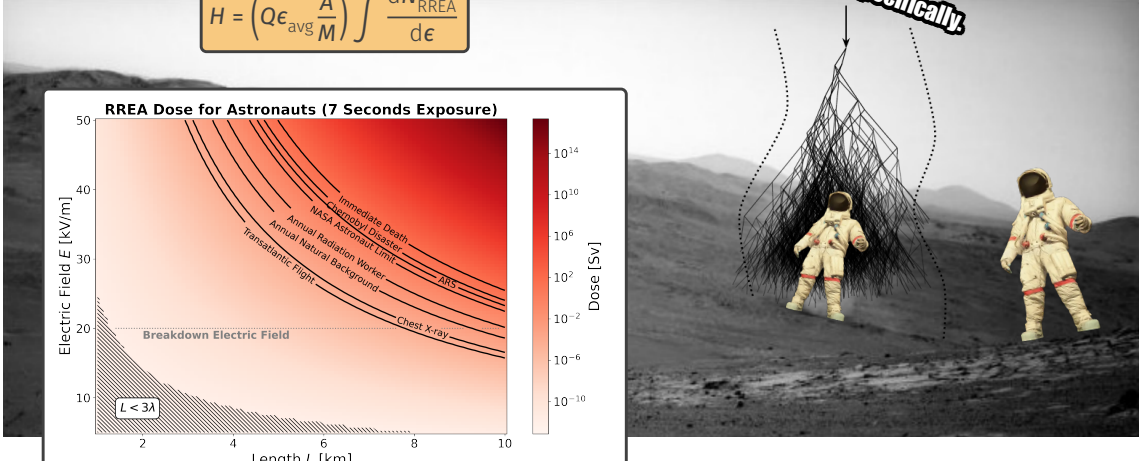
- RREAs are either not possible under Martian conditions or are extremely rare and transient
- Limited vertical extent of dipole electric fields is likely the main factor preventing RREA initiation
- Turbulence and charge neutralization may further limit dust devil electric fields, preventing RREA initiation
- Strong electric fields observed by Chide et al. (2025) may be highly localized and limited in extent, duration, and homogeneity

Implications for Human Exploration on Mars

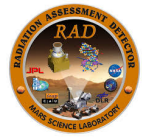


Implications for Human Exploration on Mars

$$H = \left(Q\epsilon_{\text{avg}}\frac{A}{M}\right)\int \frac{\mathrm{d}N_{\text{RREA}}}{\mathrm{d}\epsilon}$$



Limitations & Outlook



- No evidence for RREAs does not rule out their occurrence
- Non-detection cannot constrain whether E-fields are microscopic or macroscopic but sub-RREA in scale
- RREAs may have occurred outside rover encounter times
- MSL/RAD data alone cannot support planet-wide conclusions
- The model is simplified → Detected RREAs would require detailed knowledge of RREA and dust devil parameters

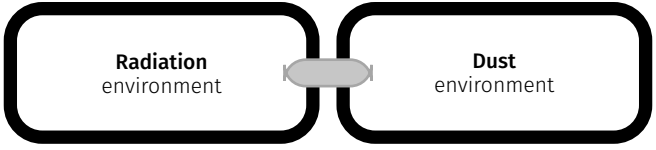
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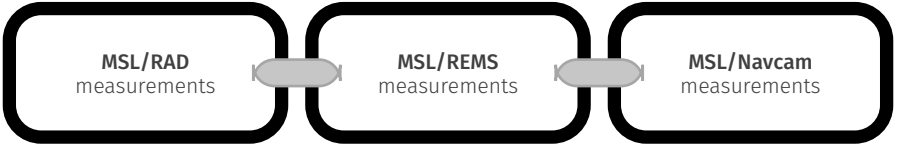
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⇒ Martian E-field measurements are currently still lacking and are highly recommended in future missions



Conclusion


Radiation
environment
Dust
environment


MSL/RAD
measurements
MSL/REMS
measurements
MSL/Navcam
measurements