How dielectric breakdown weathering may contribute to the lunar exosphere

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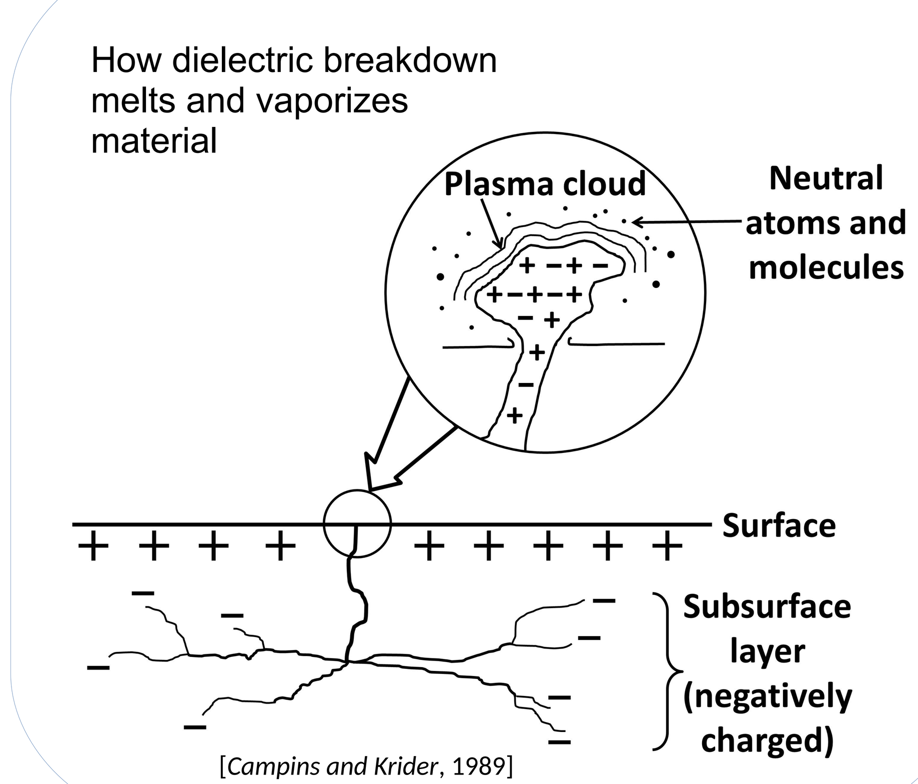
In space, energetic charged particles can penetrate electrical insulators, i.e., cause deep dielectric charging, which increases the electric field within the material.

If enough particles penetrate the insulator before it can dissipate the charging, the insulator undergoes dielectric breakdown ("sparking").

Dielectric breakdown was studied with the Combined Release and Radiation Effects Satellite (CRRES—at left), which measured breakdown ~4300 times while passing through Earth's radiation belts.

Conditions for breakdown: ~10^{10} charged particles cm^{-2} deposited within the discharging timescale

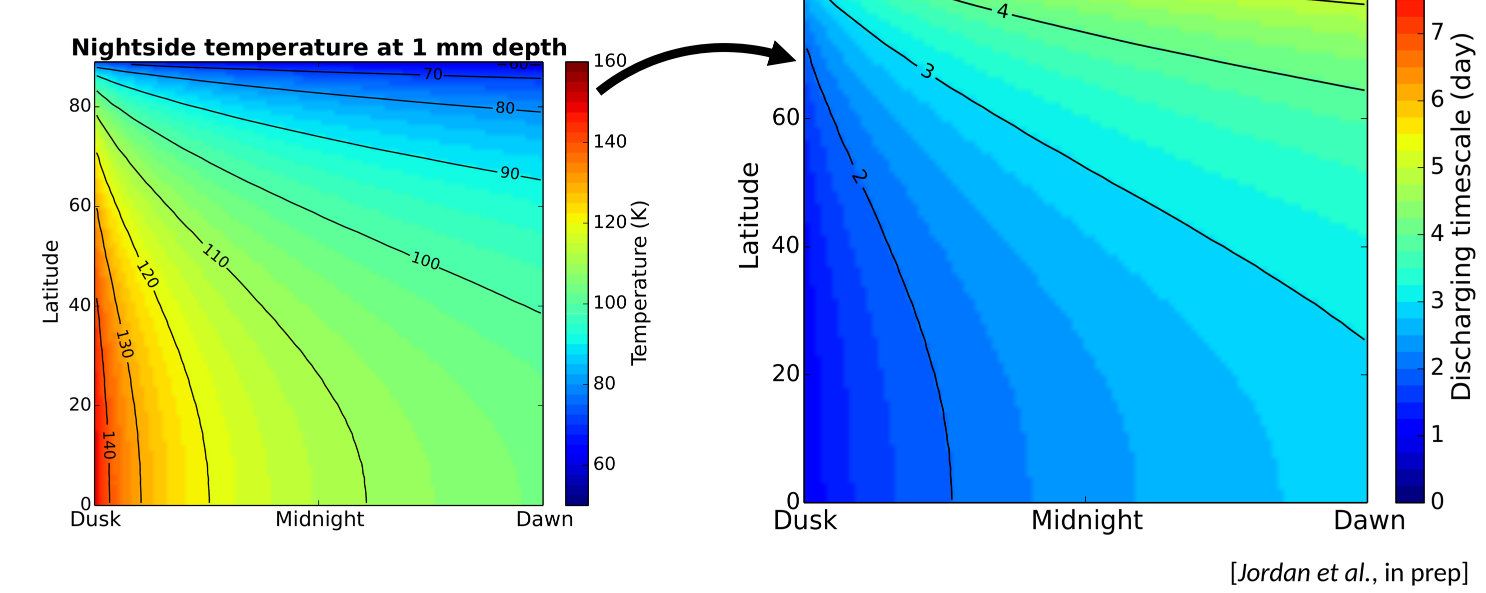


Lunar soil is an excellent electrical insulator, and it gets less conductive as it gets colder.

Experiments show that it undergoes dielectric breakdown under the same conditions as most other solid insulators [*Kirkici et al.*, 1996; *Shusterman et al.*, 2016a, b].

Lunar soil is more electrically insulating on the nightside, where it is colder. On the nightside, it needs ~2-7 days to dissipate any deep dielectric charging.

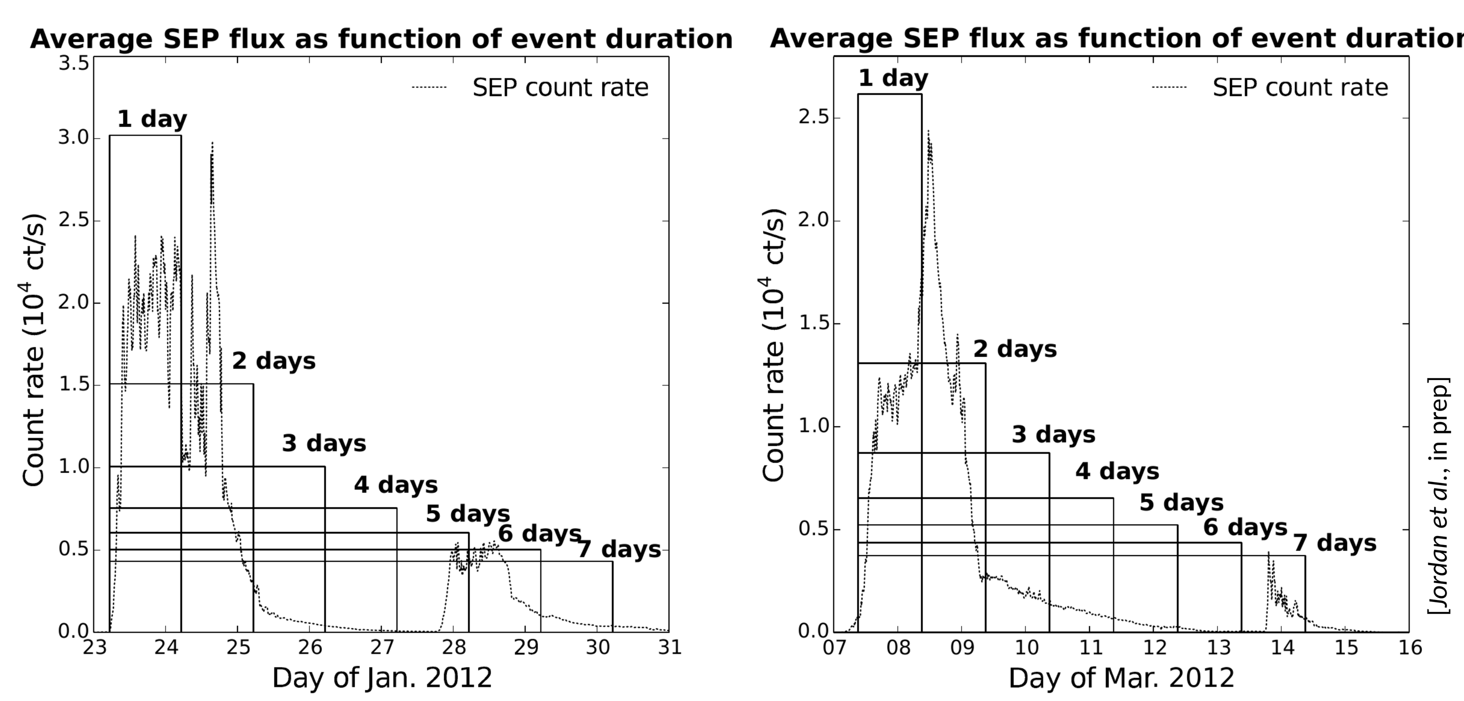
$$\text{Discharging timescale} = \frac{\text{Permittivity } (\sim 2\varepsilon_0)}{\text{Conductivity (fcn of temp)}}$$



Solar energetic particle (SEP) events deposit their charge in the top ~1 mm of lunar soil.

The largest SEP events can deposit ≥10^{10} charged particles cm^{-2} within the discharging timescale of soil on the nightside—*meeting the conditions for breakdown*.

At right: the two largest SEP events measured by the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) on LRO.

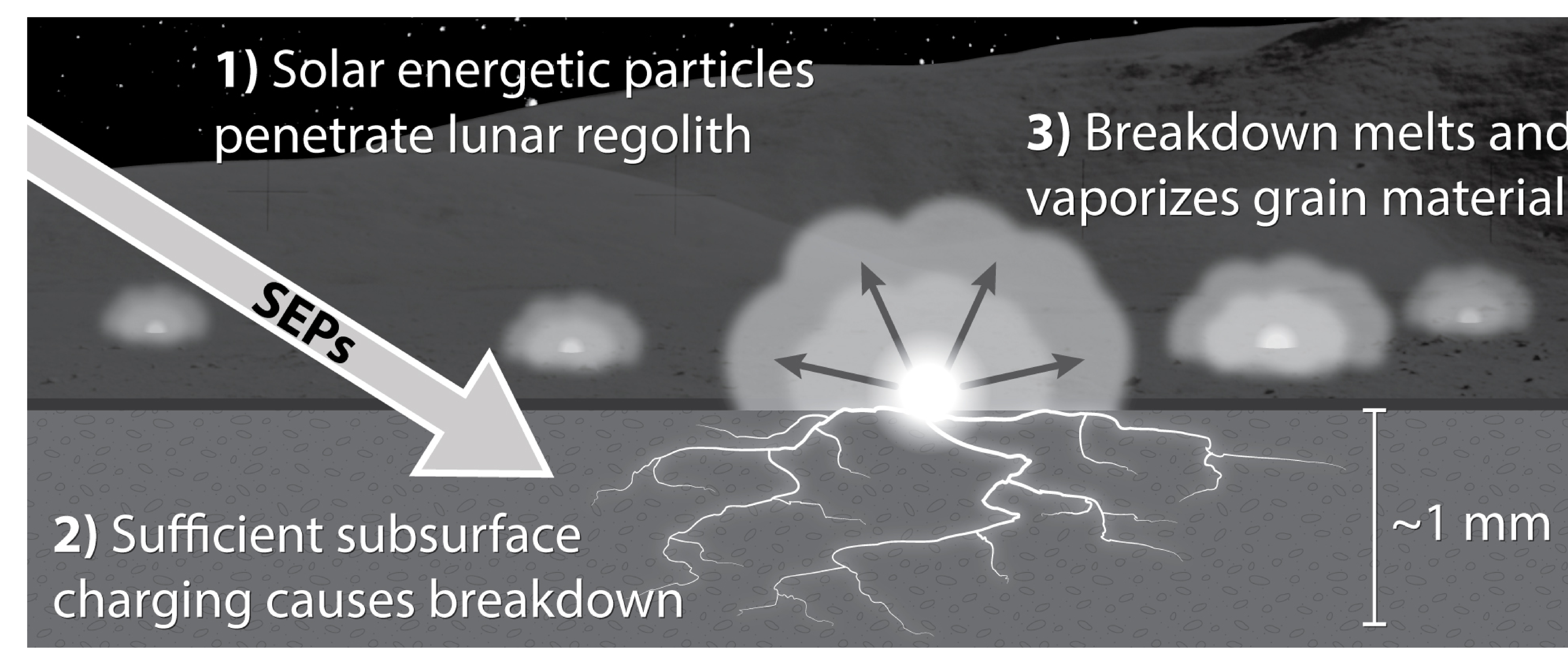


SEP events typically deposit ~95% of their fluence in 3 days [*Kecskeméty et al.*, 2009].

Colder regolith:
→ lower conductivity
→ slower to discharge
(~2-7 days)

SEPs can create stronger electric fields

Cold temperatures and very large SEP events may cause the Moon's nightside to meet the criteria for dielectric breakdown



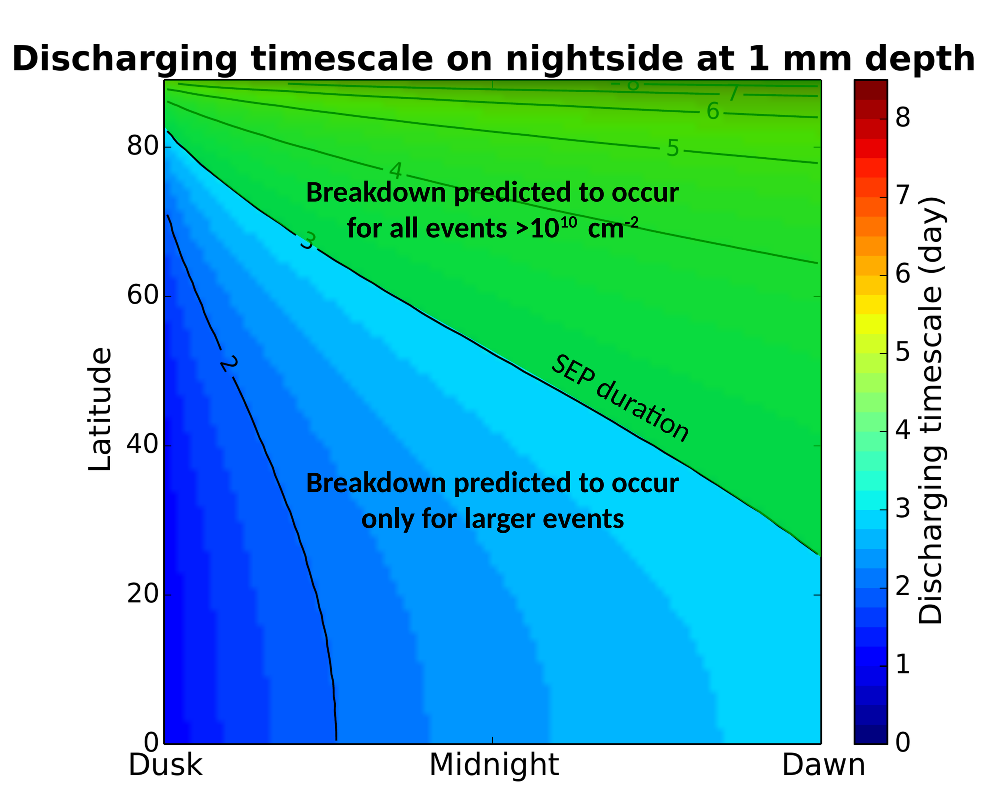
[Jordan et al., 2017]

Like meteoroid impacts, dielectric breakdown melts and vaporizes.

Consequently, breakdown should be stoichiometric, that is, it should release all regolith constituents into exosphere—even species that solar wind doesn't readily sputter, such as Si, Al, Mg, Ca, and Fe [*Flynn and Stern*, 1996; *Stern et al.*, 1997; *Cook et al.*, 2013].

We assume:

- The energy partitioning of melting/vaporizing is same as in hypervelocity impacts (90%/10%)
- Only ~10% of vapor escapes top 1 mm (conservative); the rest is deposited on surrounding grains

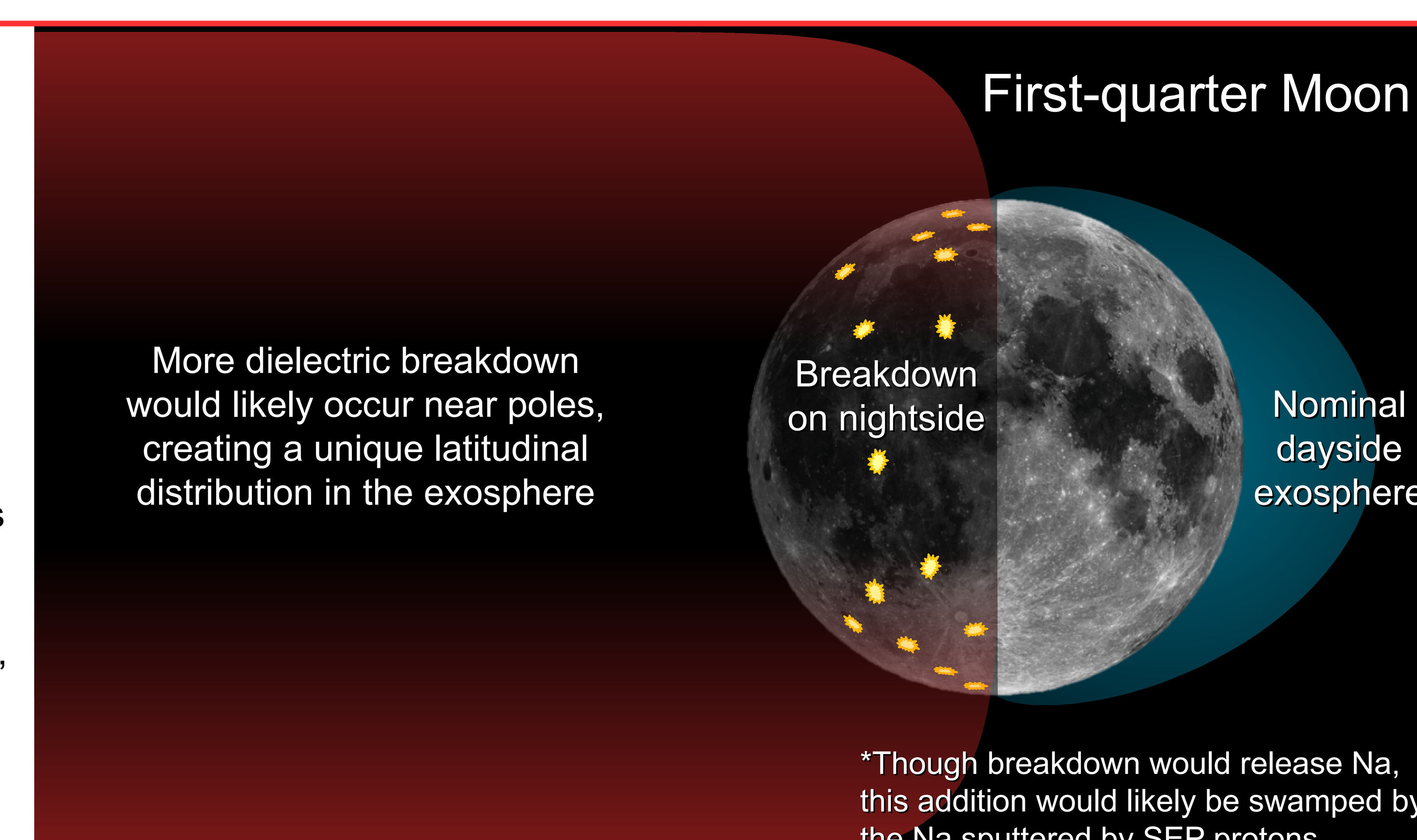


Predictions

Two scenarios:

1) Threshold SEP event affects only green area at left (~1/yr)
   - Vaporizes ~10^3 kg
   - Releases ~1% mass of exosphere
2) Largest SEP events affect most of nightside (once every few years)
   - Vaporizes ~10^5 kg
   - Temporarily doubles exospheric mass

Although some species may condense out quickly [*Berezhnoy*, 2013], Si, Al, Mg, Ca, and Fe may still be detectable by ground-based instruments. An increase in species more refractory than Na should be detectable.



Future work:

Use exosphere model [*Wilson et al.* 1999, 2003] to predict what the exosphere might look like as a function of SEP fluence and lunar phase

Experiments in near future may help determine how much vapor escapes. Stay tuned...