Low-Frequency Electromagnetic Methods for Multi-Scale Subsurface Planetary Exploration

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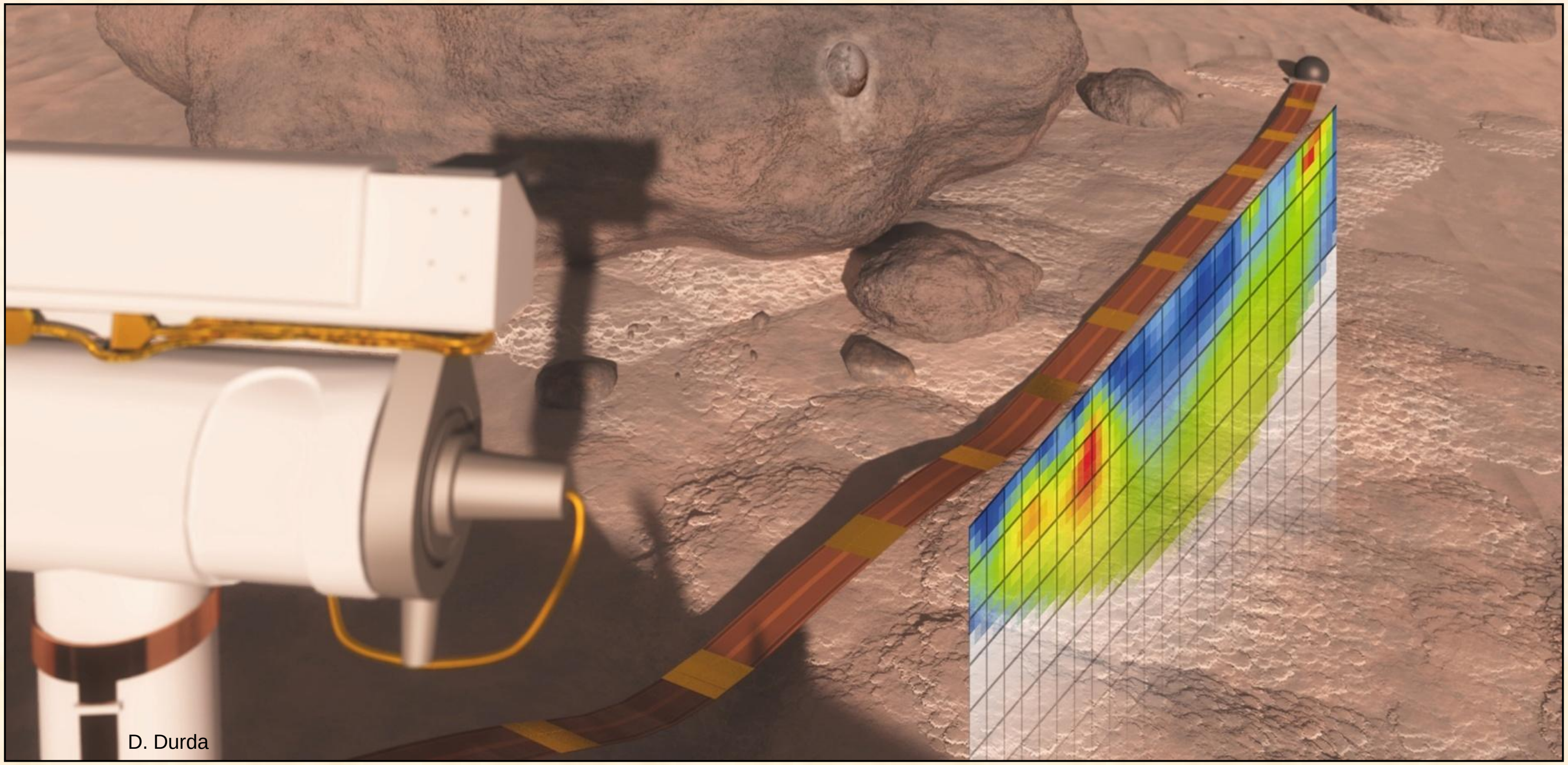
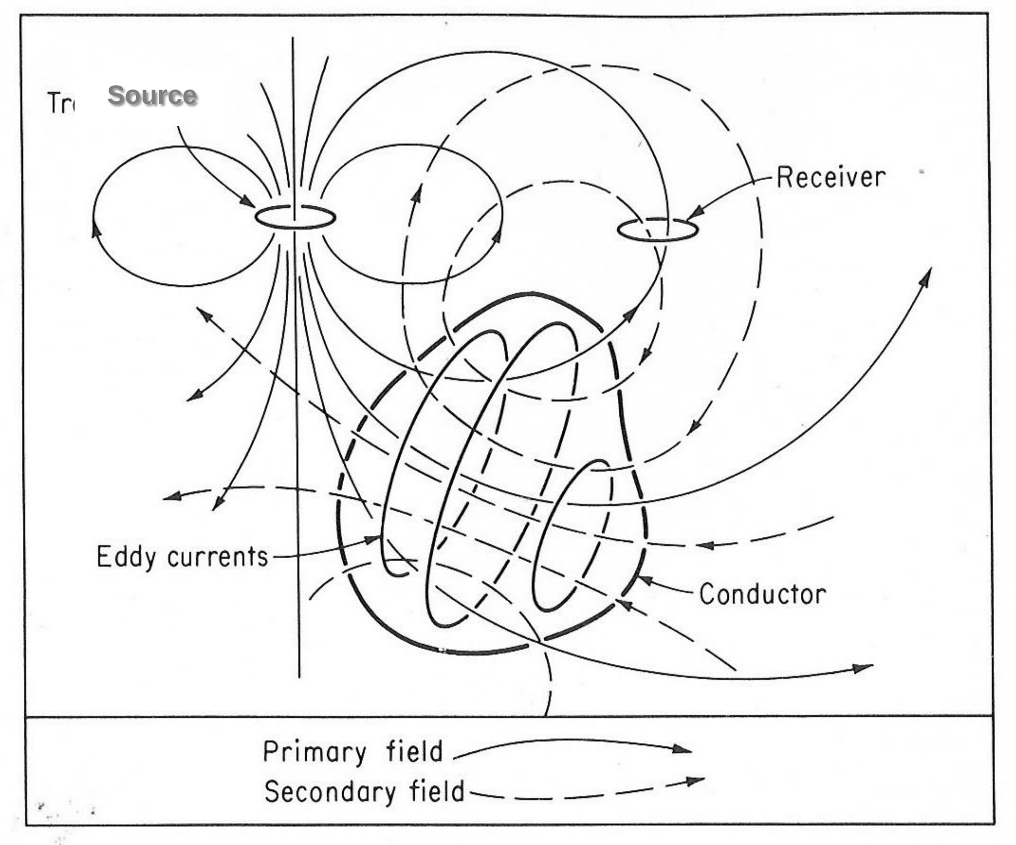


Geophysical Methods

- Seismology
  - Gold standard for internal structure, esp. global.
  - Not very sensitive to water.
- Ground-Penetrating Radar
  - Good structural resolution
  - Limited investigation depth.
  - More sensitive to water.
- Inductive EM
  - Very sensitive to water.
  - Very high sensitivity to selected properties for specialized investigations.
  - Large exploration depth.
  - Poorer resolution.

Grant and West, 1968



Skin Depth (km) = $0.5 \sqrt{\rho/f} = 0.5 \sqrt{T/\sigma}$

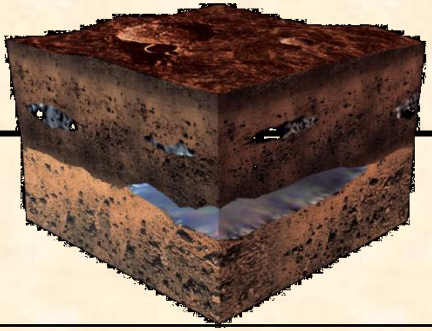
f = frequency, Hz; T = period, sec

ρ = resistivity, Ω-m; σ = conductivity, S/m

DEEP SOUNDING (kms to >100 km)

Natural-Source Electromagnetics

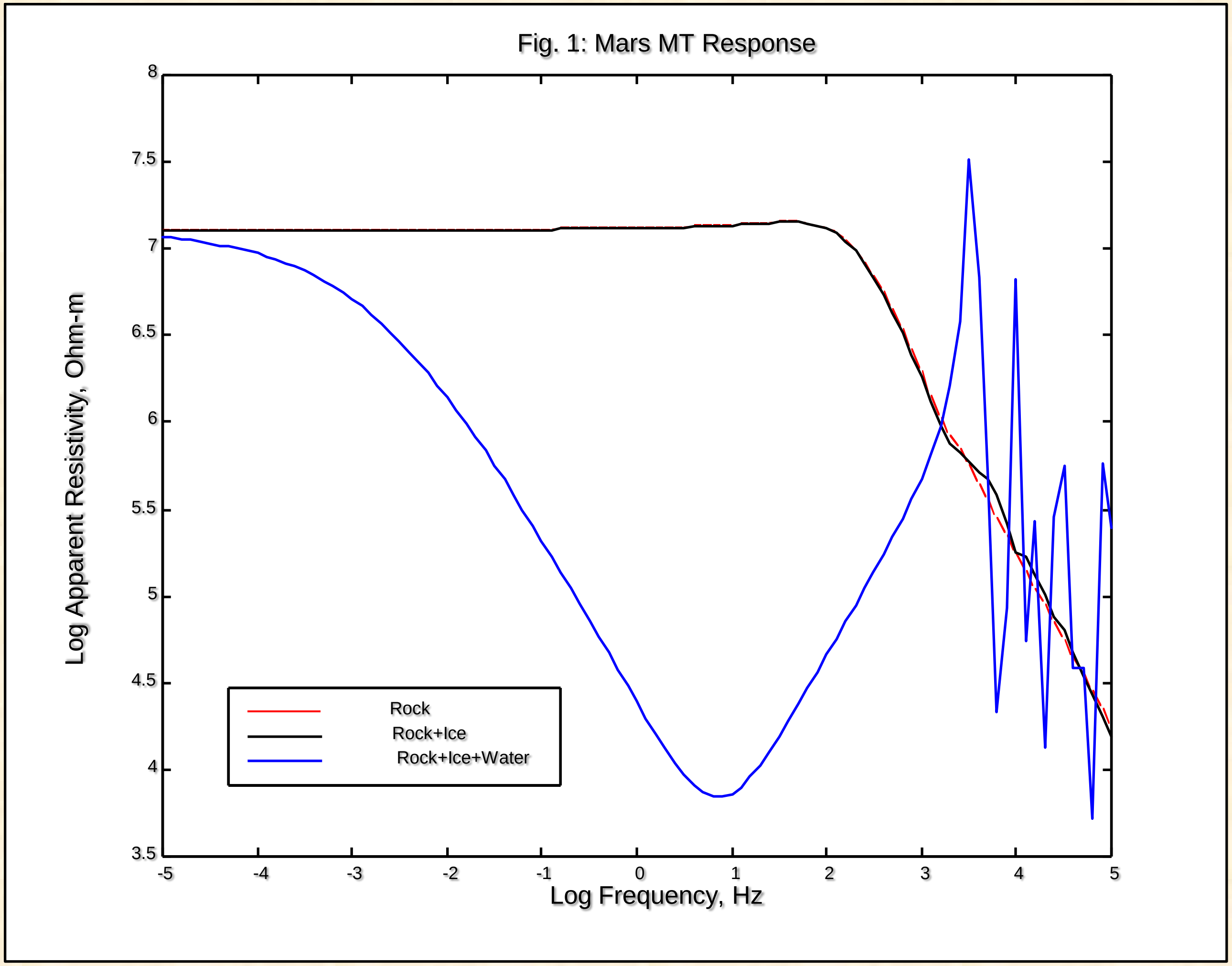
Magnetotellurics, Geomagnetic Depth Sounding



<u>Target</u>	<u>Frequency</u>
Water Table (kms) Habitability, geothermal gradient (joint with heat flow)	mHz – kHz solar wind, lightning
Crust (tens of km) Differentiation history (joint with seismology)	mHz – Hz solar wind
Lithosphere (> 100 km) Thermal state (joint with seismology, heat flow)	μHz (diurnal) to mHz ionosphere, solar wind

Mars Groundwater is a Near-Ideal EM Target

Resistor (7 km) – Conductor (1 km) - Resistor

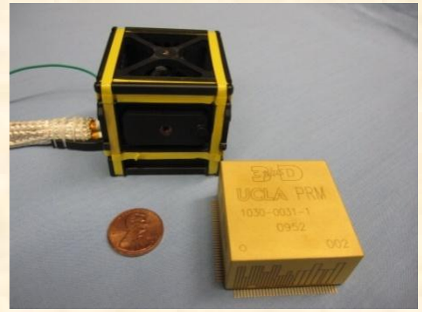


Grimm, 2002

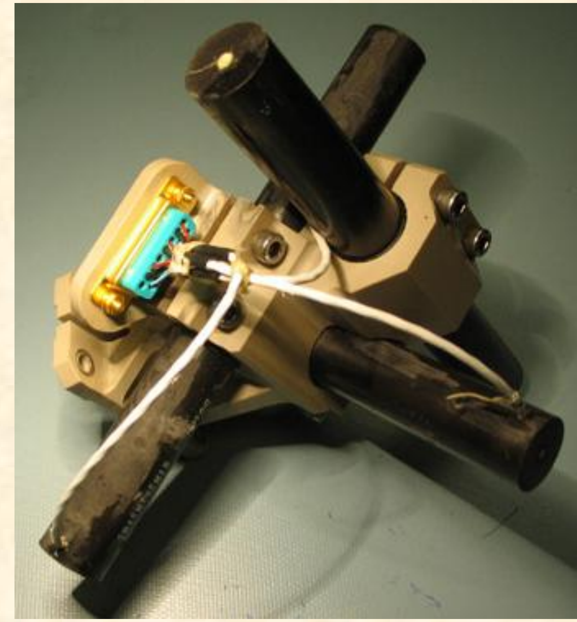
- Dry, very resistive cryosphere over saline, conductive groundwater
- EM discerns groundwater over wide frequency band

Sensors

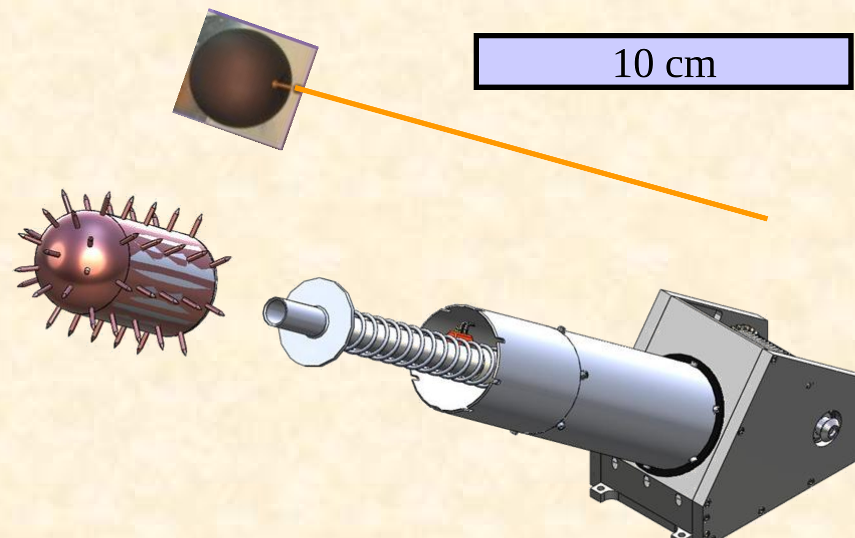
- Sensor package is essentially a classical space-physics experiment operated on the ground.
- Magnetometers
  - Fluxgates < 1 Hz, Induction (Search Coils) > 1 Hz
- Electrometers
  - Response to near DC under galvanic coupling; capacitive coupling requires high-impedance preamplifiers, circuit shielding and guarding.



UCLA FGM
(R. Strangeway)

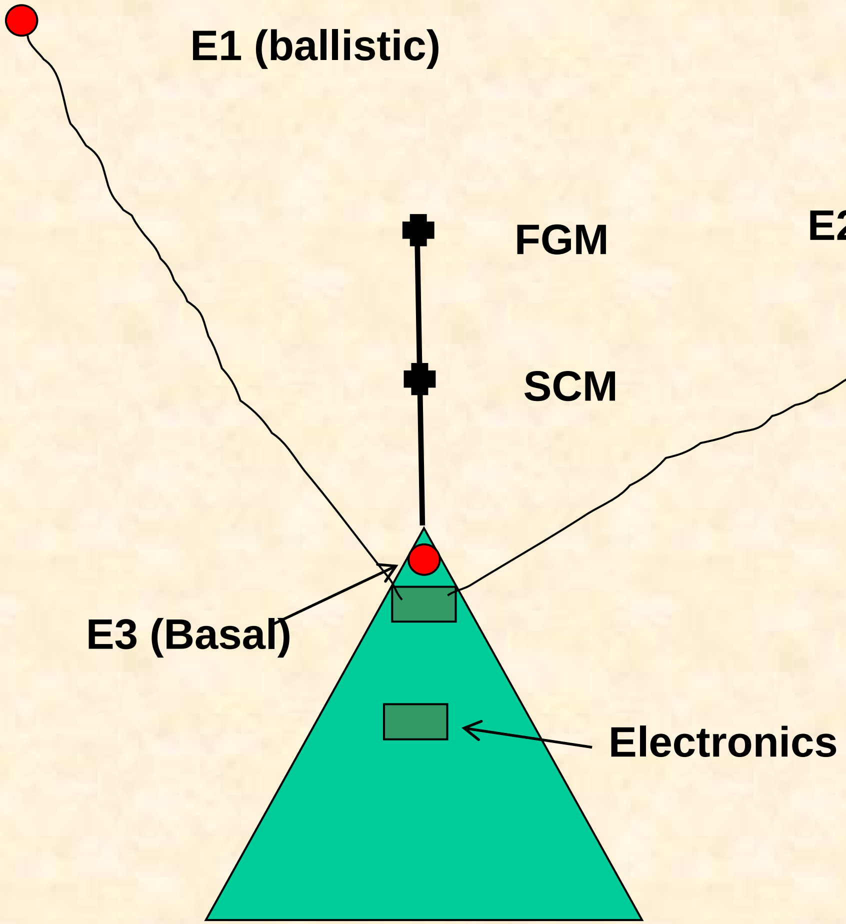


THEMIS SCM Roux et al.



Balloon Electrode (top) and Ballistically Deployed Ground Electrode (bottom); G. Delory

EM Sounding: Implementation



Generalized Lander

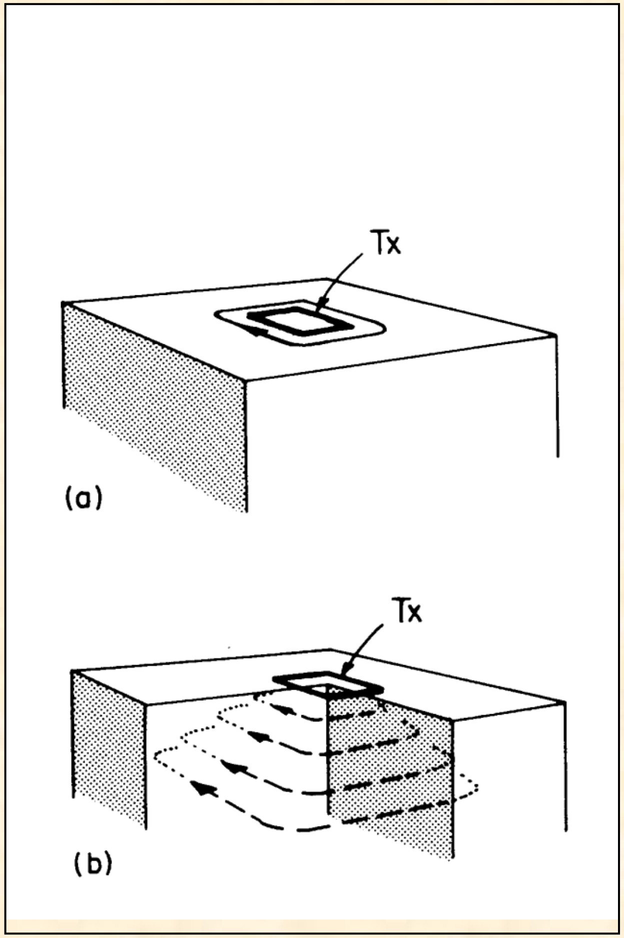
Lunette Lander (JPL)

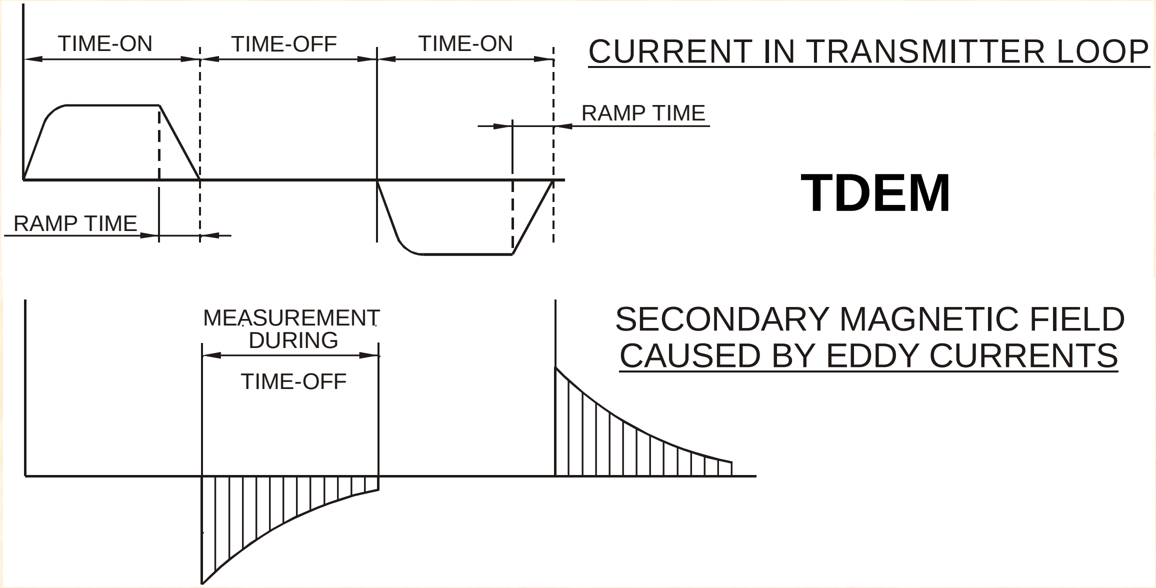
PI. C. Neal, Notre Dame

INTERMEDIATE SOUNDING (10s m to few km)

Controlled-Source Electromagnetics

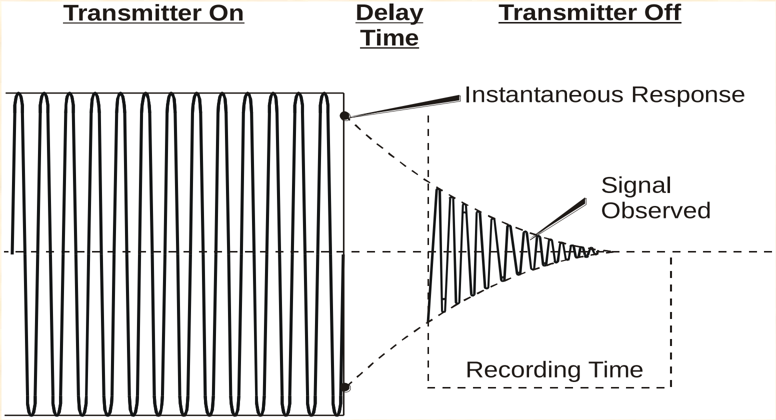
Time-Domain EM, Surface Nuclear Magnetic Resonance



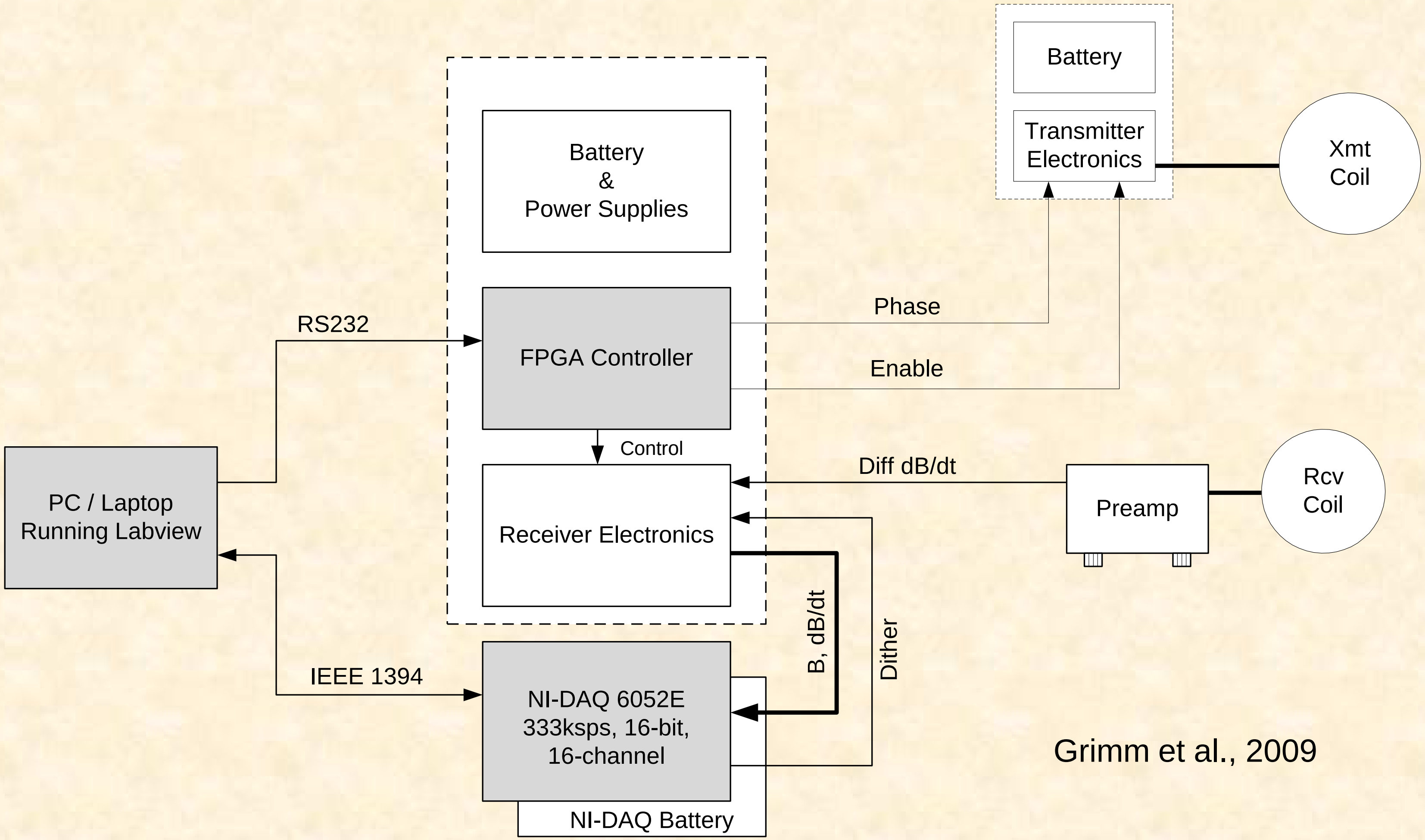


TDEM

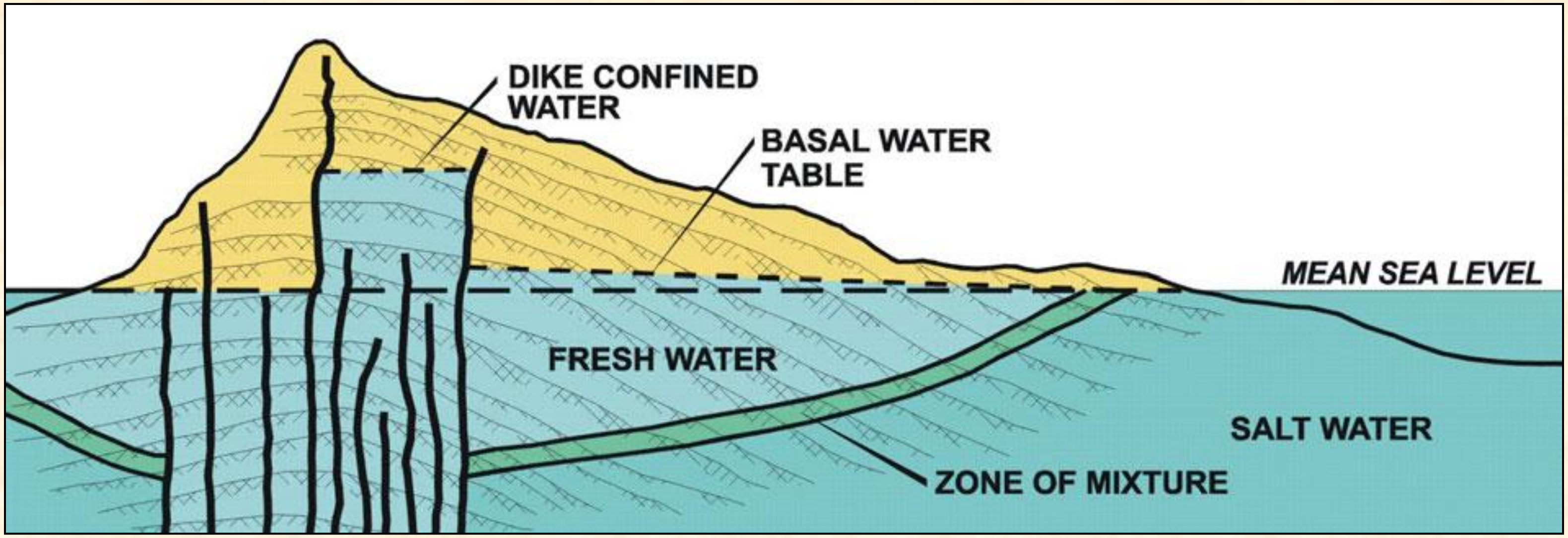
Grimm, 2003

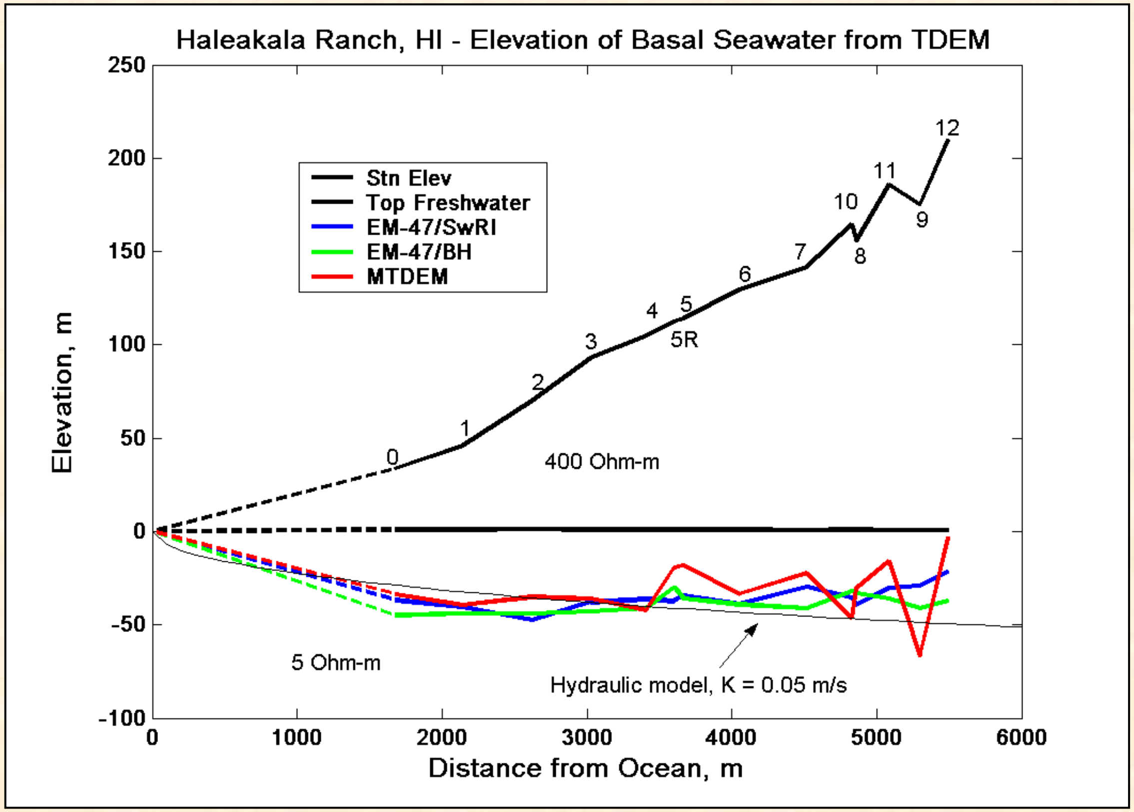


SNMR



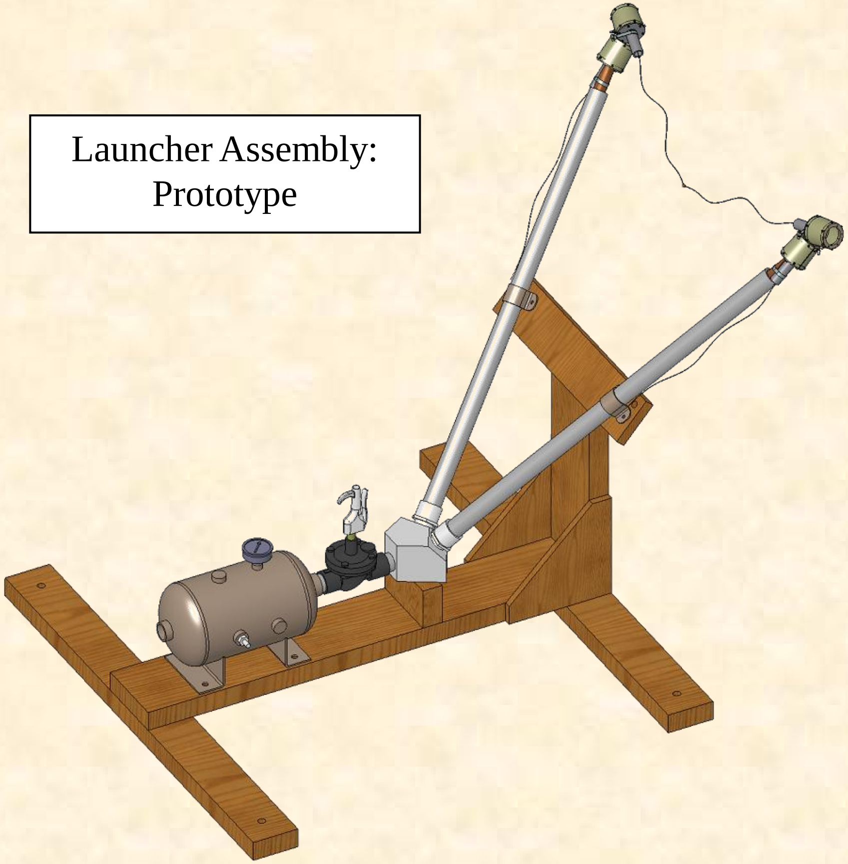
Grimm et al., 2009

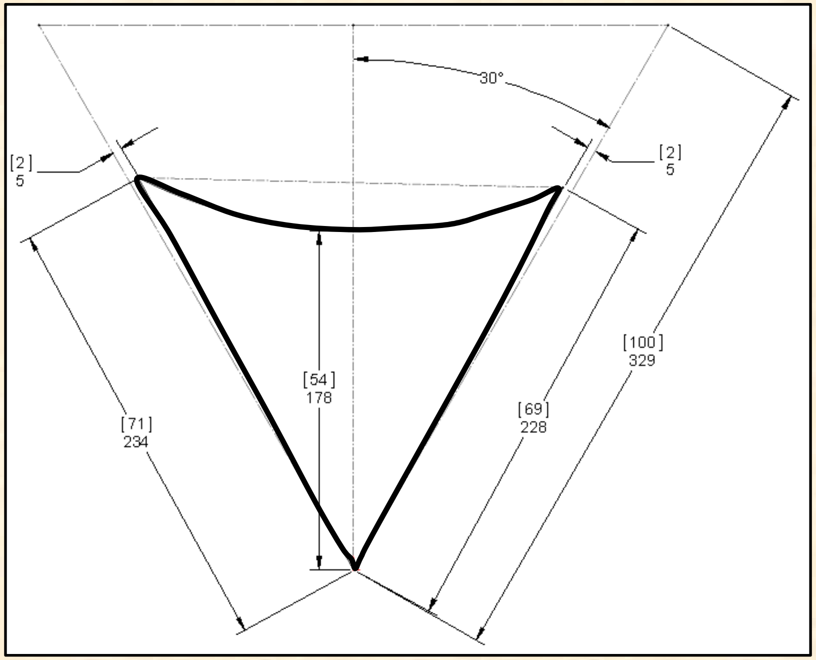


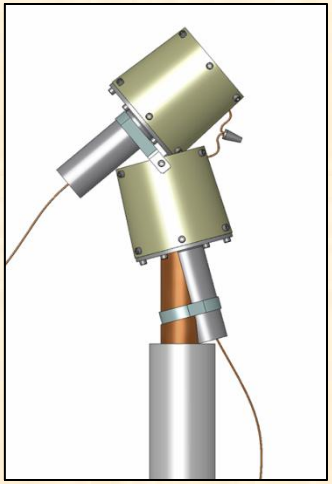


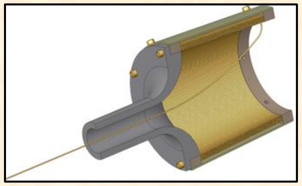
Grimm et al., 2009

Launcher Assembly:
Prototype



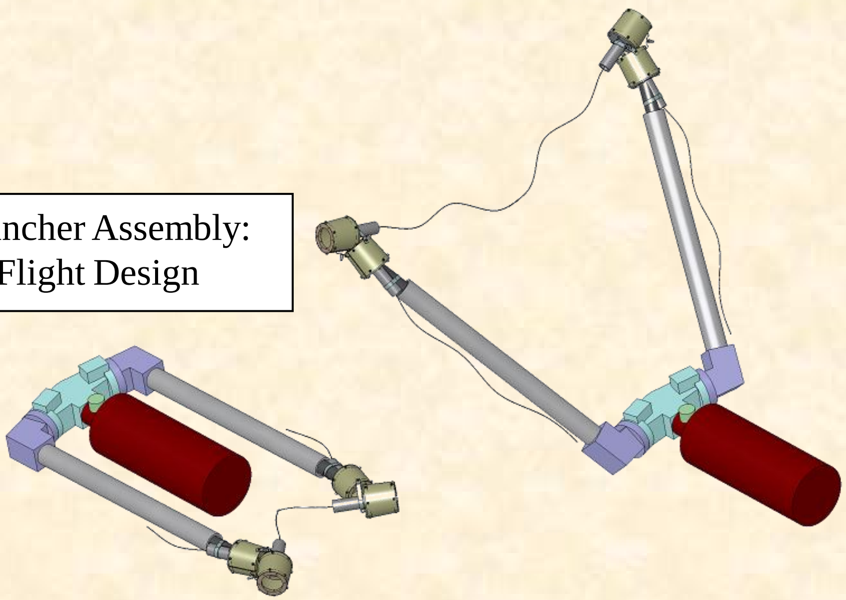






Grimm et al., 2009

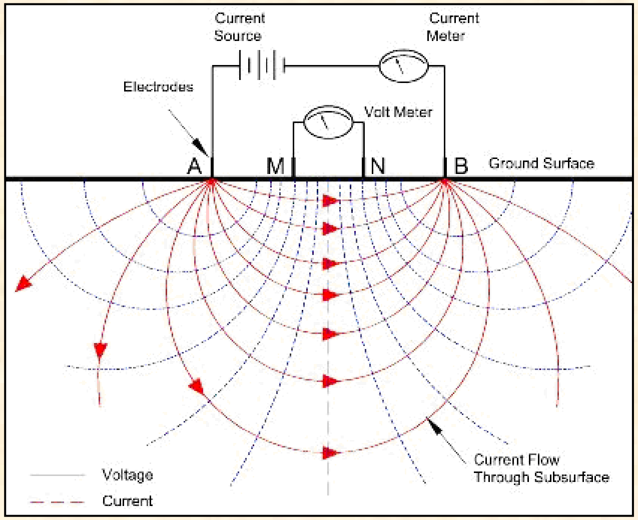
Launcher Assembly:
Flight Design

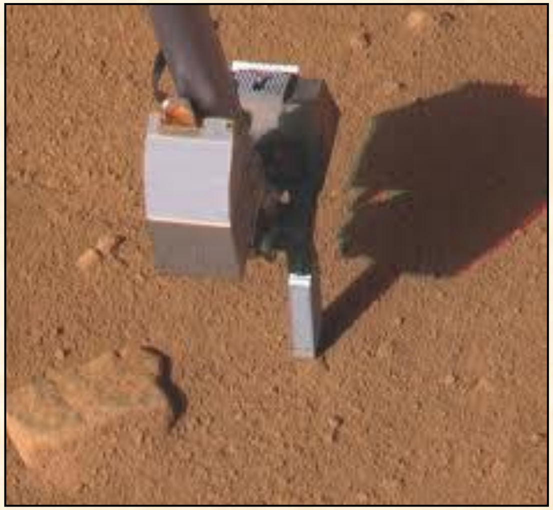


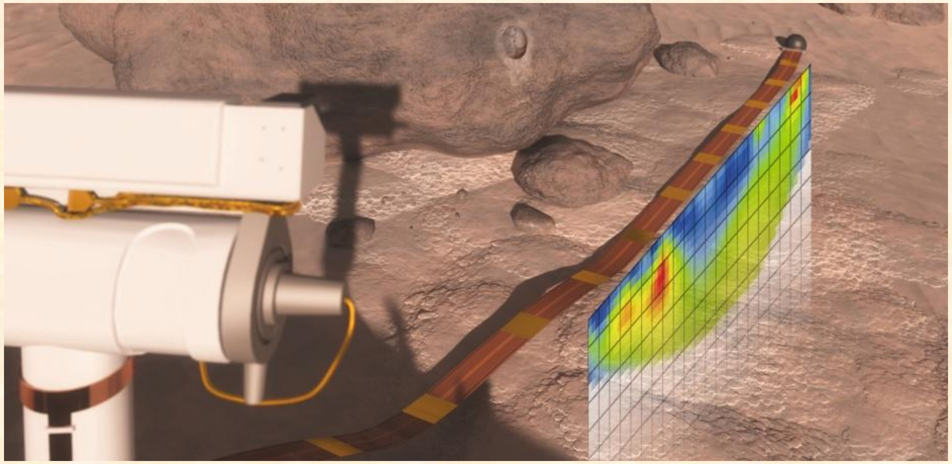

Launch viewed from
behind launcher.

SHALLOW SOUNDING (m to 10s m)
Controlled-Source Geoelectrics
Dielectric Spectroscopy

- Surface electrode array
- Inject I, measure V amplitude + phase, convert to conductivity + permittivity.
- Investigation depth proportional to electrode spacing: use multielectrode array to generate 2D cross-section at fixed location.

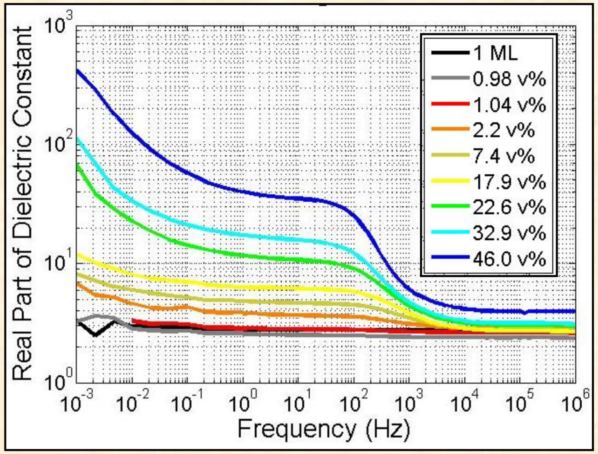




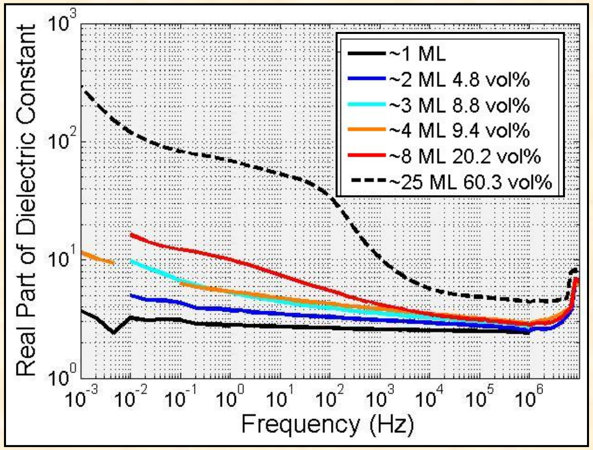


Dielectric Spectroscopy Distinguishes Ice and Adsorbed Water

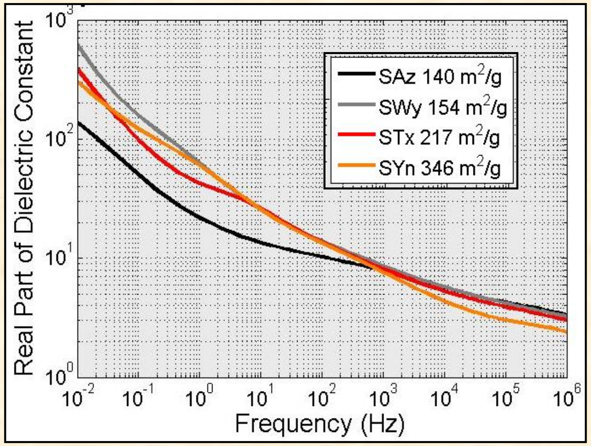
Fine-Grained Sand



JSC Mars - 1



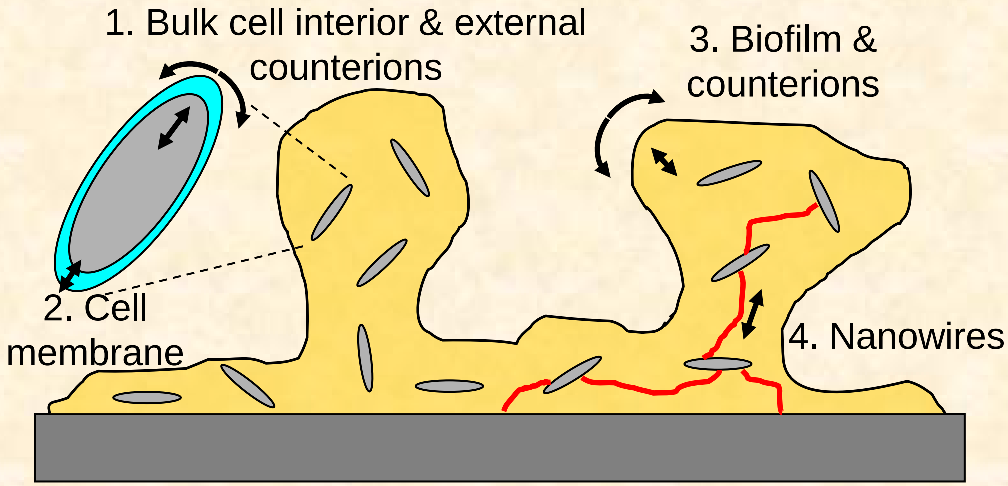
Smectites, 3 ML

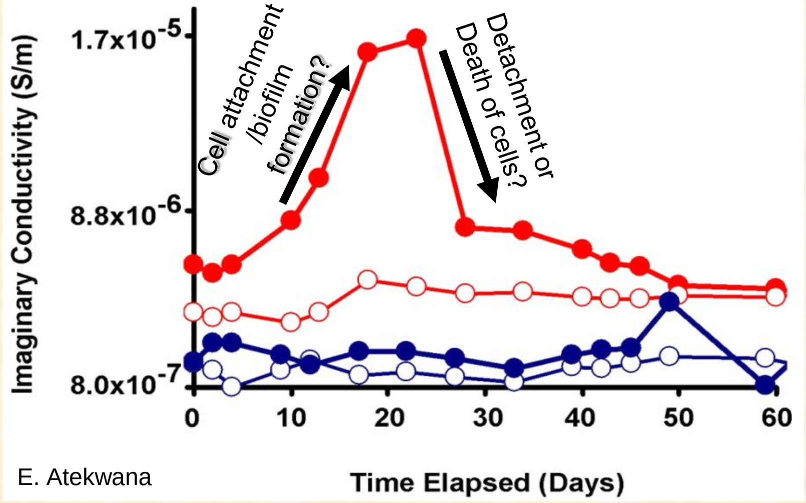


Coarse **Fine**

- Ice relaxation + DC conductivity dominate in sands
- Broadband dispersion dominates in clays
- Martian regolith likely between sand and JSC-Mars-1.
  - Assess H_2O content and state to few % accuracy, ~1% threshold.
  - Complements neutron spectroscopy and GPR

Biogeophysics





- Living cells display several polarization mechanisms under applied electric fields.
- Electrical properties through life cycle of microbial colonies have been extensively studied in laboratory columns.
- Substantial investment by DOE, hydrocarbon industry in using biogeophysics for cleanup monitoring.
- Use on Mars to assess microbial activity beneath few meters of irradiated and oxidized regolith.

Conclusions

- Low-frequency EM better than GPR for investigation to km depths and beyond.
- Natural-source methods require minimal resources and have greatest investigation depth (kms – 100 km)
  - Groundwater, crust, lithosphere.
- Large controlled source (200-m loop) optimal to assess shallower groundwater (10s m to few km).
  - Time-domain EM, Surface NMR
- Small controlled source (several-m electrode array) measures both conductivity and permittivity to depths of meters.
  - Distinguish ice from adsorbed water at percent levels.
  - Detect microbial activity.