National Aeronautics and Space Administration

SOUNDING FOR (LIQUID) GROUNDWATER
TH$_2$OR: TRANSMISSIVE H$_2$O RECONNAISSANCE

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Program: Strategic Initiative

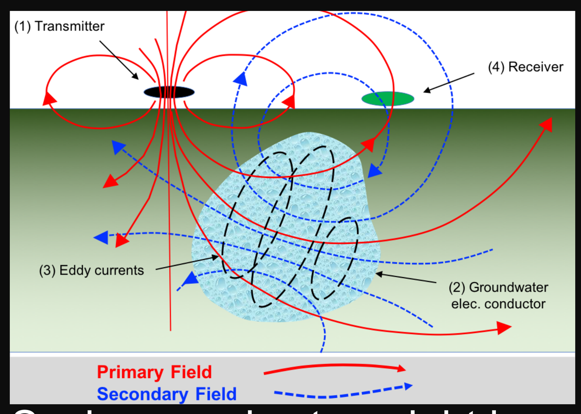
Project Objective

Demonstrate the feasibility to remotely sense **liquid** subsurface water from the Martian surface.

- Water is expected to exist at depths of many kilometers
- Target a low-mass (<10 kg) & low-power (<10 W avg) EM (electromagnetic) instrument

This will allow us to:

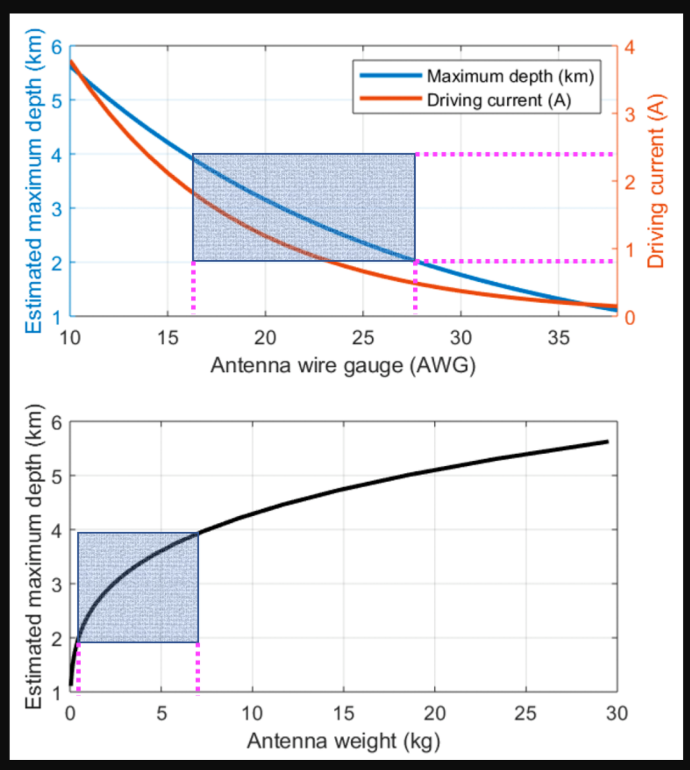
- Unambiguously distinguish signals of liquid water from ice, hydrated sediments, and magnetized rocks
- Determine the salinity and help estimate the chemical composition of such groundwater.



Such groundwater might be the only habitat for extant life on Mars if it still exists today.

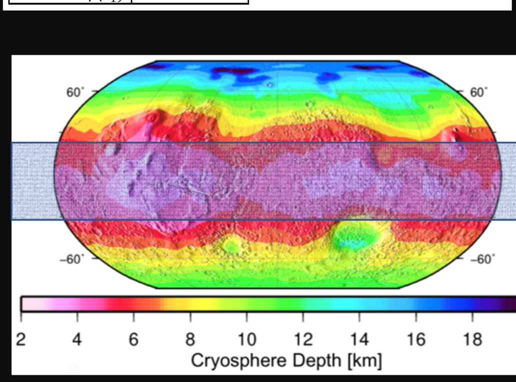
FY19 Results

- ~100 m loop diameters can reach sounding depths of many kms on Mars with < 10 W and integration times of hours.
- If mission constraints do not allow a large loop, a ~10 m diameter TEM system can theoretically sense Martian aquifers down to ~2-3 km if the integration time and power can be extended.
- ~2-m loop TEM systems with their modest mass, power, and AWG are suited to study subsurface liquid water below ~1 km on Mars. This can be useful for shallow brines or to identify potentially shallower methane sources in Gale Crater.
- Magnetotelluric systems can passively measure liquid water kms to tens of km depth if the right natural frequencies exist ← InSight data.



Description	Value
TEM bandwidth	20 kHz
Transmitter power	10 W
Receiver's noise figure	10 dB
External noise temperature	450 Kelvin
Surface temperature	-55 C
Overburden conductivity (σ_1)	1e-12 S/m

Description	Value
Wire Gauge	Variable
TX/RX diameter	100m
# of turns	1
Groundwater conductivity (σ_2)	0.1 S/m
Groundwater body thickness	100 m
Integration time	1 hour
Step Repetition Frequency	1 Hz



Figures show the calculated capability for a notional TEM system (0.5-6.5 kg, 10 W) capable of sounding to ~2-4 km on Mars, which is our predicted average depth of pure water in typical "tropical" landing regions.

Benefits to NASA and JPL (significance of results)

Our results showed

1. that the most suited low mass & low power active approach to search for liquid water in the Martian subsurface is TEM sounding. This lays the scientific foundation to design and develop the TH$_2$OR hardware,
2. that we can sound for liquid groundwater on Mars down to kilometers of depth with an instrument that fits in a small spacecraft,
3. which "knobs" allow modifying the instrument to sound deep enough and comply with mission requirements once they are set,
4. that as a passive alternative, magnetotelluric (MT) sounding is complementary if the right natural frequencies occur on Mars's surface,
5. applicability to other solar system bodies (for liquid water & ore detection).

We find that TEM is ideally suited as a low-mass & low-power active device to search for liquid groundwater (and ores) on Mars (& beyond). Detection of liquid water to depths of many kilometers is feasible. This work provides the foundation for the data inversion & hardware development over the next 2 years.

Expanding current state of the art

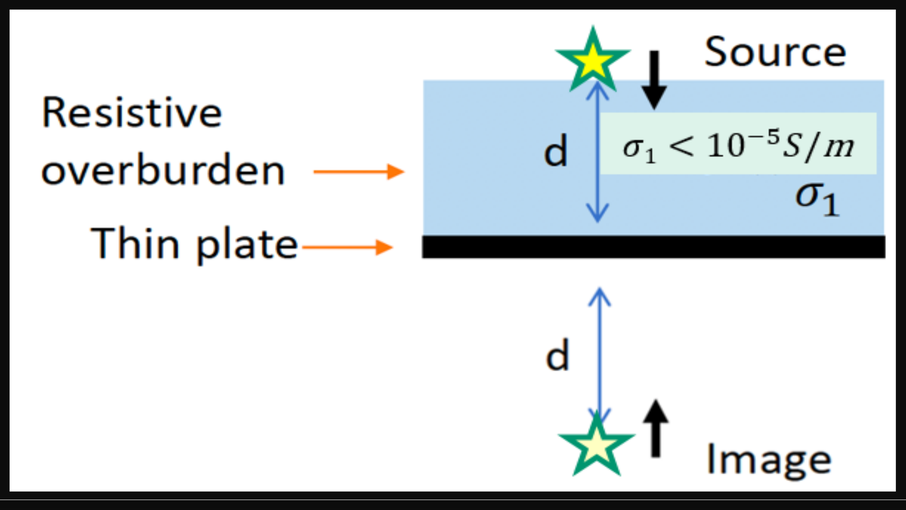
Method	SNMR Surface Nuclear Magnetic Resonance	TEM Transient Electromagnetics	MT Magnetotellurics	MTF Magnetic Transfer Function	Orbital GPR Ground-Penetrating Radar	Static GPR	Mobile GPR	Seismic Single Station	Seismic Interferometry	Seismic Reflection
Family		Low Frequency Electromagnetic			High Frequency Electromagnetic			Seismic		
Source	Active + Crustal Field	Active	Passive	Passive	Active	Active	Active	Passive	Passive	Active
Water Discrimination	Excellent (Nearly Unique)		Very Good Reflectivity 20-85%		Good No aquifer penetration. Reflectivity ~20%			Fair Reflectively ~3%, mode conversions ~0.3%		
Aperture	100 m	100 m	10 m	n/a, but requires orbital reference	<10 m	10 m	<1 m	n/a	kms	kms
Investigation Depth	100s m	kms	>10s km	10s km	100 m	km	10s m	>10s km	kms	kms
Coverage	Static, 1D	Static, 1D	Static, 1D anisotropic	Local (on rover)	Global 2D or 3D	Static, 1D anisotropic	Local (on rover)	Static, 1D	Local	Local
Resources	N/A (>100 kg)	Medium (10 kg, 30 W)	Low-Medium (3 kg, 7 W)	Low (for ground asset)	Low	Low-Medium	Low (<10 kg, 15 W)	Low-Medium SP only vs LP+SP	High to N/A	N/A

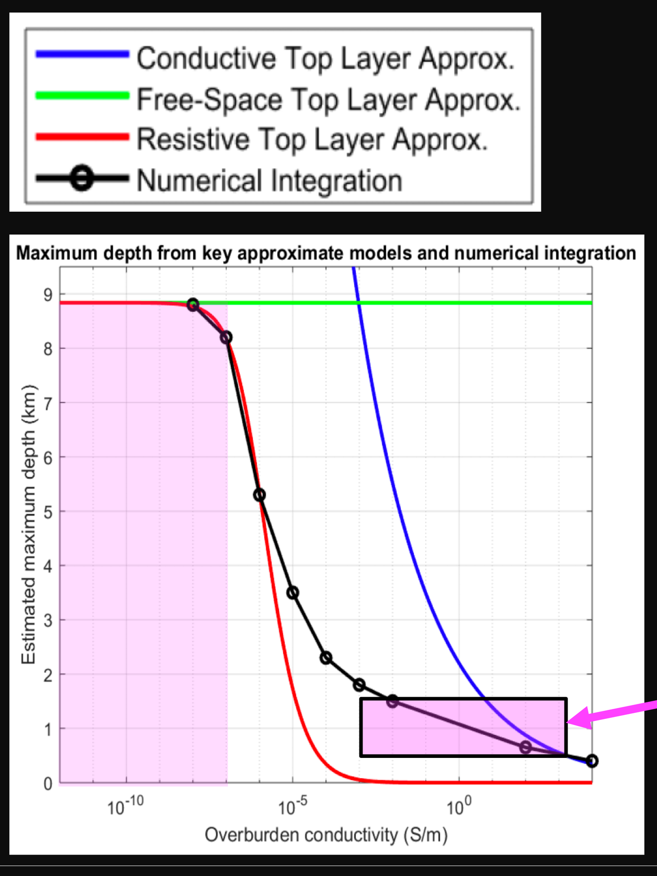
Resource assessment relative to a single Discovery to NF-class mission (orbiter, Phoenix/InSight class lander, or MER-class rover) dedicated to groundwater detection. N/A = cannot accommodate, HIGH = takes significant portion of mission, MEDIUM = nominal part of multinstrument payload but with a nonstandard deployment, LOW = nominal part of multinstrument payload,

This work exemplifies NASA's and JPL's **leadership in subsurface exploration technology for Mars & other solar system bodies**. Reaching a **TRL 4-5 ability to sound for liquid groundwater and infer salinity within 3 years** supports future mission objectives. The technological and scientific development strengthen the **engineering & scientific leadership at JPL**.

TEM Design & Architecture

- Two models are commonly used for TEM :
  - "Free-Space Top Layer" model (Moon)
  - "Resistive Top Layer" model (Earth)
- To reconcile the two models for Mars, whose subsurface resistivity is thought to be between the Earth and Moon, we implemented a more exact numerical model.





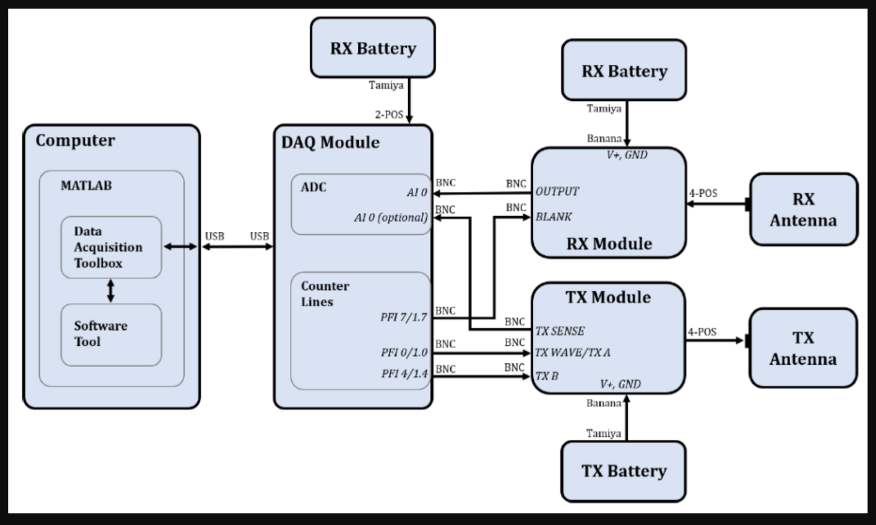
Conditions on Mars (low surface temperature, low EM noise levels, dry overburden crust) allow TEM sounding to a depth ~10x deeper on Mars than on Earth with similar mass/power resources.

Earth TEM rule of thumb
l~d
Mars increase by x 10

Description	Value
TEM bandwidth	20 kHz
Transmitter power	10 W
Receiver's noise figure	10 dB
External noise temperature	450 Kelvin
Surface temperature	-55 C

Description	Value
Wire Gauge	32 AWG
TX/RX diameter	1000m
# of turns	1
Groundwater conductivity (σ_2)	0.1 S/m
Groundwater body thickness	100 m
Integration time	1 hour
Step Repetition Frequency	1 Hz

Our system consist of a transmitter, receiver, DAQ module and a control computer (see below). The received data are inverted into electric conductivity profiles (~resistivity with depth) using our own data inversion routines in MATLAB.



TH$_2$OR Prototype Instrument Development

- We are now in the process of validating our system architecture with a down-scaled transmitter and receiver under various resistivities in our EM lab and especially in the field. Electronics has moved from breadboard to PCB.
- We are enhancing our models and our prototype based on the results from the InSight magnetometer currently measuring magnetic fields on the Martian surface. This will enable to better constrain noise levels & inversion methods.

Future Work

Lab demo of down-scaled prototype +6 months

- Test and compare prototype and inversion software with commercial unit in the Arroyo. Complete loop deployment trade space study. Explore a combined TEM/MT approach.

Field-demo of human-tended prototype +12 months

- Field demo on test site (Arroyo, Table Mountain, Tecopa, Hawaii)
- Demonstrate detection ability of groundwater below bedrock and sediments
- Measure salinity and compare with tapped aquifers

Publications:

Stamenković et al. "The next Frontier for Planetary and Human Exploration." *Nature Astronomy*, 3(2), pp. 116-120, 2019.

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