Virtual Research Presentation Conference

Sounding For Groundwater (TH_2OR: Transmissive H_2O Reconnaissance)

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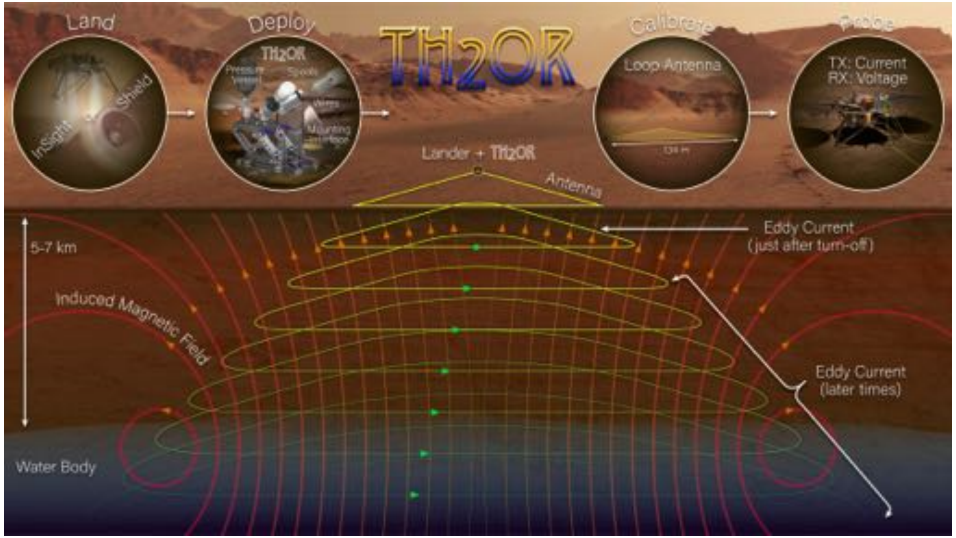
Tutorial Introduction

Abstract: The "holy grail" of planet exploration is the quest for life. This quest has been framed around "follow the water", with the implication that seeking liquid water is equivalent to seeking habitable environments. For Mars, we have learned that the only place where liquid water could still exist today is in the Martian subsurface. In typical landing regions those depths are generally between 2-7 km. This task aims to develop the technology needed to detect liquid water in the Martian subsurface to depths of ~ 7 km, far beyond the reach of radar.

TH_2OR stands for "**T**ransmissive **H_2O** **R**econnaissance" and uses **t**ransient **e**lectro**m**agnetics (TEM) to detect groundwater. TEM is different from radar as it is not sensitive to dielectric constant but, rather, to electrical conductivity.

Practically, as we show in the image to the right, we deploy a closed loop, turn periodically a DC current of ~1-5 Amp on and off. This generates a variable magnetic field, which diffuses into the ground. If there is groundwater, then eddy currents are being induced, which re-induce a measurable voltage in our surface loop. **The water can be seen!**



TH_2OR consists of a small electronics package, one single transmit & receive loop (yellow equilateral triangle on the surface with sides 134 m long) and the system that deploys that loop (total instrument footprint is <6 kg, 3 u, <500 Wh/sol). We measure the electric conductivity as a function of depth. The sensing area is a half-circle with radius of ~7 km beneath the instrument allowing to determine the depth to the water table and its salinity.

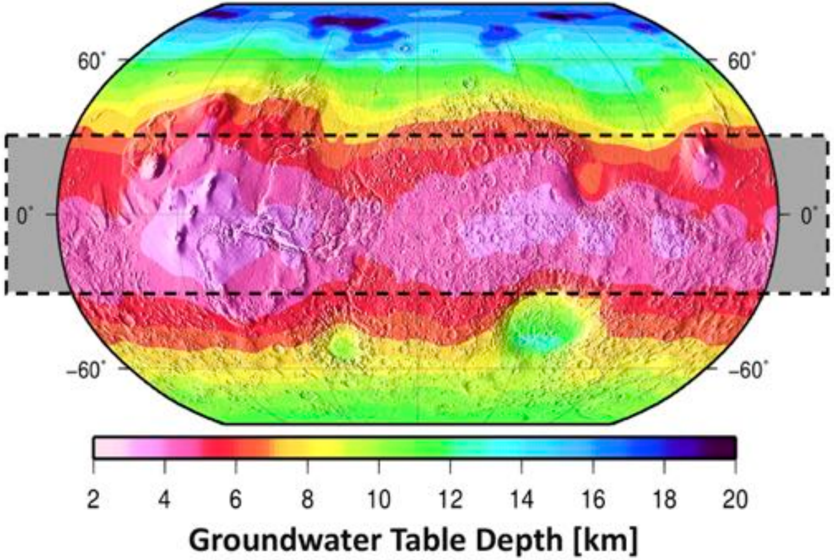
Problem Description

a) **Context**: Liquid water in large quantities can only be stable at great depths of many kilometers, as we show in the image to the right. Only freezing point reducing salts can bring this depth, locally, closer to the surface. The depths where groundwater might be hiding are out of reach of radar and lower-frequency technology, such as TEM, is needed to sound to depths of many miles.

b) **SOA**: TEM instruments are among the most prominent instruments to search for groundwater on Earth, and have, due to their great success, not changed much in design in the last three decades. This provided the opportunity to re-design TEM systems with modern electronics, miniaturization and flight-like components. Commercial systems weigh many tens of kilograms, our complete TH_2OR instrument is < 6 kg.

c) **Relevance to NASA and JPL**: TH_2OR enables low mass, low power solutions compatible with Small Spacecraft to search for groundwater, but also ores for ISRU across the solar system.

WATER IN EQUATORIAL REGION ~2-7 km depth

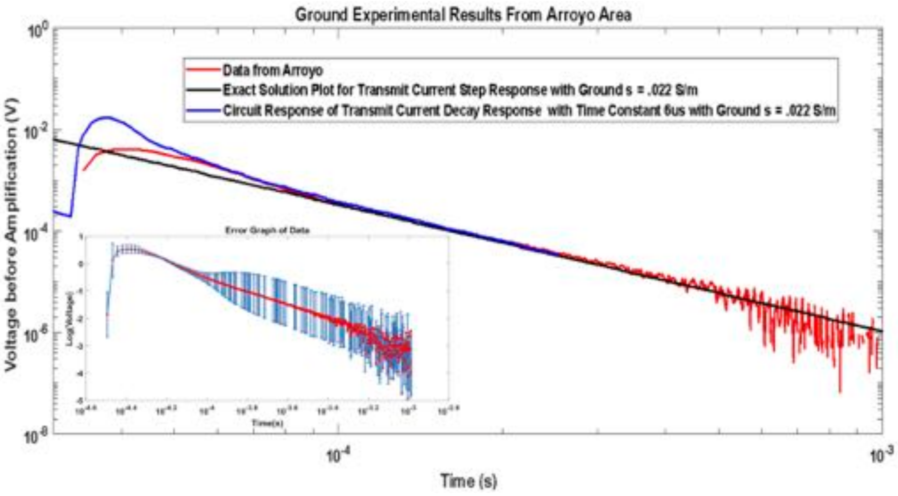


Mars groundwater table depth (assuming no freezing-point-depressing salts, see Stamenković et al., 2019b) depends on surface temperature and local heat flux. For simplicity, we assume only a latitude-dependent surface temperature model. For common landing constraints, closer to the Equator, potential depths to pure liquid water are ~2-7 kilometers.

Methodology

a) **Formulation, theory or experiment description**: A bipolar periodic switching on and off of a 1-5 Amp DC current in our loop generates in the subsurface eddy currents in conductive materials such as groundwater. Those currents in turn generate a variable magnetic field, which induces a voltage in the same loop on the surface, measured when the loop's current is off. To the right, we show data that we have taken with our prototype in the Arroyo, illustrating the methodology.

b) **Innovation, advancement**: It is important to note that this is the first planetary TEM that is being developed. Our innovation is mainly based on a fresh re-design of the system using 21st century electronics instead of the analog architecture of commercial units that is more than three decades old. Faster processing, higher gain, higher bit rates, smaller components, and improved forward models that describe the propagation of the signal through various media are our key advancements, which allowed us to reduce mass and power consumption.



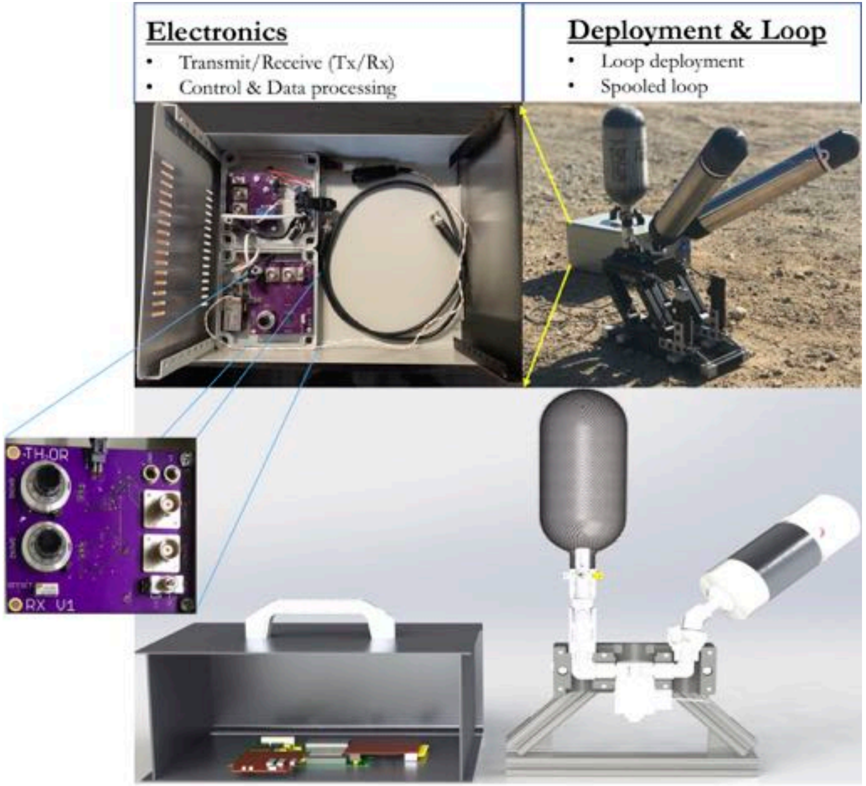
Data (red) taken in the Arroyo Seco with the 2nd generation prototype. Inversion (dark blue, black) shows that the Arroyo Seco can be assumed as a homogeneous subsurface with a 22 mS/m electrical conductivity, which is a typical value for hydrated crust as expected in this region. The oscillations in late time (above 10 µs) are due to the received signal reaching the noise floor of our system. The sounding depth is calculated to be 380 meters.

Results

a) **Accomplishments versus goals**: We accomplished all our goals for FY20, which included: (1) to complete our forward models and predict our capabilities of finding groundwater in the Martian Deep, (2) to mature the electronics and the control software for a terrestrial-applications prototype, (3) to start validating this system and our models with a commercial TEM unit and (4) to perform a thorough trade study to determine the best deployment system for our loop.

b) **Significance**: We have now a working prototype, which is shown in the image to the right, consisting of electronics and deployment units. The low mass and power requirements of TH_2OR open up endless possible applications using low-cost missions to explore groundwater and ISRU on Mars and beyond.

c) **Next steps**: Extensive field testing and validation is the major task for FY 21. We will also mature the electronics design to include bipolar current switching, allow the merging of detector and receiver loop into just one single loop to minimize mass. And we will add a flight-like FPGA to mature TH_2OR as close as possible to TRL 5.



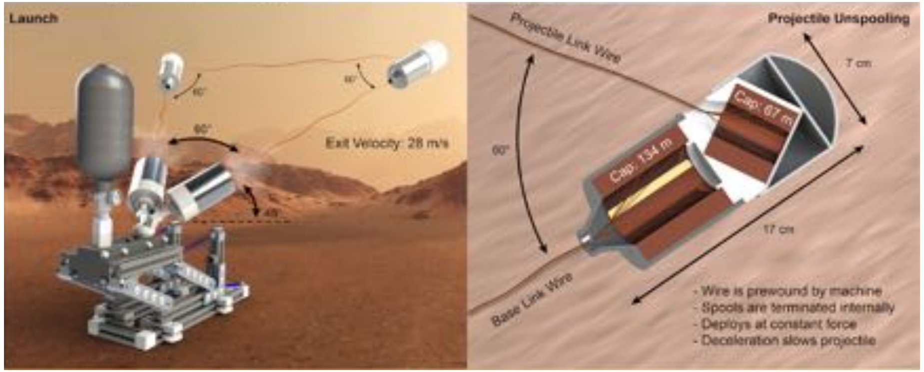
Current TH_2OR prototype. Images and CAD of Electronics (signal transmit/receive boards) & deployment subsystems. Highlighted is the Receive (Rx) board.

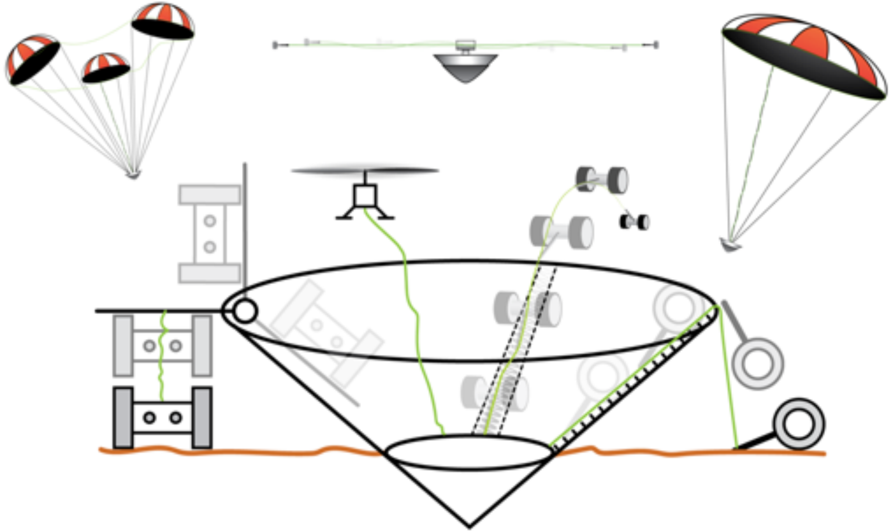
Results (Loop Deployment)

The major take home message is:
We have low-mass solutions for deploying our loop!

We have performed an intense and dedicated trade study for the deployment. This resulted in 25 deployment architectures, which are shown in the image to the lower right, using rovers, UAVs, projectiles, angular momentum, parachutes, inflatables, and springs. We developed a rating and selection process guided by quantities associated with capability, mass, complexity, robustness and testability to select three most promising candidates: a ground ballistic method, deployment from one rover or Puffers, and an EDL-based deployment.

In FY 20, we have, as a first step, focused on the ballistic approach and have built a fully functioning prototype called "Mjolnir" (aka Thor's Hammer, shown in the top image to the right). Mjolnir deploys a triangular loop using pressurized gas and our field testing in the Arroyo is starting in FY 21.





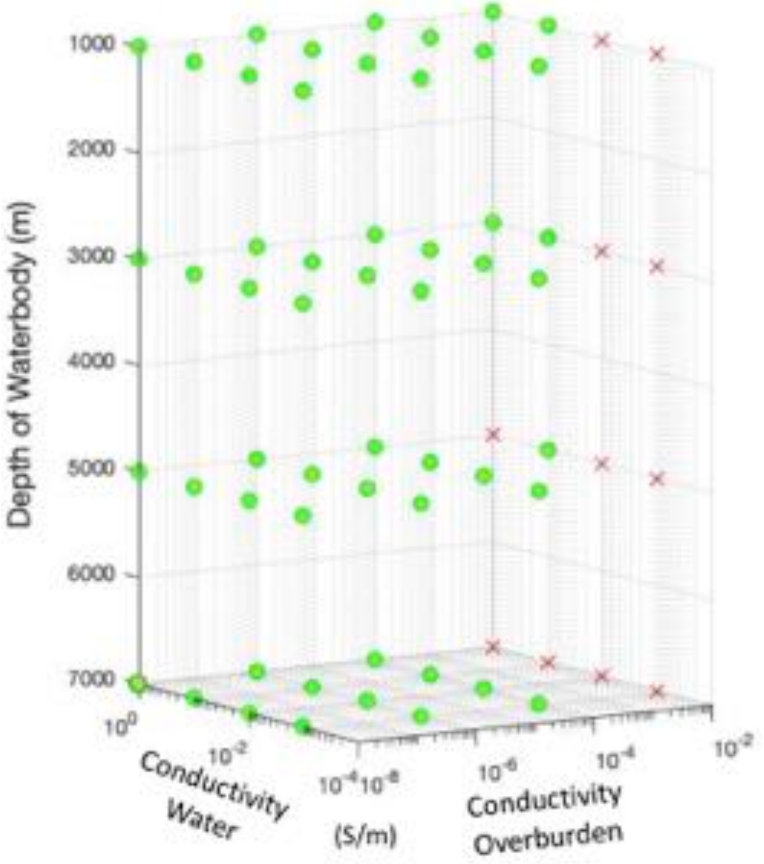
Results (Sounding)

The major take home message here is:
Yes we can (sound deep enough)!

To get to that conclusion, we ran many models consisting of rock layers of variable thickness above a groundwater table, assuming a great variety of material properties for rock and groundwater. We then checked whether the transition to the groundwater can be detected at a given depth.

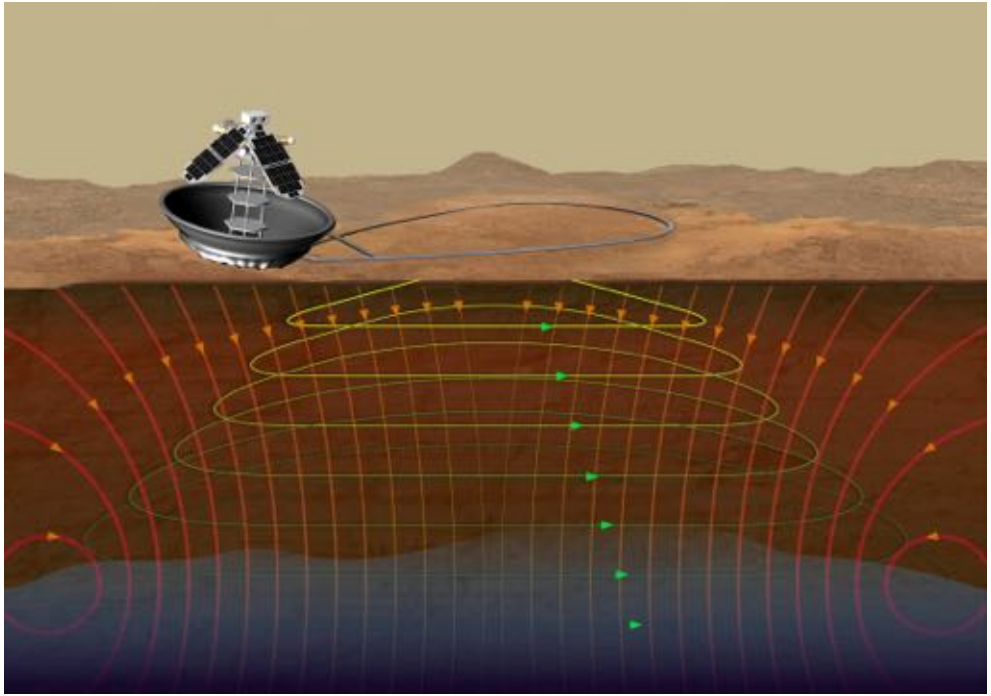
The Figure to the right summarizes these individual results. Green circles represent that the mentioned water depth can be observed for the given combination of rock and groundwater electrical conductivity, red crosses represent a non-ability to detect groundwater to the specific depth.

For all reasonable water & overburden conductivities for Mars, we find that we can detect groundwater to a depth of ~7 km.



Summary

- Liquid water can exist at ~kms depth and is the best location for habitable zones on contemporary Mars
- Transient Electromagnetic Sounding is best suited to detect & characterize liquid groundwater on Mars with small mass & costs
  - Penetration depths of many kms
  - Does not depend on ambient sources
  - Modest resource requirements
- TH_2OR can detect liquid groundwater to many kms depth with a payload mass ~6 kg
- **We can finally answer the question: Is there liquid water, and possibly extant life, on Mars?**



Publications and References

- Stamenković, V., et al. 2019, Nat. Ast. 3. doi.org/10.1038/s41550-018-0676-9
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