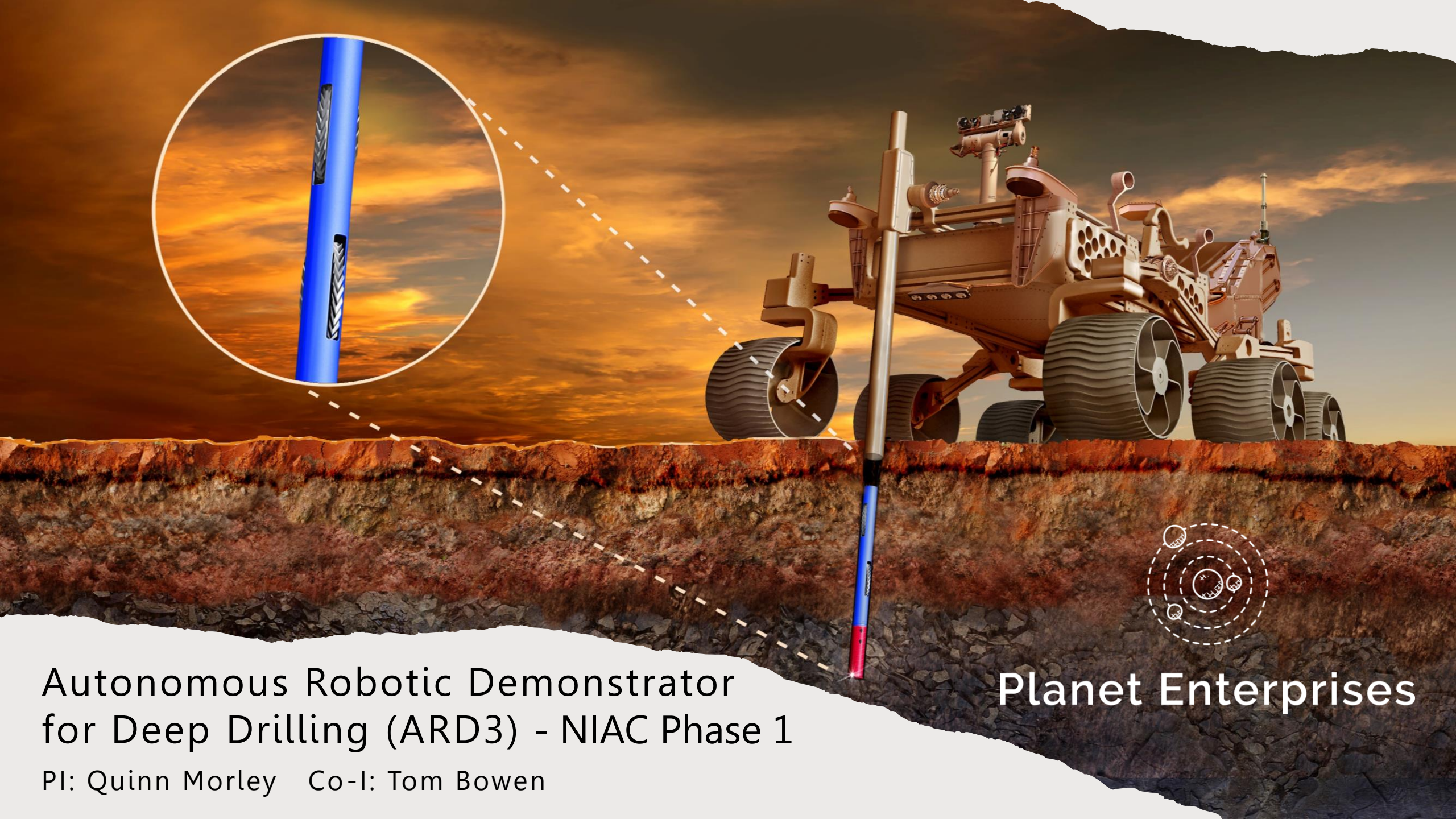


Autonomous Robotic Demonstrator for Deep Drilling (ARD3) - NIAC Phase 1

PI: Quinn Morley Co-I: Tom Bowen

Planet Enterprises

“If you were standing on the Mars SPLD in the summer, and you were to dig a hole in the ice, what would the material be like?”

To support early work on deep drilling in Martian polar environments, we need notional answers to this question.

SPLD Characterization

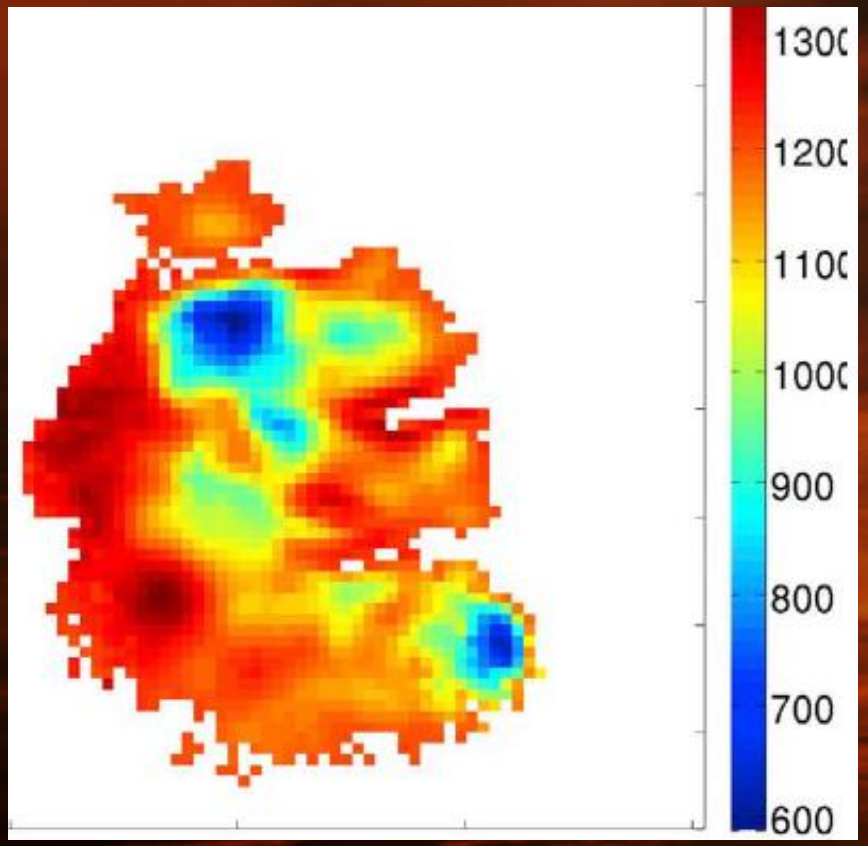
Can we believe the material is **hard ice?**

- Bar-Cohen, Y. and Zacny, K. (2020), "Advances in Extraterrestrial Drilling" state:
  - "Ice on Mars, Europa, and Enceladus is very cold, while the gravity in all cases is low. Both of these aspects create an extremely stable borehole that would remain open for years." (p. 178)
  - They cite Molaro et. al, (2018), doi.org/10.1029/2018JE005773 which puts forth that ice grains sinter together over time forming a hard substrate – this concept is the basis of the hard ice assumption
- Zuber, M. et. al, (2007). doi:10.1126/science.1146995 claims SPLD is "clean" water ice with 15% dust
- Arthern et. al (1999) "Densification of Water Ice…" is very influential. doi.org/10.1006/icar.1999.6308
- Below is an example of hard, dirty (for Earth) ice from the NEEM borehole in Greenland
  - Smith, I. et al, "The Holy Grail: A road map for unlocking the climate record stored within [the PLD]"

SPLD Characterization

Are we worried that the material is **crumbly or otherwise non-cohesive?**

- The sintering model may not be able to fully capture the effect of 10% – 20% regolith present (in layers), and the effect on hardness / cohesiveness
- Li, J. et. al (2012) doi.org/10.1029/2011JE003937 claim that there is a large variation in density in the SPLD (see graphic at right)
  - Low density is caused by porosity; high density by dust
  - This contradicts Zuber and Arthern from the previous slide
  - **Can porosity affect / negate the hard ice assumption?**
  - Is it possible that porous ice can still sinter together forming a hard, cohesive substrate?



Keep the original question in mind as we introduce you to our NIAC study. We are evaluating key innovations that could make autonomous deep drilling in Martian polar regions feasible. We need your help!

Mission:

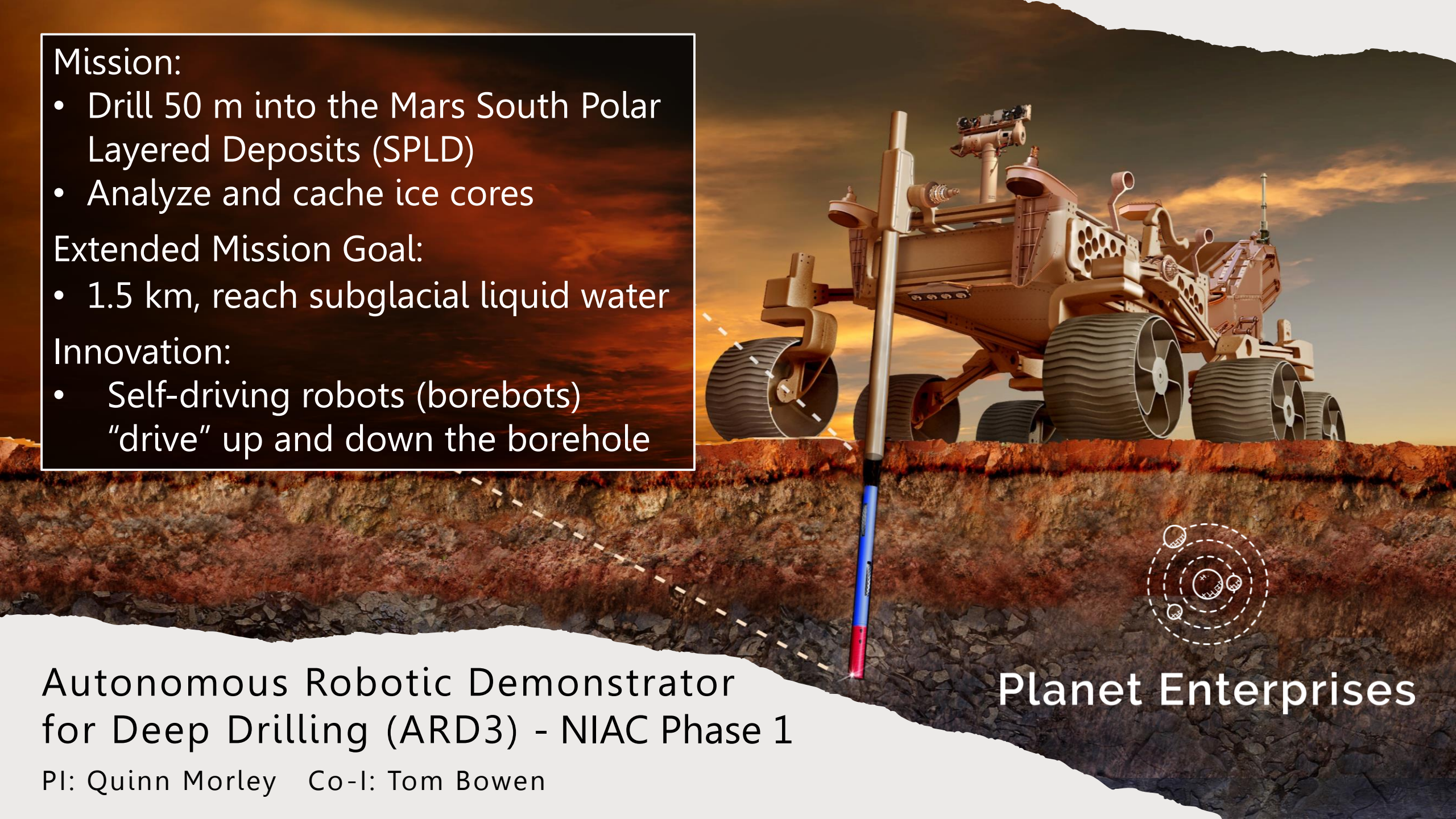
- Drill 50 m into the Mars South Polar Layered Deposits (SPLD)
- Analyze and cache ice cores

Extended Mission Goal:

- 1.5 km, reach subglacial liquid water

Innovation:

- Self-driving robots (borebots) “drive” up and down the borehole



Autonomous Robotic Demonstrator for Deep Drilling (ARD3) - NIAC Phase 1

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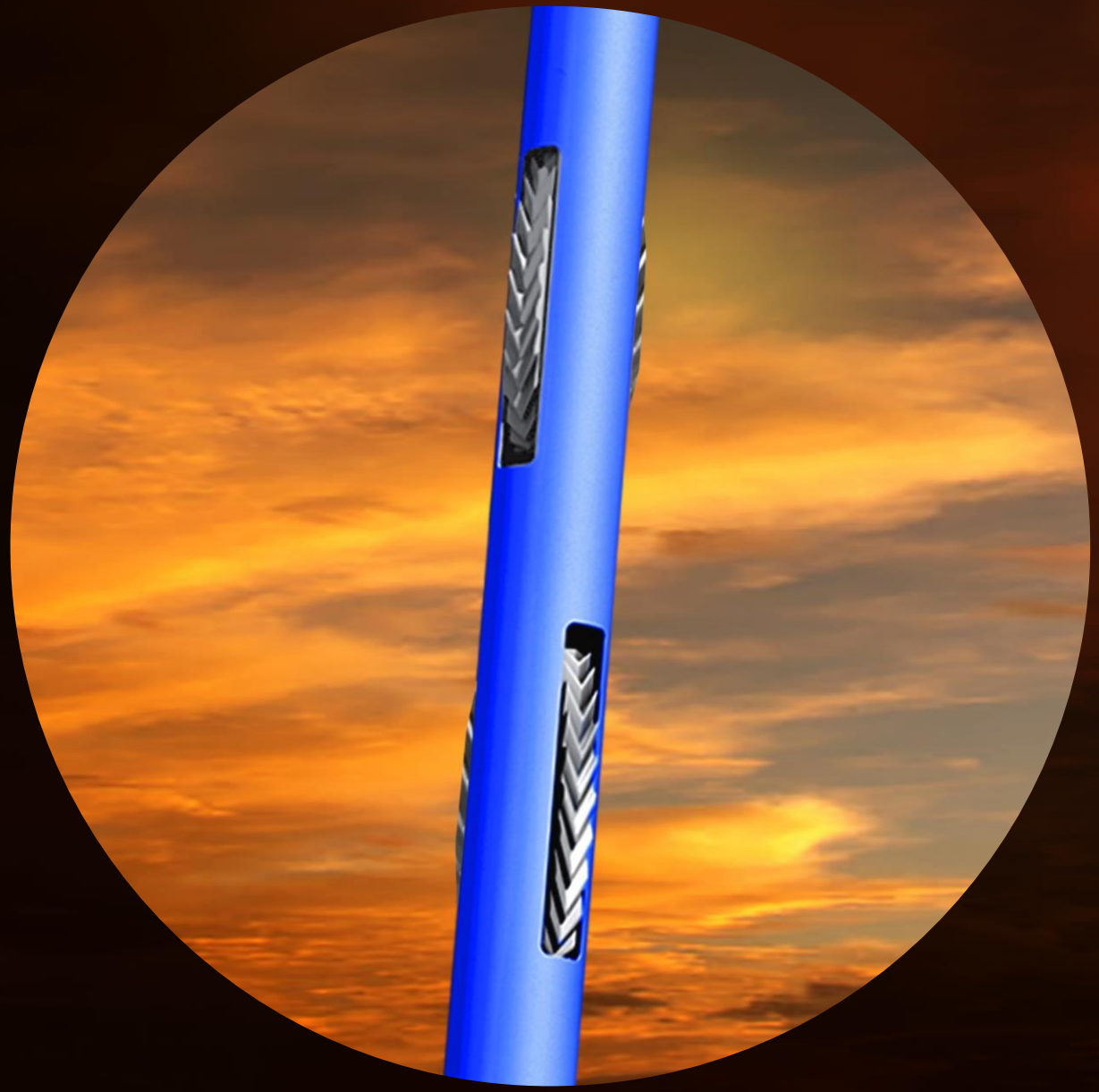
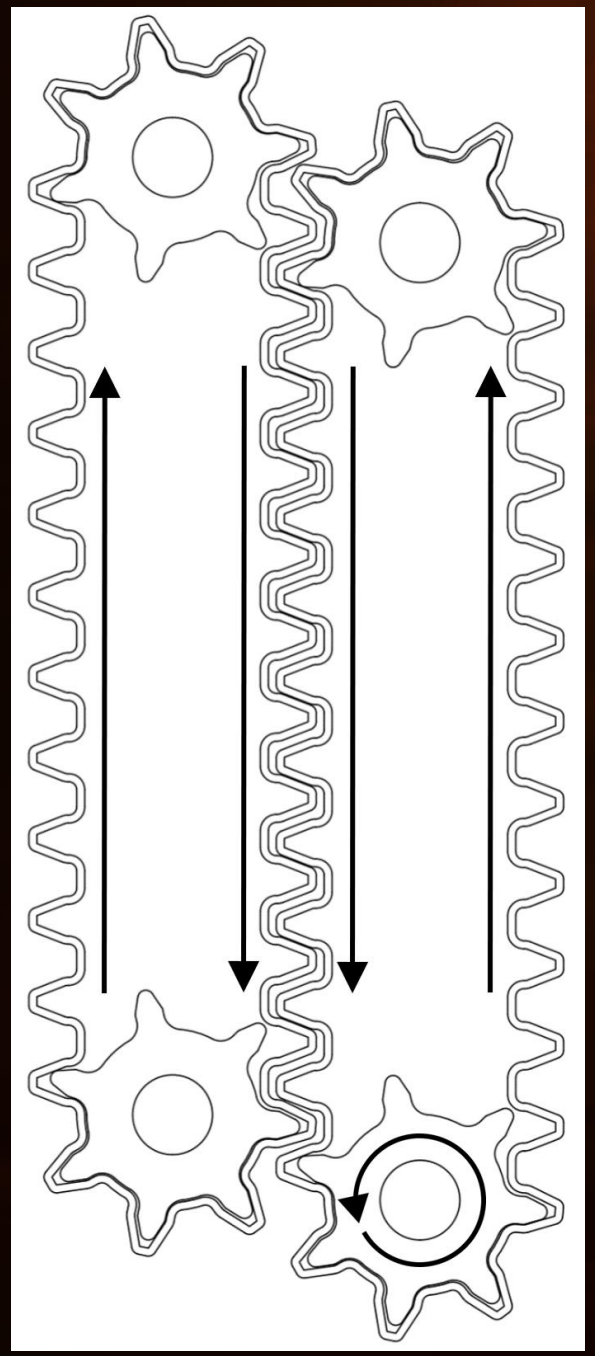
Borebot Drivetrain



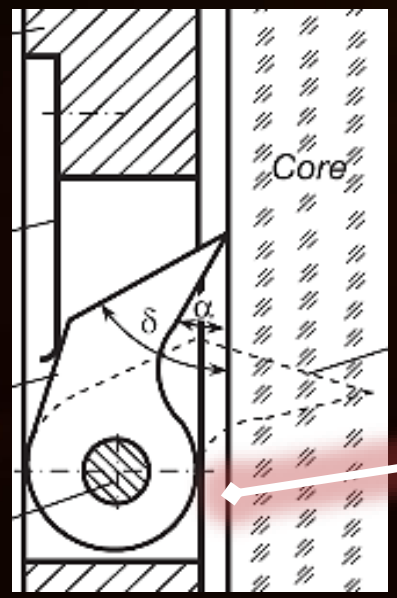
- Tank tracks shown are actually flexible ring gears
- As prototyped, the entire drive system is made of flexible components: small chunks of ice or rock could pass through without causing binding or failure
- This NIAC study is mainly focused on the feasibility of self-driving drilling robots in the context of SPLD deep drilling from a rover
  - Drivetrain is priority #1



Borebot Drivetrain 64 mm bore dia.

- Pressure on the wall of the hole can be varied in design, but we only have a few options for changing this in-situ
- Depending on the nature of the substrate, **there is a potential for dramatic and quick erosion of the borehole wall**
  - This is the main motivator for our characterization efforts
- Drilling challenges relating to the substrate are also significant, but are easier to mitigate

Mitigating Drilling Challenges – Hard Ice is Preferred



- Drilling hard, very cold ice is an exercise in chip clearing
- Increased system reliability overall
- Mechanically simpler drill head
- Cores can easily be broken off with a variety of “core dogs,” which cause the core to fracture at the desired location, and retain it for transport
- This would provide us with a slightly larger core, lower power consumption, more room for chip clearing
- **Hard ice: virtually no borehole wear-and-tear from the drivetrain.**

Mitigating Drilling Challenges – Crumbly Ice

- We have developed an innovation for reliable capture of non-consolidated ice cores as a mitigation measure if the hard ice assumption is rejected
- Carbide teeth are brazed onto a steel-bladed spherical iris
- The main drill motor is used to actuate the iris via a clever pin-puller strategy
- A ratchet mechanism is envisioned to allow stopping-down the aperture and holding, while the entire drill turns to cut into the core. This way, hard ice or rock could also be cut with this catcher
- 10-second video: https://git.io/JsKah

Please Contact Us!

- A notional understanding of the substrate is needed to plan future work
- We are aware that future characterization efforts are already in development, but these may not be focusing on the sort of qualitative traits we need to understand in order to support deep drilling activities
- Humans are unlikely to operate in polar regions, so autonomous deep drilling is the most logical path forward for SPLD ground operations
- Our 8-page NIAC white paper is available at https://git.io/Js2bu

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