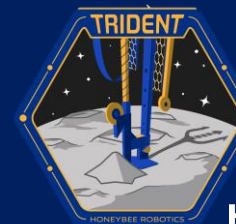




TRIDENT Lessons Learned

Isabel King, Research Engineer / TRIDENT Payload Downlink Lead

6/4/2025



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Honeybee Robotics
2408 Lincoln Avenue
Altadena, CA 91001

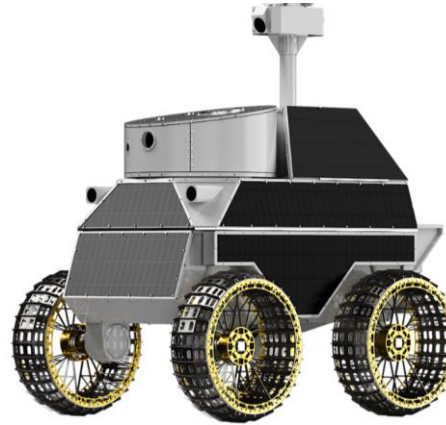


About Honeybee



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- ▶ Founded in NYC in 1983
- ▶ Two divisions: Motion Control (MC) in CO, and Exploration Systems (EX) in CA
- ▶ EX makes integrated robotic systems to touch life and mine the sky
- ▶ Acquired by Blue Origin in 2022

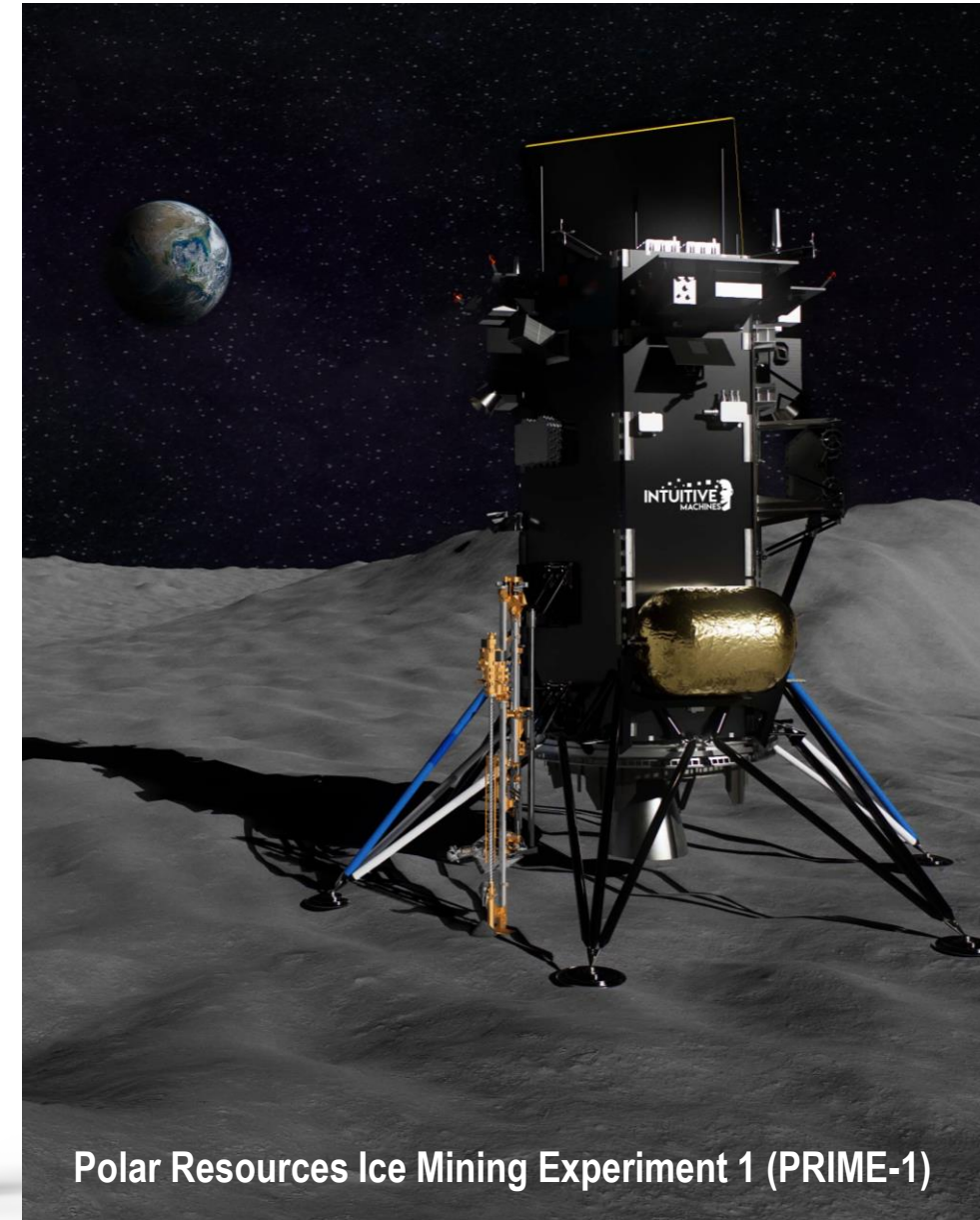
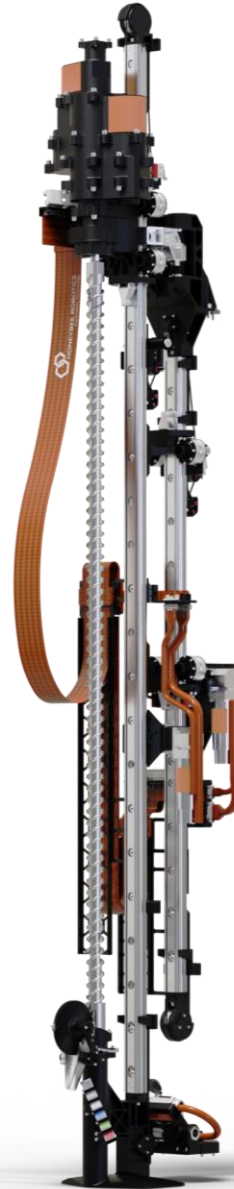


TRIDENT & PRIME-1 Overview



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- ▶ TRIDENT is a two-stage 1-meter rotary percussive drill
- ▶ Manifested on VIPER and PRIME-1 with the goal of investigating volatile resources at the lunar south pole
- ▶ PRIME-1 was aboard IM-2 Athena vehicle, which launched February 2025 and landed March 2025

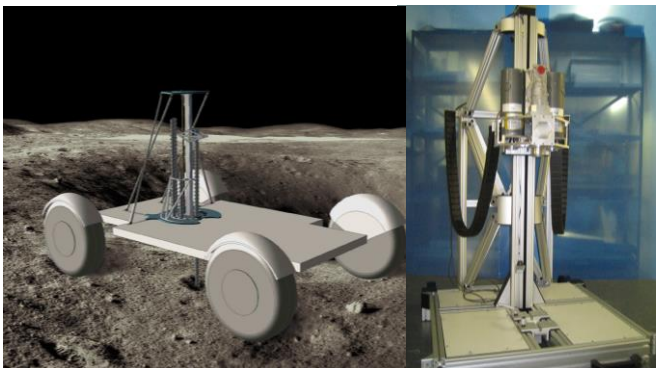


Polar Resources Ice Mining Experiment 1 (PRIME-1)

TRIDENT Path to Flight



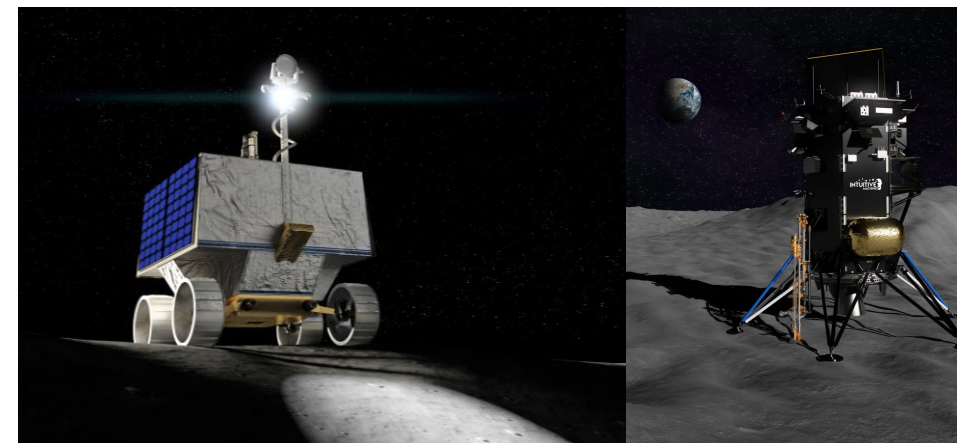
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CRUX



LITA



VIPER and PRIME-1

2005

2008 – 2010

2011 – 2013

2014 – 2018

2019 – 2025



Icebreaker



Resource Prospector



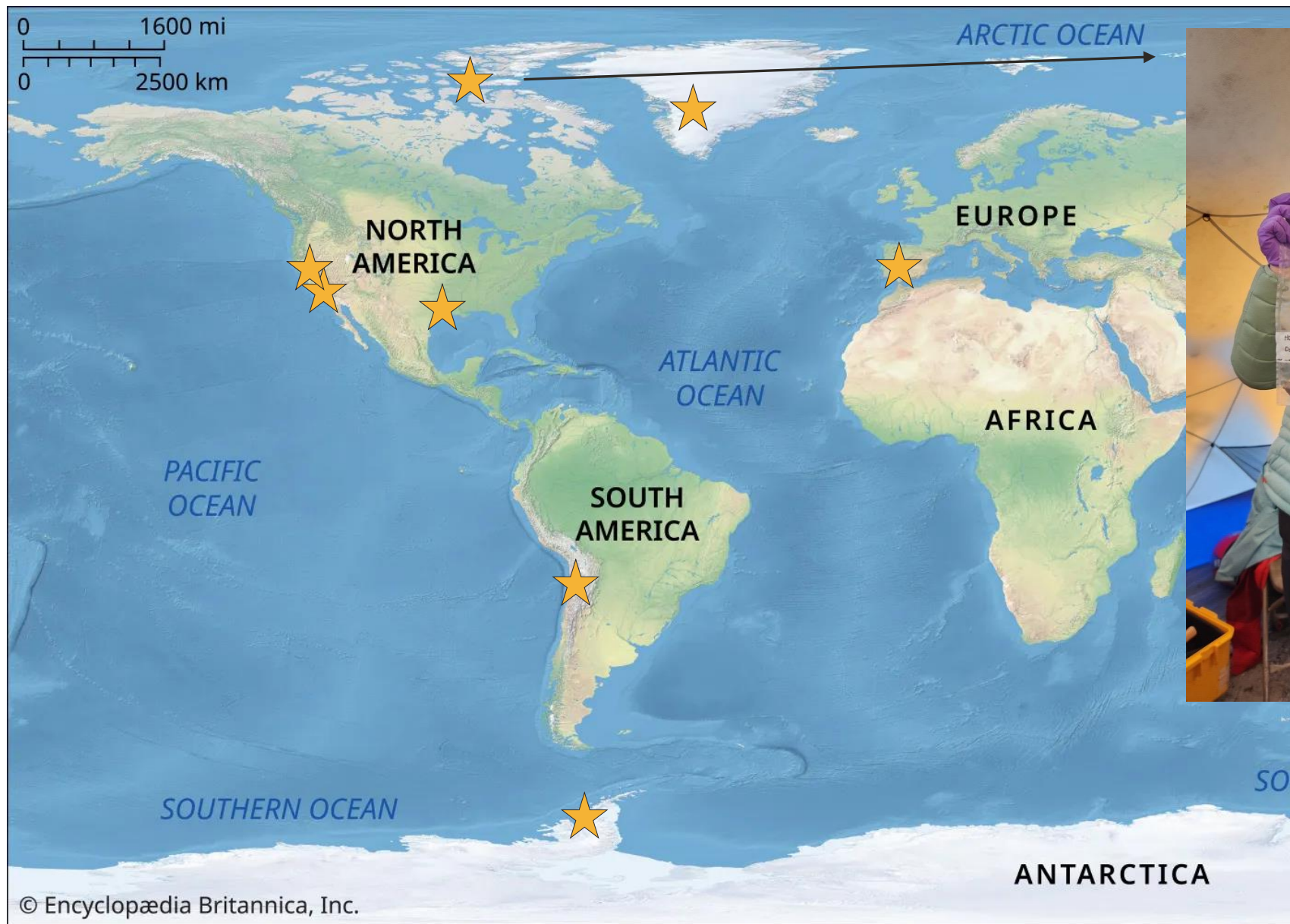
March 2025
PRIME-1 Flight Ops



Field Testing Map



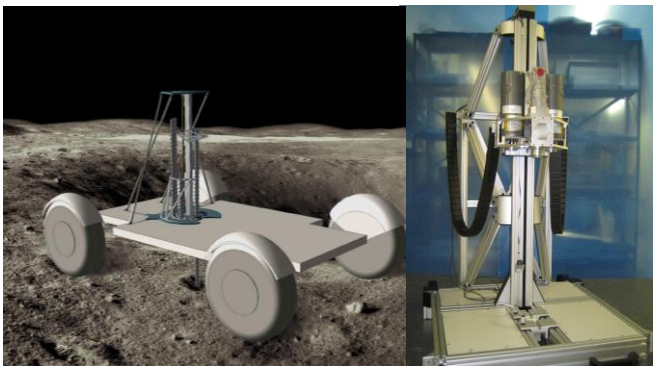
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TRIDENT Path to Flight



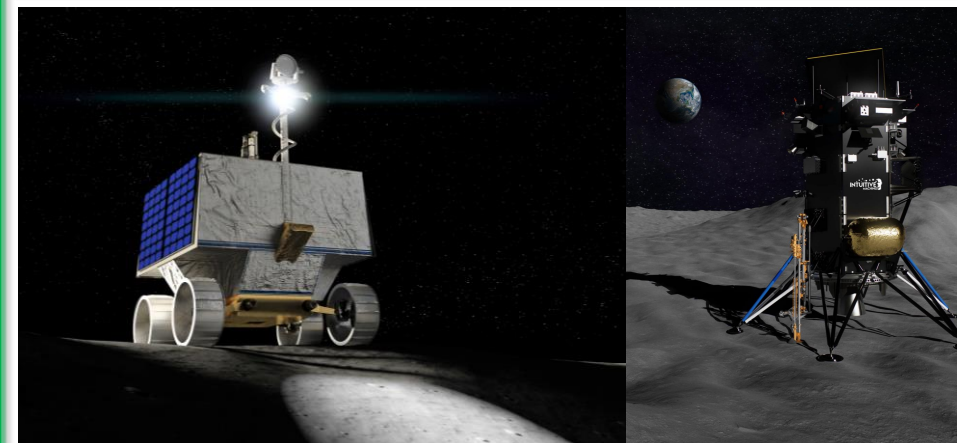
HONEYBEE ROBOTICS
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VIPER and PRIME-1

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March 2025
PRIME-1 Flight Ops



TRIDENT Flight Qualification



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Cleanroom Assembly & Functional Check Outs



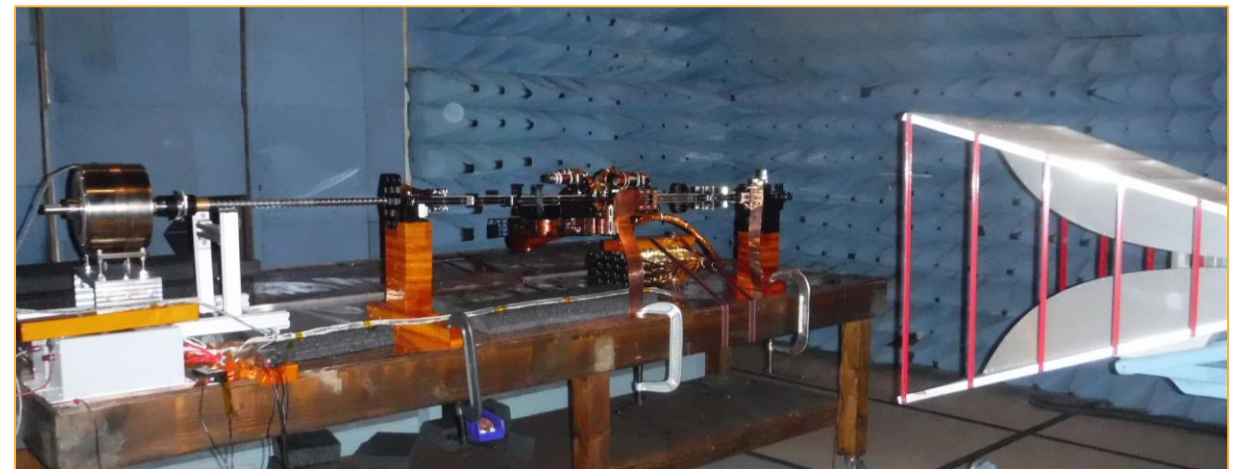
Thermal Cycling (TVAC)



Life Testing



Mechanical Loads Testing



Electromagnetic Compatibility (EMI/EMC)

Operations Summary



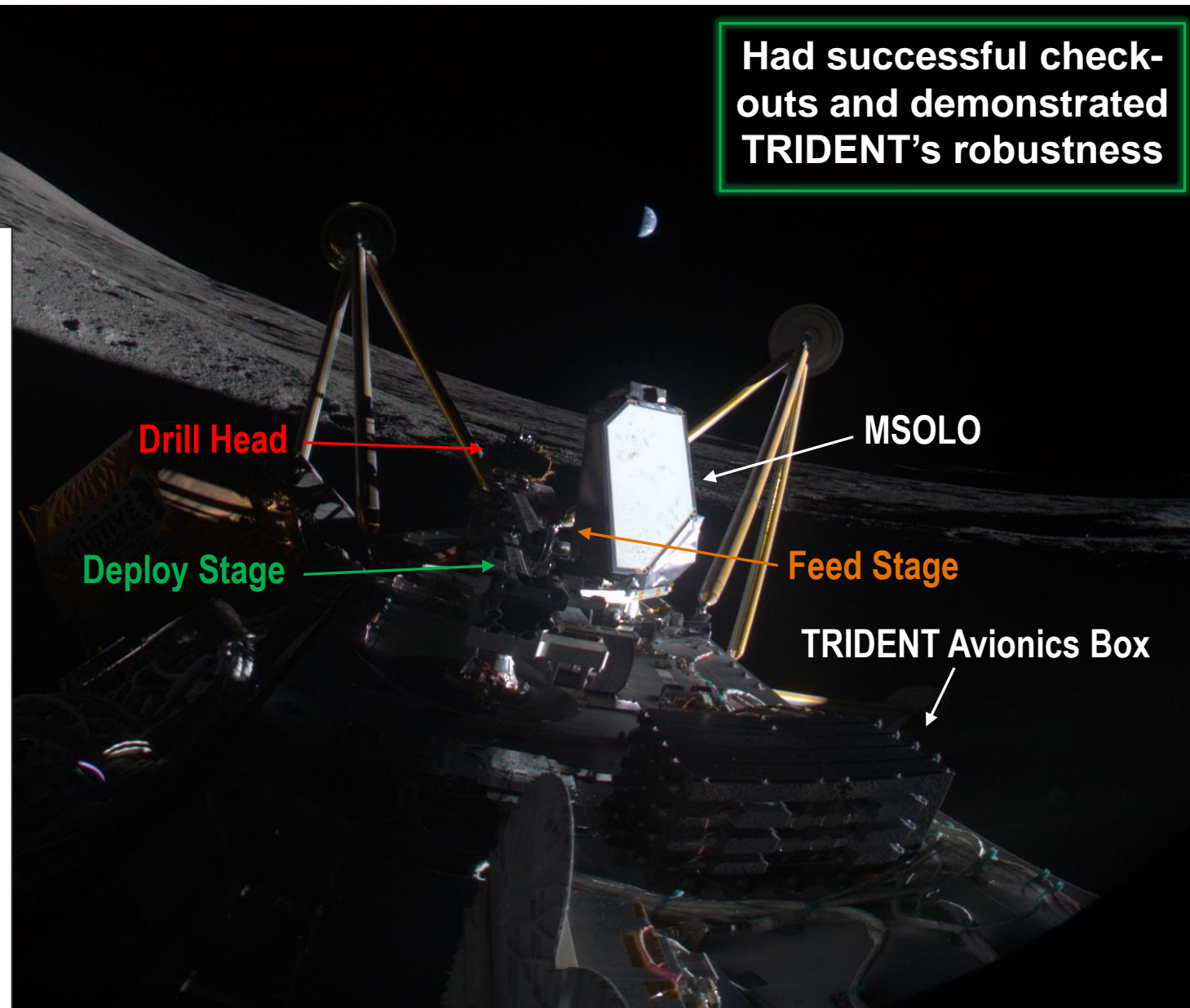
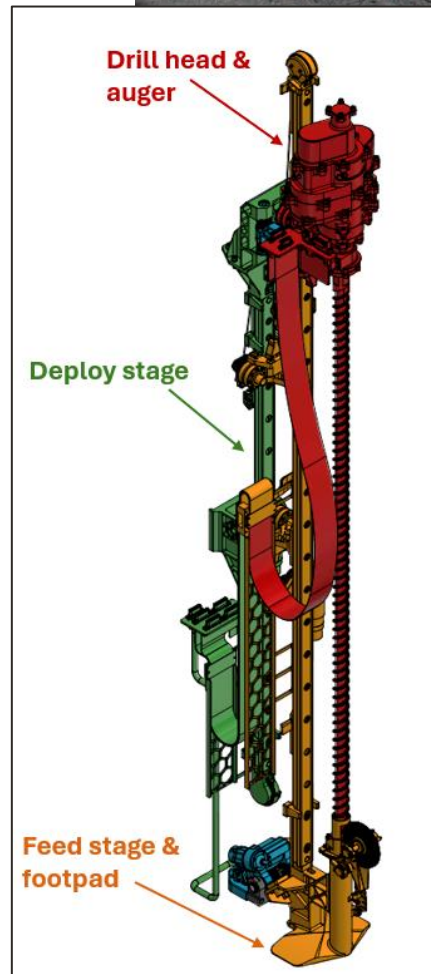
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Nominal In-Transit Check Out

- ▶ Auger rotation
- ▶ Recorded thermal and avionics health data

Surface

- ▶ Auger rotation
- ▶ Auger percussion
- ▶ Released launch locks
- ▶ Deployed to 'surface'
- ▶ 'Drilled' to 1 meter depth
- ▶ Cycled heater in drill bit
- ▶ Recorded all thermal data

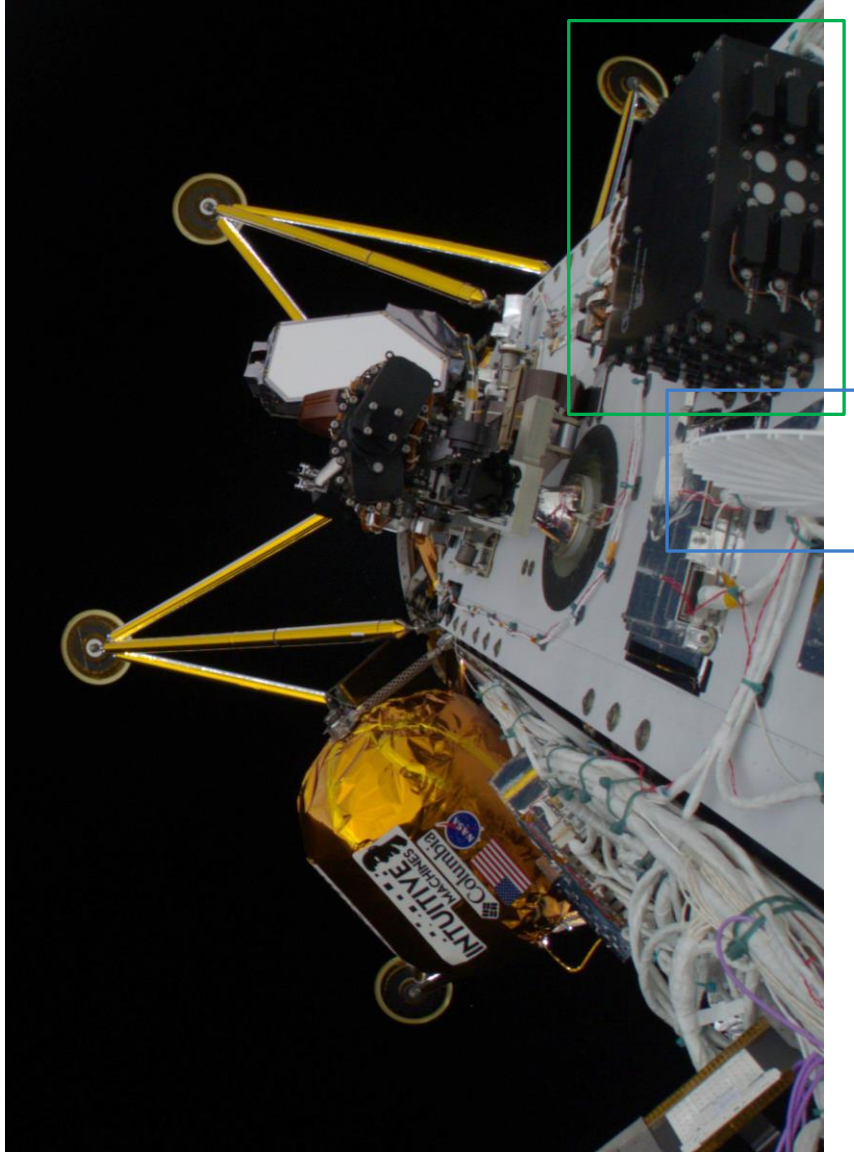


Operated in Dusty Environment

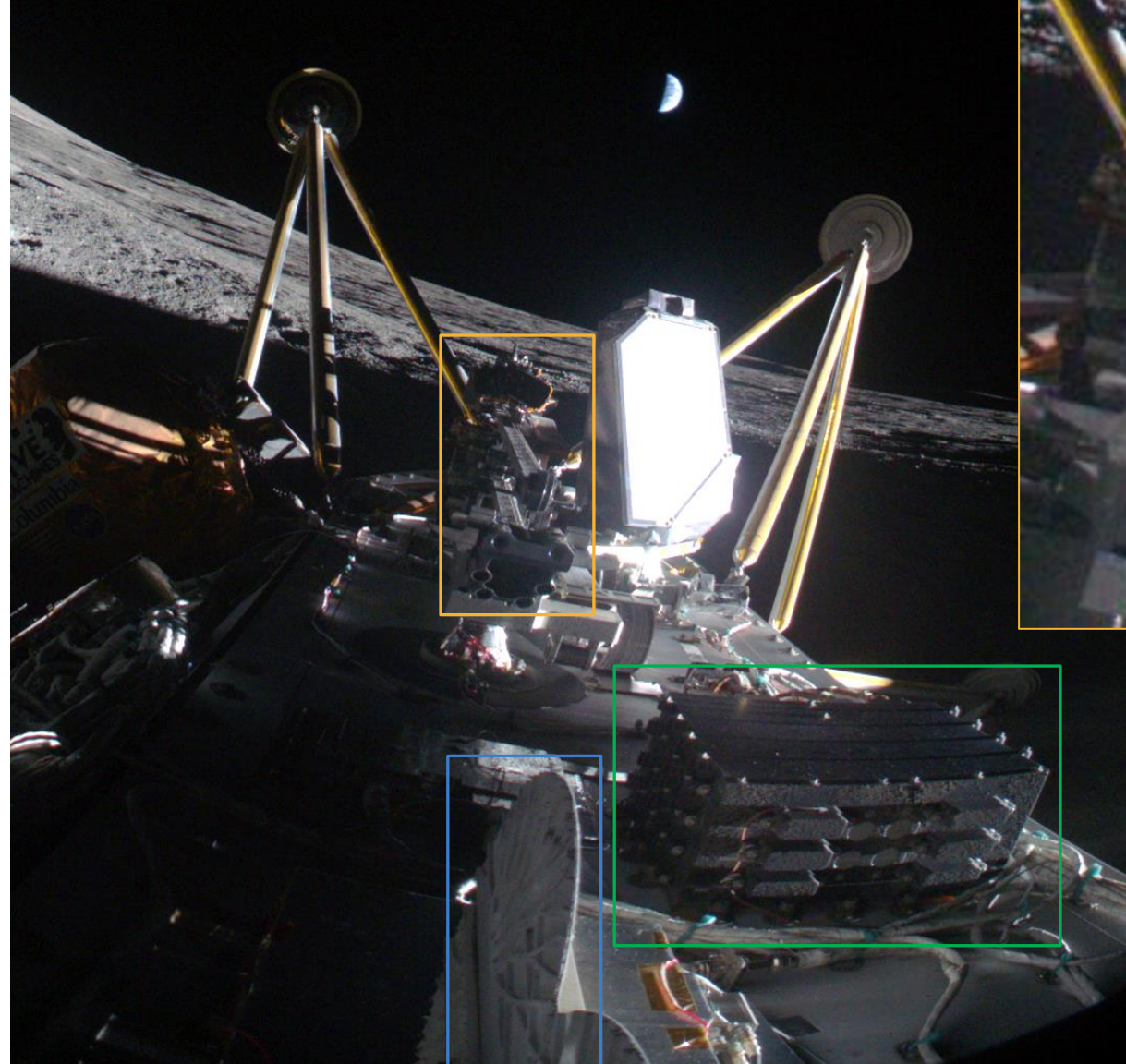


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In Transit



On the Lunar Surface



1. Proposal Phase

- ▶ Add margin to everything, ex. mass/power/data volume/operations time
- ▶ Allocate sufficient time for operator training

2. Development Phase

- ▶ You are only as good as your tests, need end-to-end tests to fully characterize system not just meet requirements
- ▶ Thorough documentation of tests and performance, comes in handy during off-nominal scenarios

3. Operations Phase

- ▶ Multidisciplinary engineering team as operators enables agile response to anomalies, no one knows the payload better than those who built and tested it – especially in the field!
- ▶ Resource efficiency: keep one dedicated person on the project, then ramp up full ops team ~months before launch
- ▶ Plan for contingencies! Although you can't plan for all scenarios, having relevant data on hand can save you



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