

Applying Data Science and AI to Advance Mission Innovation at Scale

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A little about my journey



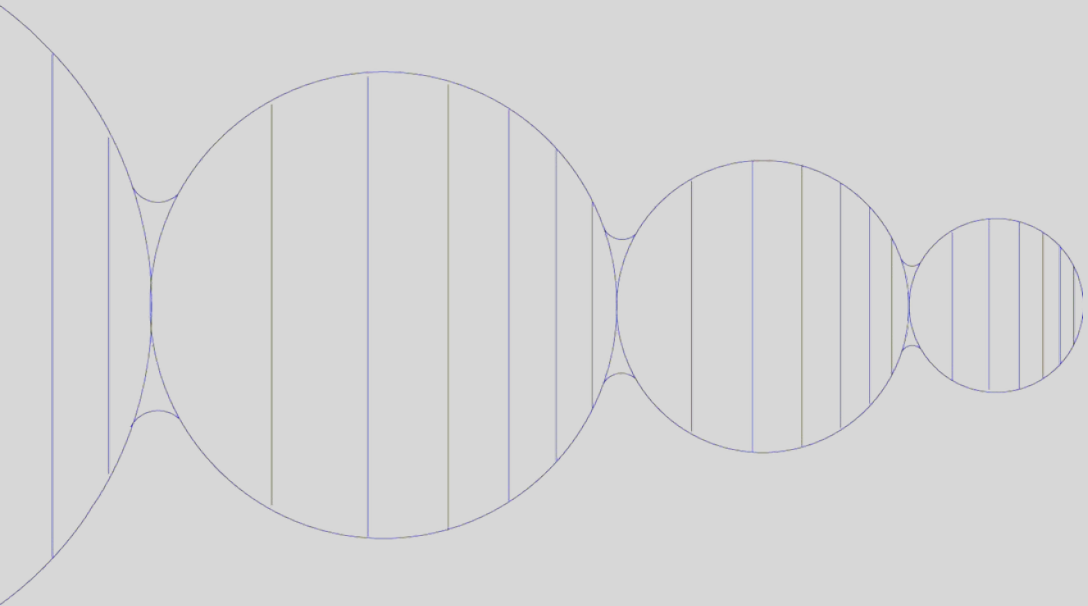








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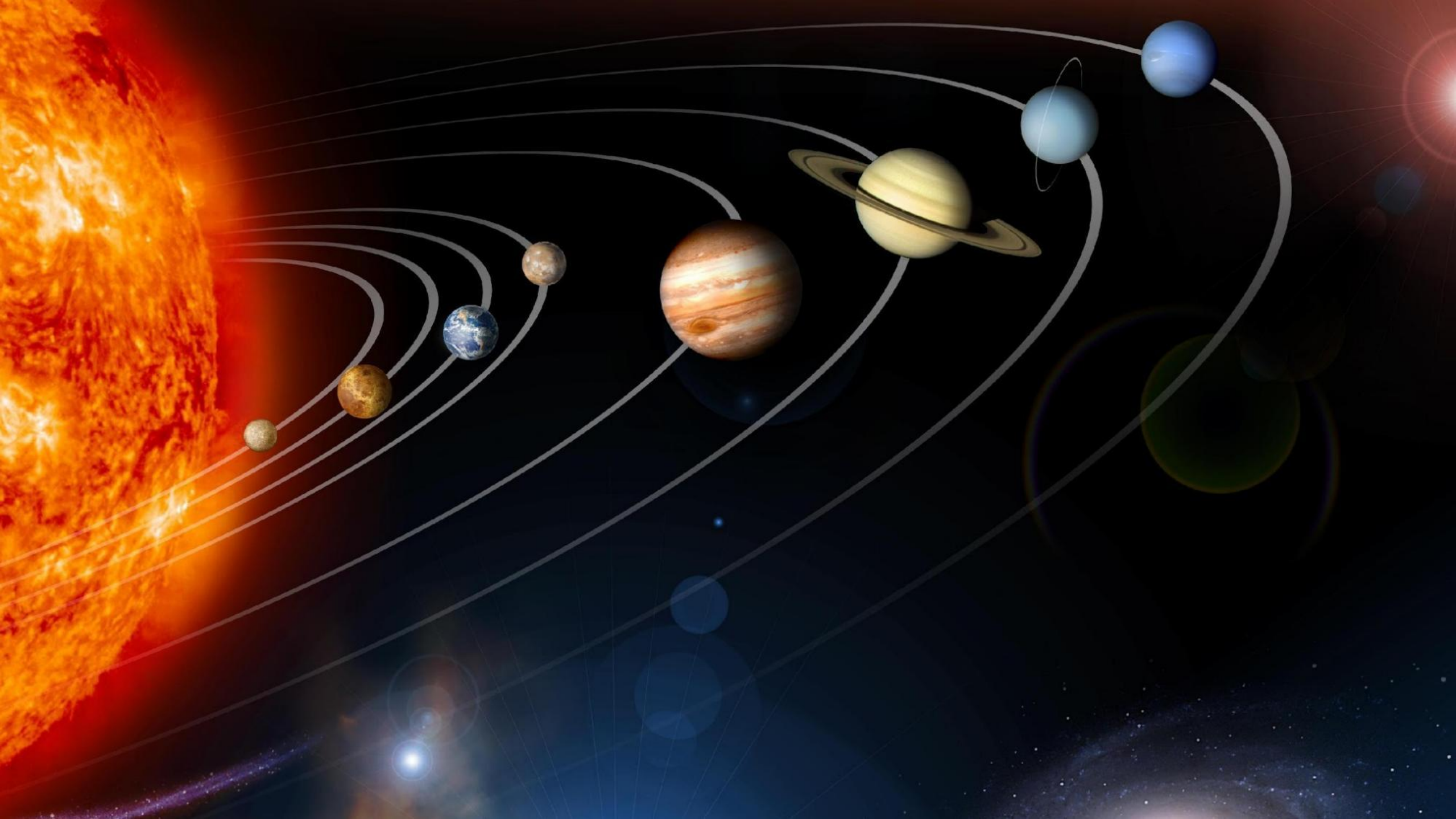
Overcoming critical challenges

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The future of AI & autonomy

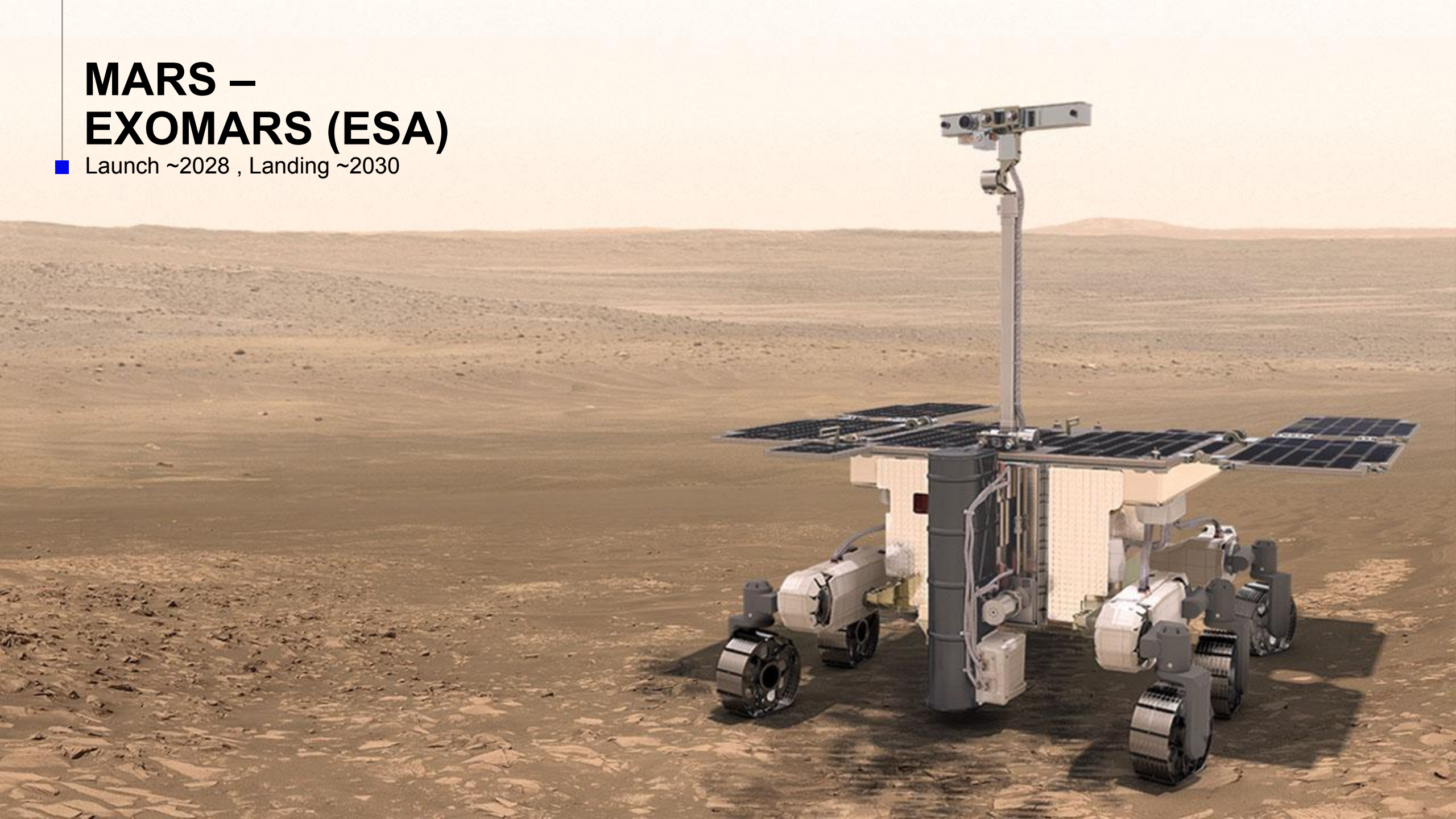
01

— Mission context



MARS – EXOMARS (ESA)

■ Launch ~2028 , Landing ~2030



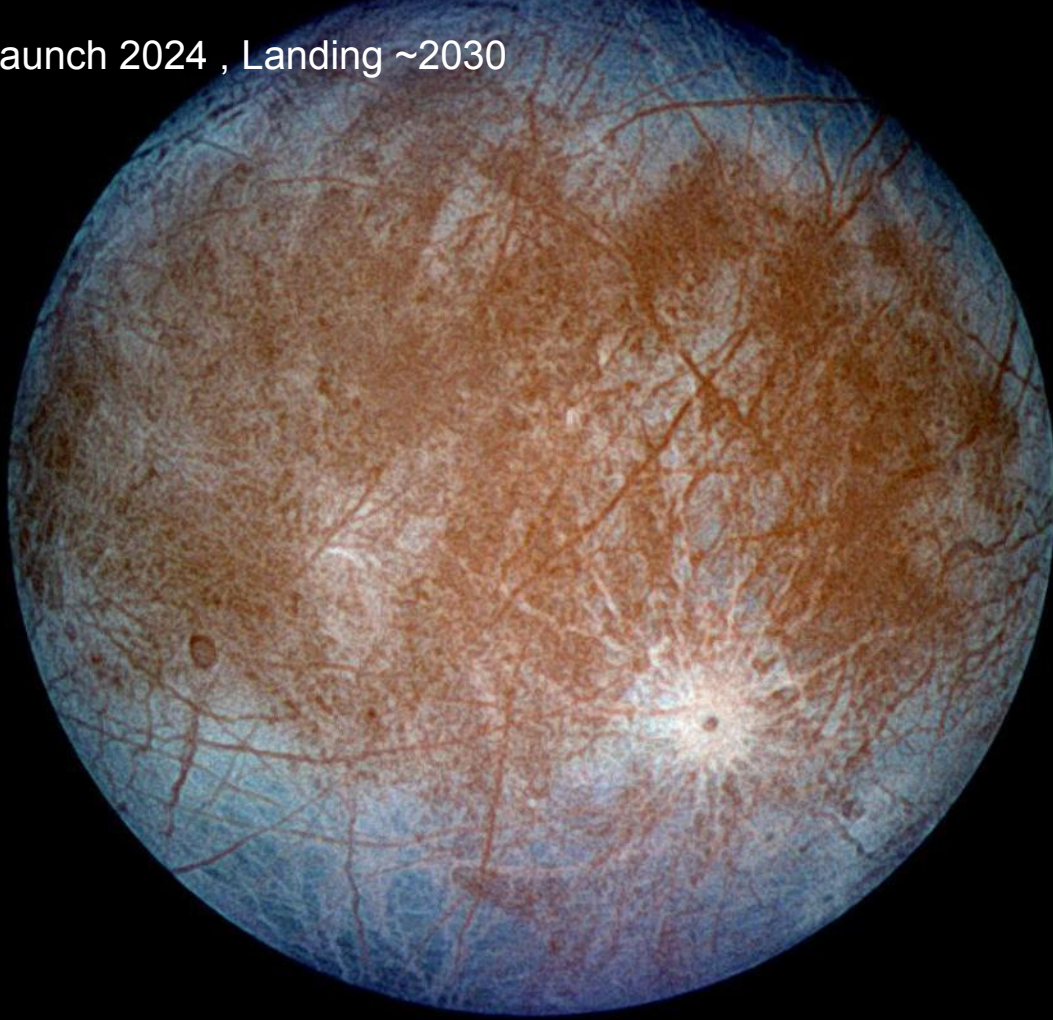
TITAN – DRAGONFLY (NASA)

■ Launch ~2028 , Landing ~2035



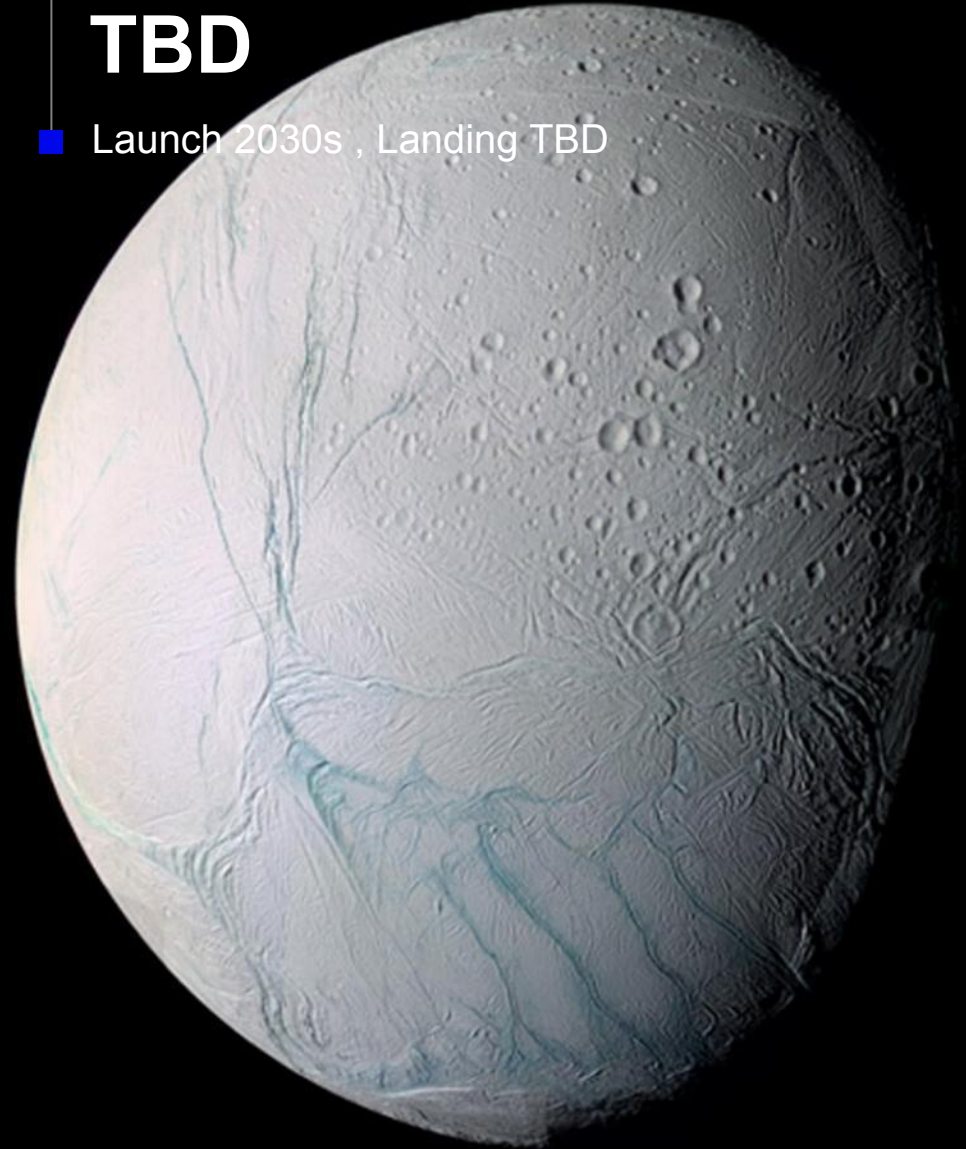
EUROPA – EUROPA CLIPPER

■ Launch 2024 , Landing ~2030



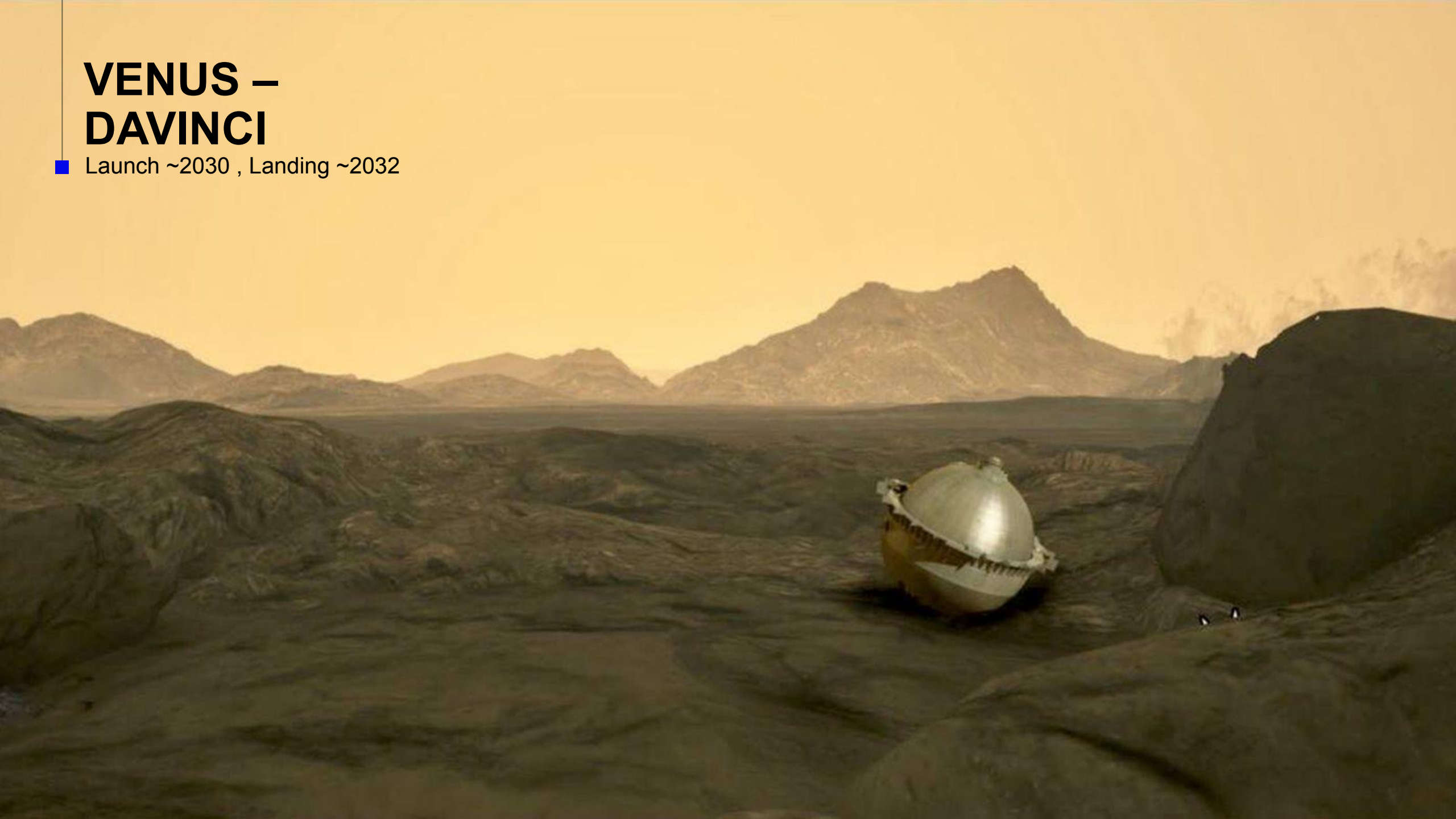
ENCELADUS – TBD

■ Launch 2030s , Landing TBD



VENUS – DAVINCI

■ Launch ~2030 , Landing ~2032

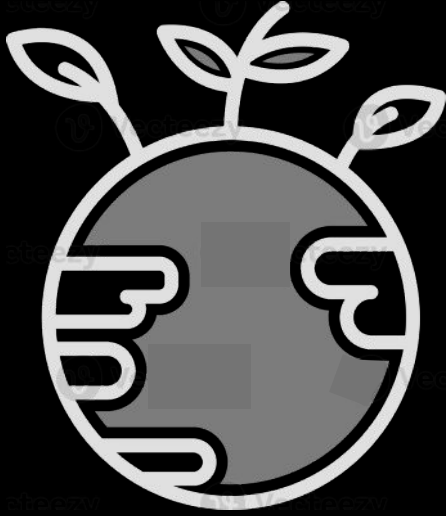


URANUS – TBD

~2030s



SPACE MISSION GOALS



Habitability

COULD LIFE EXIST?

To assess of whether an environment has the conditions necessary to support life as we know it



Life detection

DOES / DID LIFE EXIST?

To search for direct or indirect evidence of biological processes (“biosignatures”)

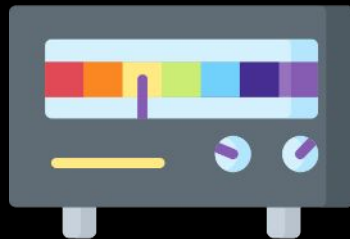
SPACE MISSION INSTRUMENTS

Space missions combine **complementary instruments** that **observe structure, measure composition, characterize environments, and probe the subsurface** – collecting evidence to build a unified understanding of the target under study!



IMAGING

What does it look like?



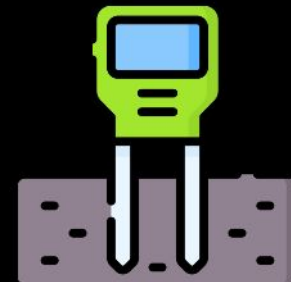
SPECTROMETRY

What is it made of?



ENVIRONMENT

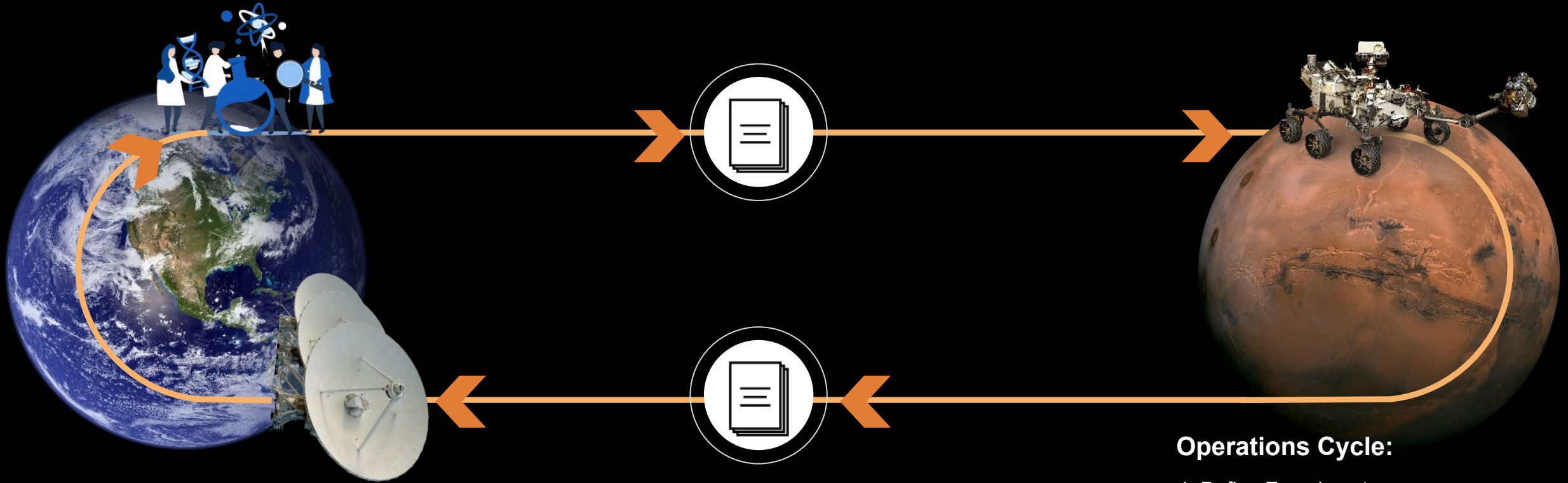
What are the conditions?



SUBSURFACE

What is beneath the surface?

SPACE MISSION OPERATIONS

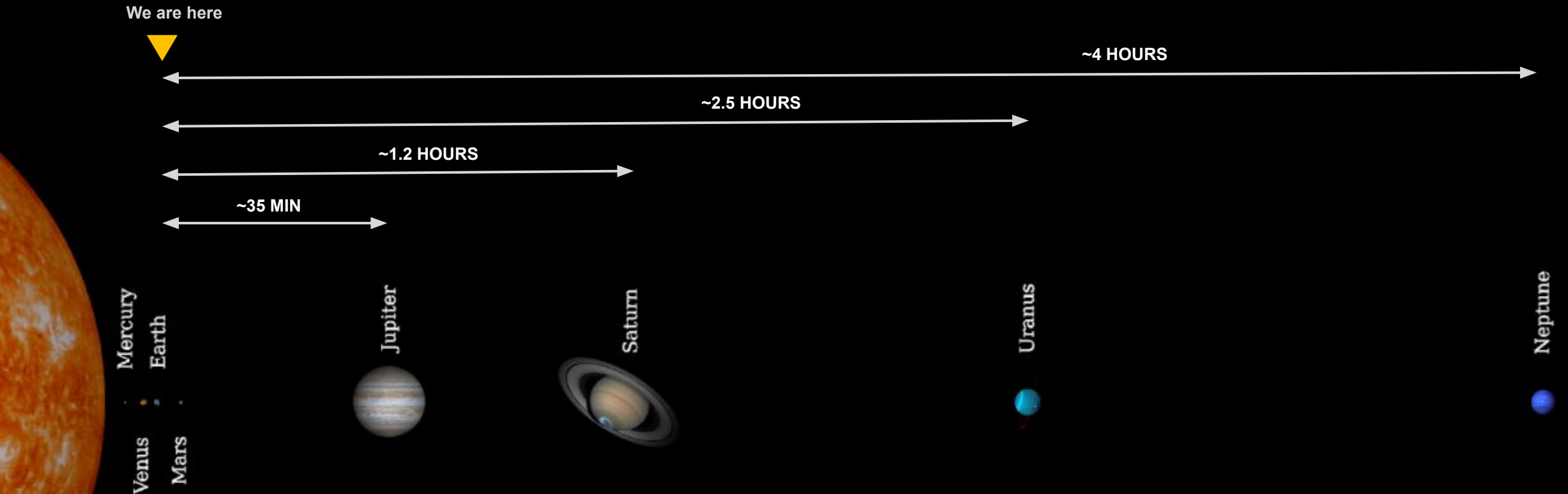


Operations Cycle:

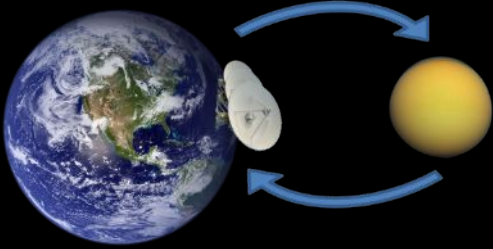
- 1: Define Experiment
 - 2: Process Data
 - 3: Analyze Results
- (Repeat)

CHALLENGES FOR OUTER SOLAR SYSTEM MISSIONS

Communication delays due to: latency (speed of light) + position relative to Earth



SPACE EXPLORATION CONTEXT



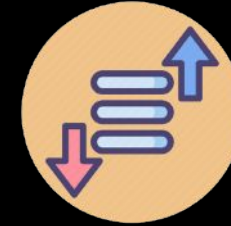
COMMUNICATION CHALLENGES

Longer communication delays,
smaller data downlink capacities:
limiting ground-in-the-loop!



DETECTION CHALLENGES

Longer communication delays,
smaller data downlink capacities:
impacting detection capabilities



DATA PRIORITIZATION

Future instruments will certainly
generate more data than can be
sent back!

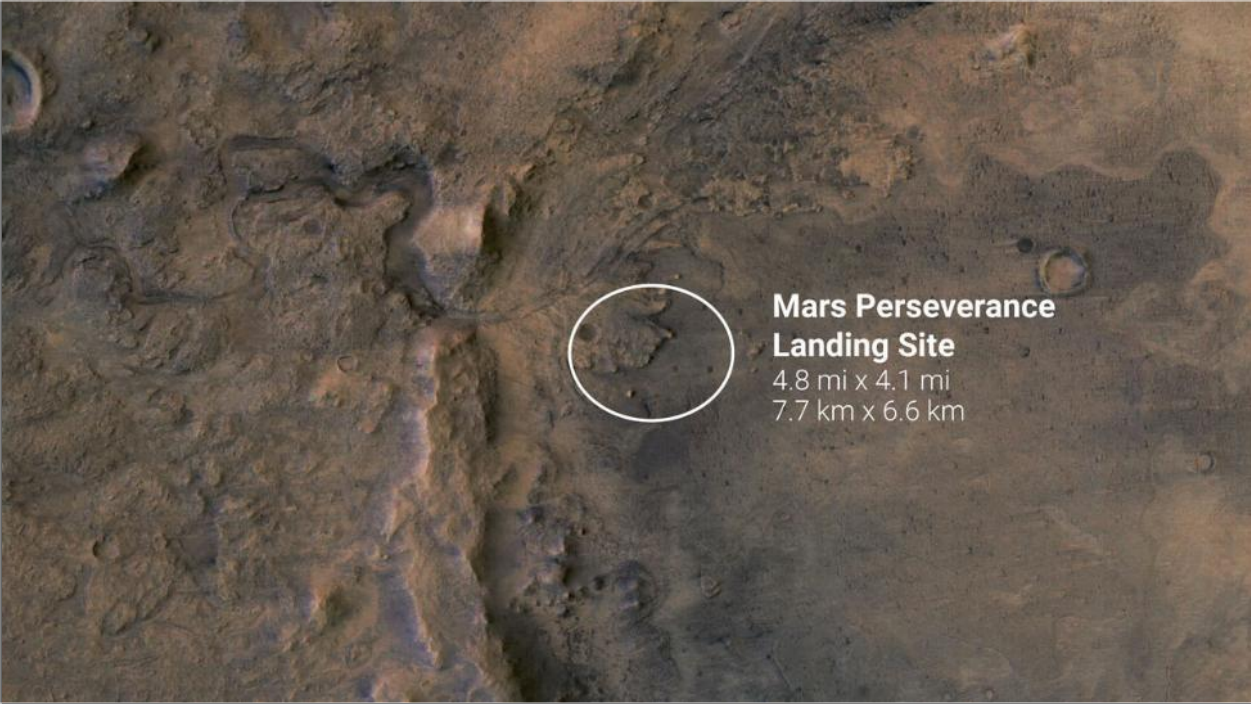
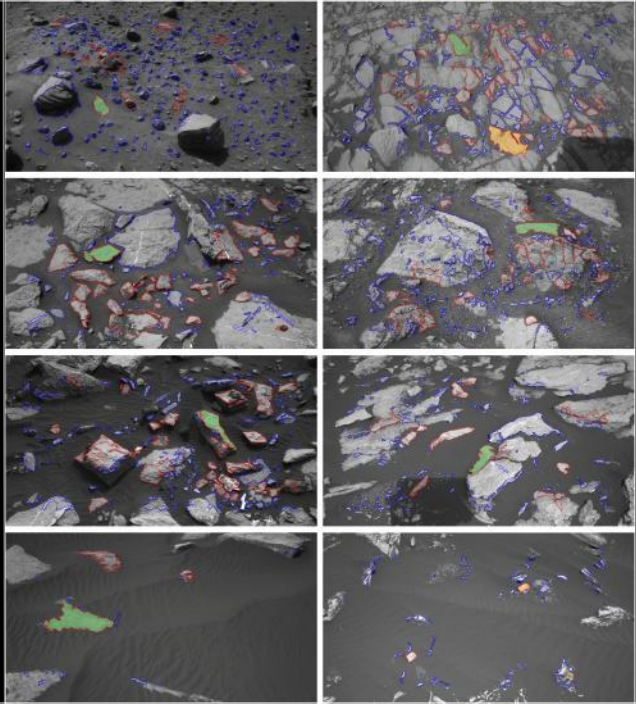


Space missions would greatly benefit from autonomy!

02

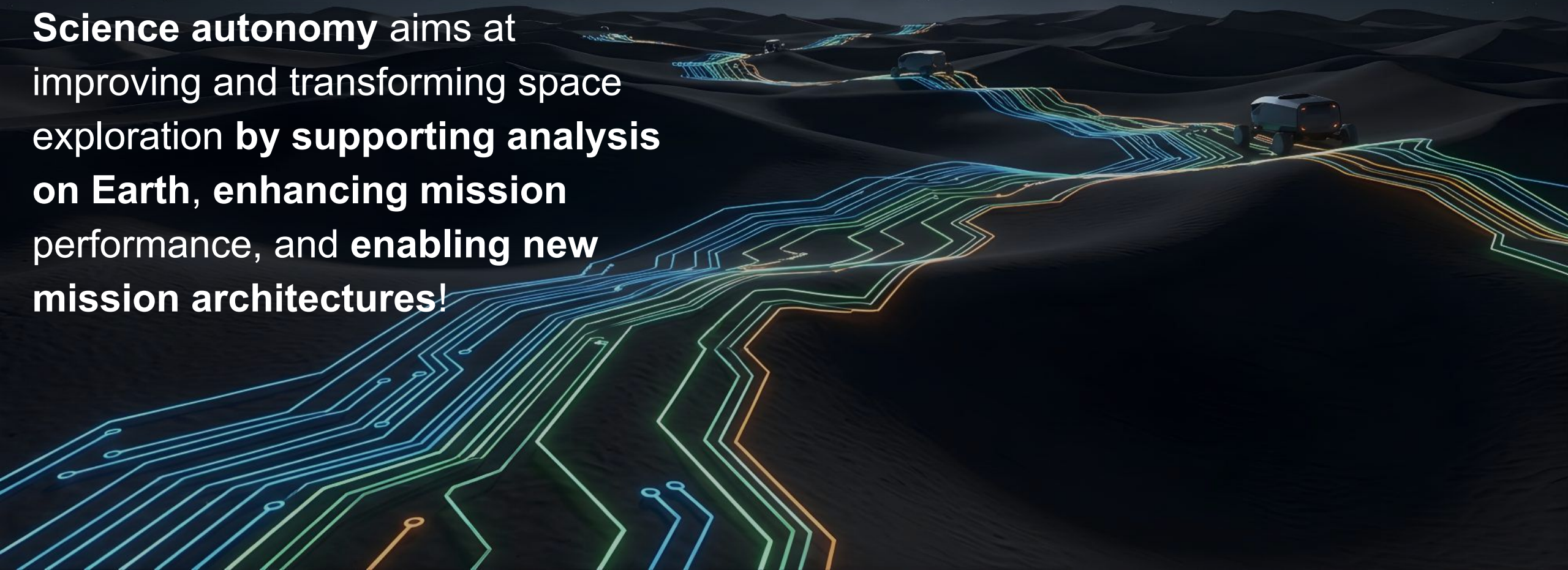
— Data science & AI in complex environments

SOME EXISTING APPLICATIONS OF AUTONOMY IN SPACE

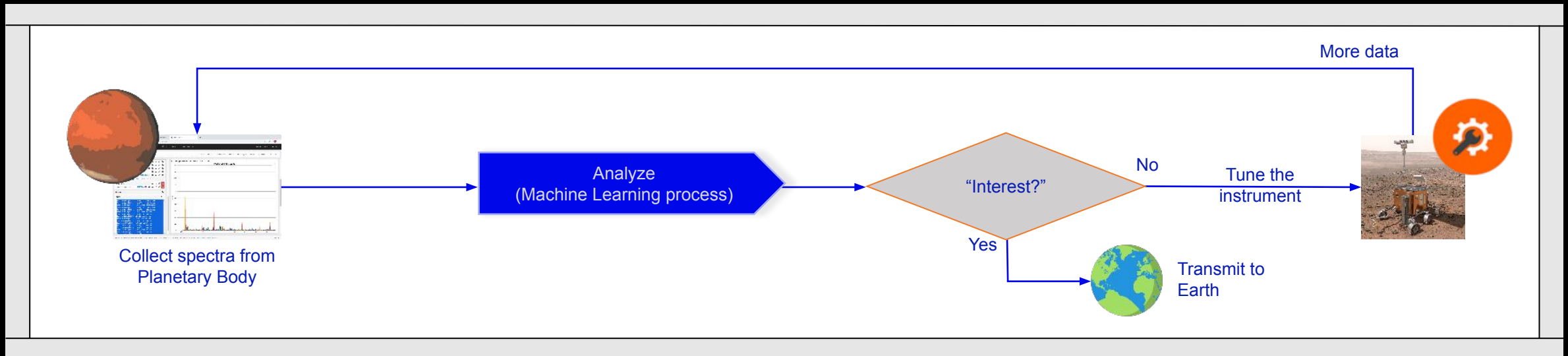
Landing Site Selection	Sampling Selection	
 Mars Perseverance Landing Site 4.8 mi x 4.1 mi 7.7 km x 6.6 km		
Jezero Crater as seen by ESA's Mars Express Orbiter (link)	AEGIS autonomous targeting for ChemCam on Mars Science Laboratory: Deployment and results of initial science team use. Francis et al. (2017)	

BUT NOT MUCH FOR SCIENCE INSTRUMENTS

Science autonomy aims at improving and transforming space exploration by **supporting analysis on Earth**, enhancing mission performance, and **enabling new mission architectures!**

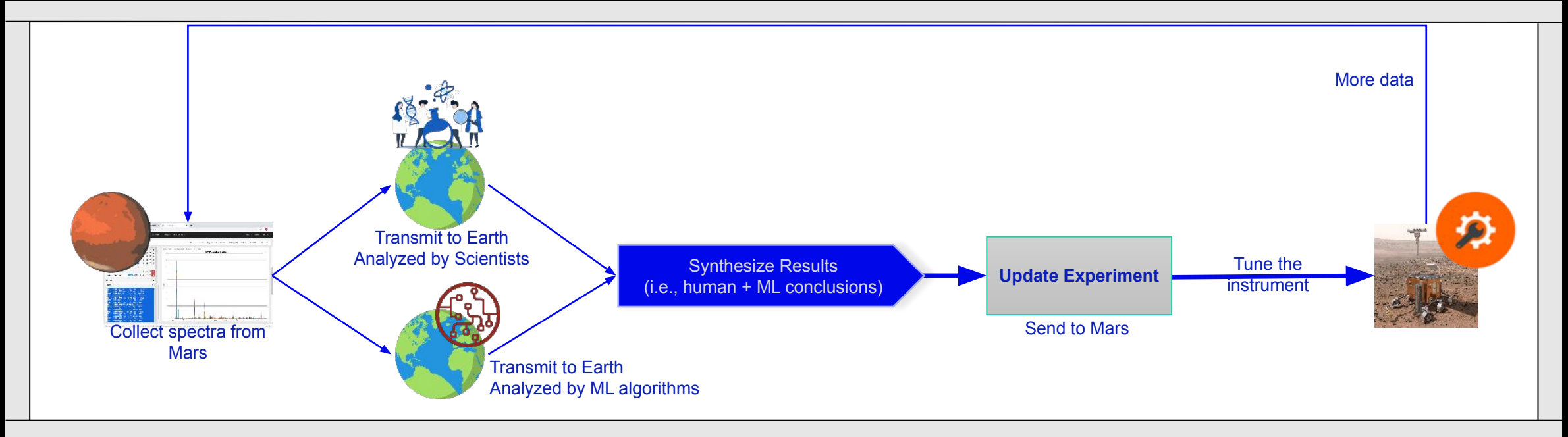


LONG-TERM GOAL: *IN-SITU* ANALYSIS



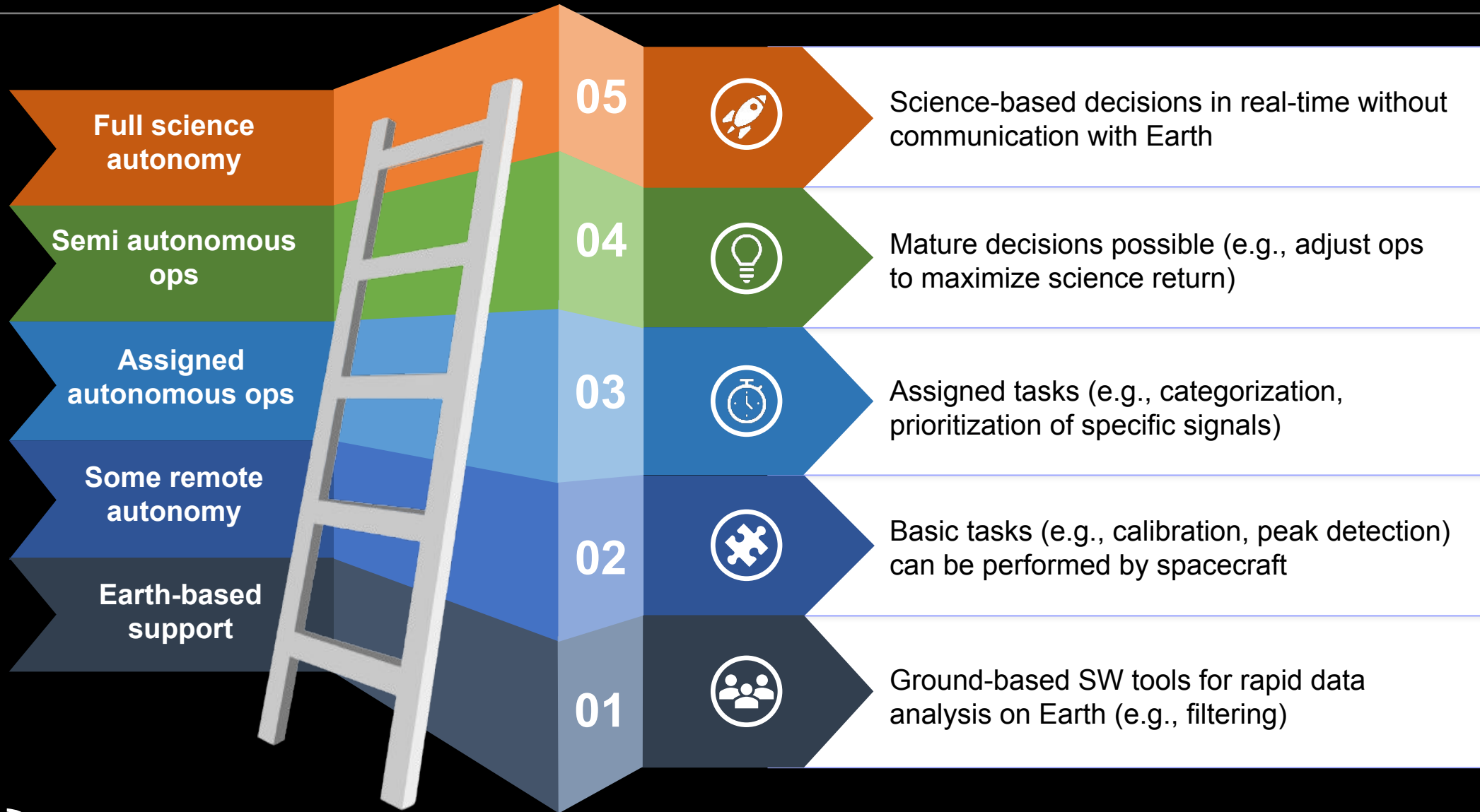
An instrument that can analyze its own data and determine what is interesting to send back to Earth and adjust its own parameters to get more information about interesting samples.

SHORT-TERM GOAL: SUPPORT ON EARTH



Develop Machine Learning tools (using Mars Organic Molecule Analyzer (MOMA) data) to help the scientists more quickly analyze the data and support them in their decision-making process.

SCIENCE AUTONOMY: STEP-BY-STEP RESEARCH



DATA-TO-DECISION PIPELINE

1



Collect

- Multi-source ingestion
- Real-time streaming
- Edge computing

2



Process

- Data cleaning
- Feature engineering
- Integration

3



Analyze

- ML models
- Statistical analysis
- Visualization

4



Act

- Recommendations
- Automation
- Feedback loops

03

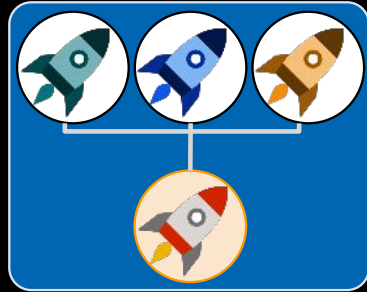
— Overcoming critical challenges

IMPLEMENTING DATA SCIENCE + ML: SOME CHALLENGES



DATA SCARCITY

Flight data are rare, expensive, often unlabeled :(



FLIGHT HERITAGE

Innovation is bounded by previous flight missions (e.g., compute power)



EXPLORATION

Enabling discovery beyond life-as-we-know-it
(big focus on unsupervised learning)



SCIENCE TRUST

Interpretability of models' results is mandatory!

HOW AI + QUANTUM CAN HELP IN THIS CONTEXT

Current challenge what is holding us back	AI + Quantum opportunity what could be a solution approach	Mission impact what it could enable
 Data scarcity Flight data are rare, expensive, often unlabeled :(	Physics-informed AI + synthetic data generation Generative AI, quantum-enhanced inference, and physics-based models to extract more from less	Improved AI models More accurate and robust AI models through improved training with limited mission data
 Flight heritage Innovation is bounded by previous flight missions, high barrier to new technologies	Digital engineering + explainable AI Simulation, verification workflows, and quantum-accelerated analysis to reduce validation effort	Faster adoption to flight Accelerate transition from innovation to mission-ready capability while reducing program risk
 Complex exploration We don't know what we don't know :)	Hybrid quantum-classical optimization + AI agents Quantum optimization for combinatorial problems, AI planning agents for autonomous decision-making	More science per bit Maximize science return through more efficient autonomous exploration and resource utilization in limited context
 Science trust & explainability Need for reliable, interpretable, and verifiable scientific results	Explainable AI + uncertainty quantification Trusted AI workflows, digital twins, and quantum methods for improved modeling and analysis	Higher confidence in scientific discoveries Improve confidence in scientific results through transparent, verifiable, and reliable AI

04

— The future of AI & autonomy

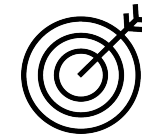
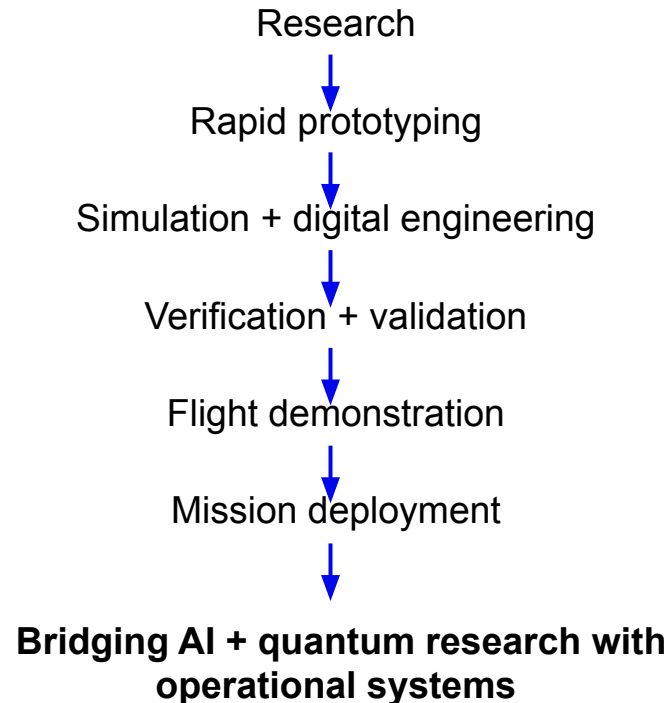
PROJECT137: THE INNOVATION ENGINE FOR AI + QUANTUM



Quantum Sky vision

- AI + quantum-enabled mission autonomy
- Learn from limited mission data
- Autonomous onboard decisions
- Explain and verify AI outputs
- Adaptability to changing environments

PROJECT 137 Innovation engine



Mission outcomes

- Autonomous science ops
- Edge AI decision-making
- Hybrid quantum optimization
- Trusted + explainable AI
- Reduced mission risk
- Faster technology adoption

ADVANCING AUTONOMOUS CAPABILITIES FOR NEXT-GEN MISSIONS

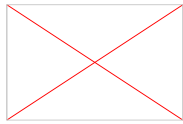
1



Scaling autonomy

Transitioning from ground-in-the-loop to full onboard autonomous decision-making and real-time instrument parameter adjustment

2



Advancing capabilities

Expanding training datasets using high-fidelity synthetic data, generative models, and physics-informed ML

3



Enabling trust & explainability

Developing robust XAI frameworks for critical decisions and multi-instrument consensus to minimize false positives

4



Mission innovation

Optimizing onboard edge computing to mitigate communication latency and bandwidth constraints while enabling novel discoveries

AI as a force multiplier

AI can be a critical enabler for achieving success in complex and high-stakes missions



Data and infrastructure foundation

Prioritize data as a strategic asset and invest in modern infrastructure, interoperability, and edge computing to enable scalable AI deployment



Responsible AI

Embrace AI and automation while maintaining human oversight, ethical standards, with explainability and trustworthiness tools



AI-ready workforce

Build diverse, skilled, multidisciplinary teams and skills to translate data into mission outcomes



Culture of innovation

Foster a data-driven culture across the organization, with continuous improvement, experimentation and learning to benefit our clients' missions

Quantum Sky is building **the next generation of mission intelligence**

by integrating trusted AI, quantum technologies, and autonomous systems. Through **Project 137**, we accelerate innovation from research to operational capability – enabling our customers to **solve mission problems that are beyond the reach of classical approaches alone.**



“It is impossible to say what is impossible, for the **dream of yesterday** is the **hope of today** and the **reality of tomorrow.**”

Dr. Robert Hutchins Goddard

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QUESTIONS