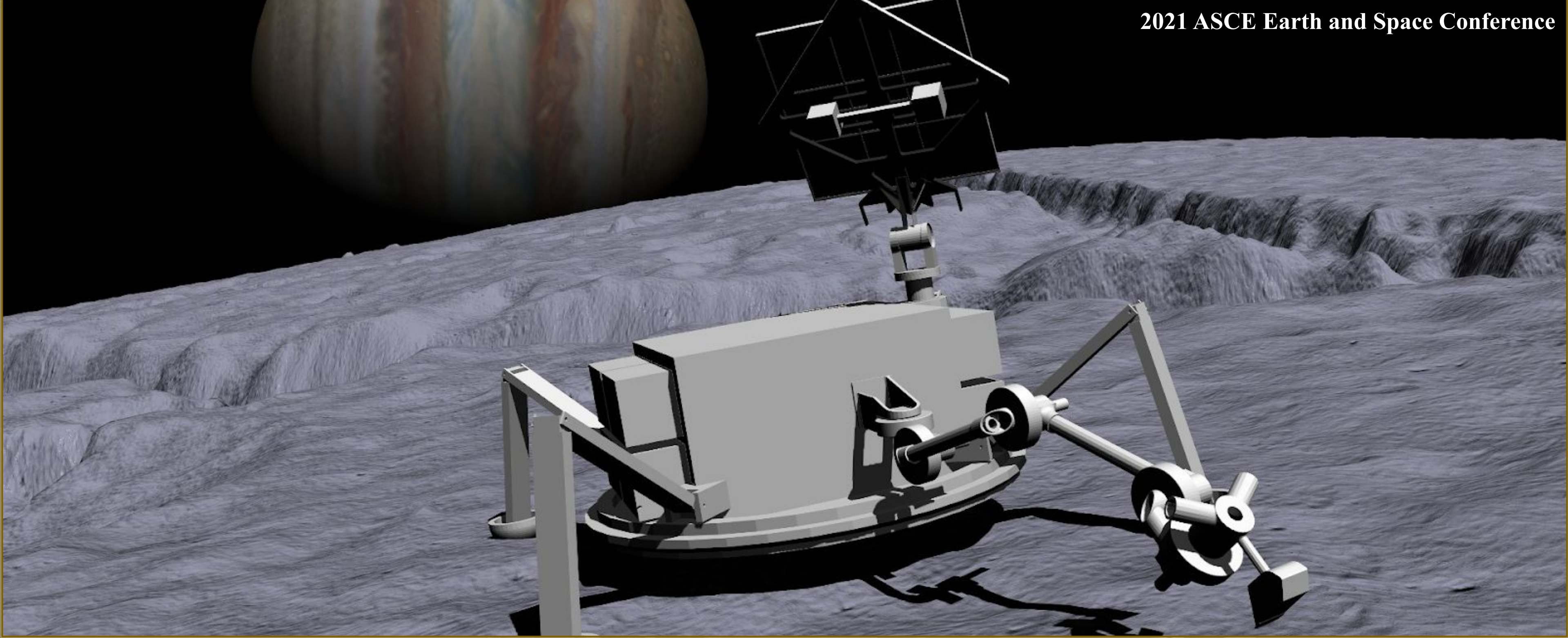
2021 ASCE Earth and Space Conference



OceanWATERS: An Autonomy Software Testbed Simulation for Ocean Worlds Missions

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PRESENTATION OUTLINE

- Background and Motivation
- Introduction to OceanWATERS
- Architecture and Simulation infrastructure
- Visual Appearance
- Surface Geometry
- Camera Simulation
- Lander System Description and Operation
- Lander/Surface Interaction Modeling
- Power and Battery Modeling
- Autonomy Module
- Conclusion and Future Work

BACKGROUND AND MOTIVATION

Outer solar system moons (Europa, Enceladus, Titan) have subsurface oceans

Past and present life may be found

Surface exploration missions

- Ground communication delays due to long distance
- Short life span of electronics due to highly radioactive environment

Need for high level of autonomy

Need for development and testing of new autonomy technologies enabling increased science operations productivity in presence of sub-system failures

INTRODUCTION TO OCEANWATERS

Ames Research Center

Jet Propulsion Laboratory
California Institute of Technology


*

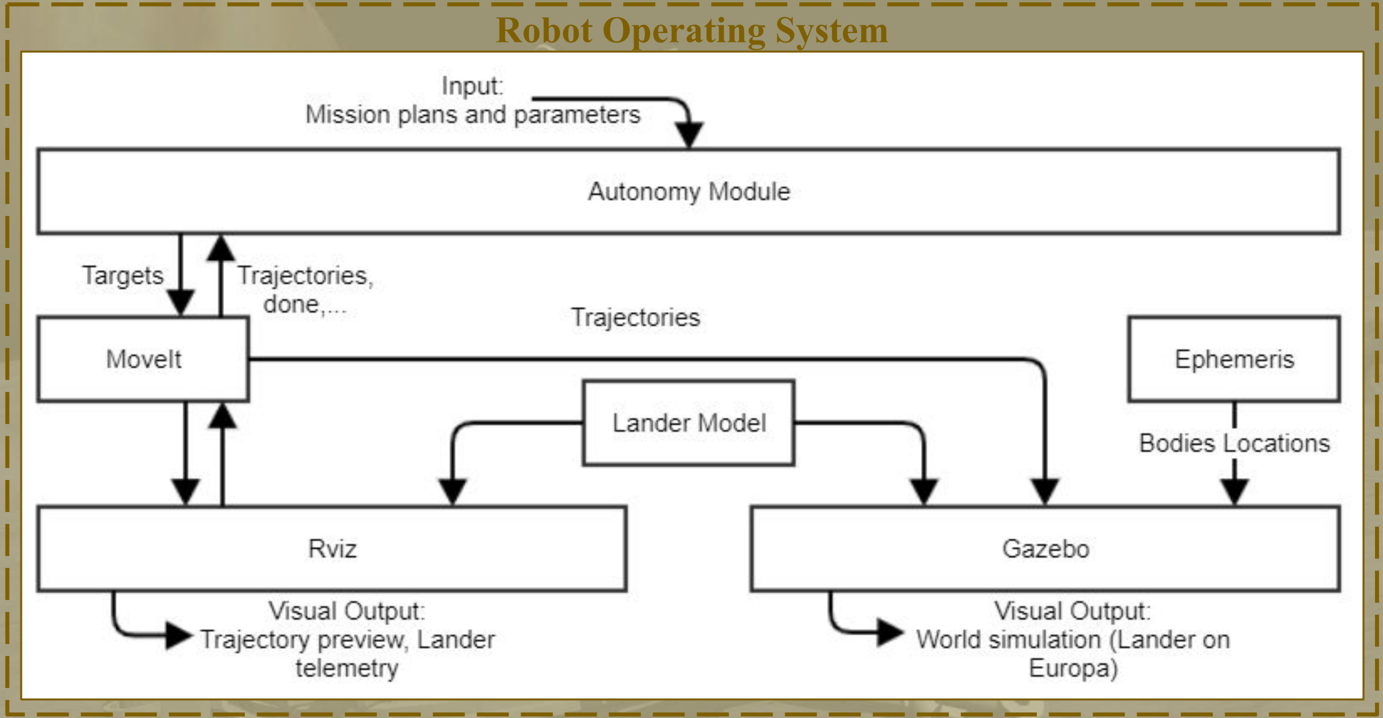
Physical testbed for validation

Europa Lander reference mission

Ocean **W**orlds **A**utonomy **T**estbed for **E**xploration **R**esearch and **S**imulation
OceanWATERS

- Lander model in simulation environment
- Test autonomous operations in presence of sub-system failures
- Based on the Robot Operating System (ROS) and Gazebo
- Open source on GitHub

ARCHITECTURE AND SIMULATION INFRASTRUCTURE



Designed to be:

- Modular
- Extensible
- Multi-process

In order to:

- Integrate components in different programming languages
- Increase adaptability to specific user cases

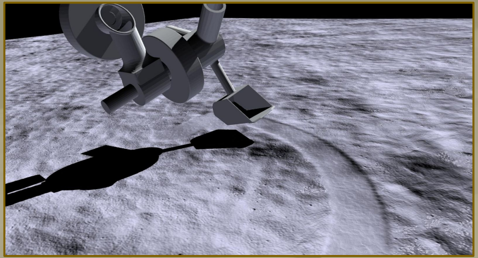
VISUAL APPEARANCE

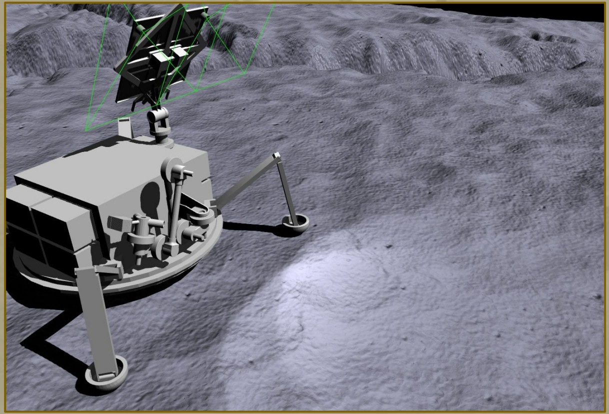
Accurate visual simulation

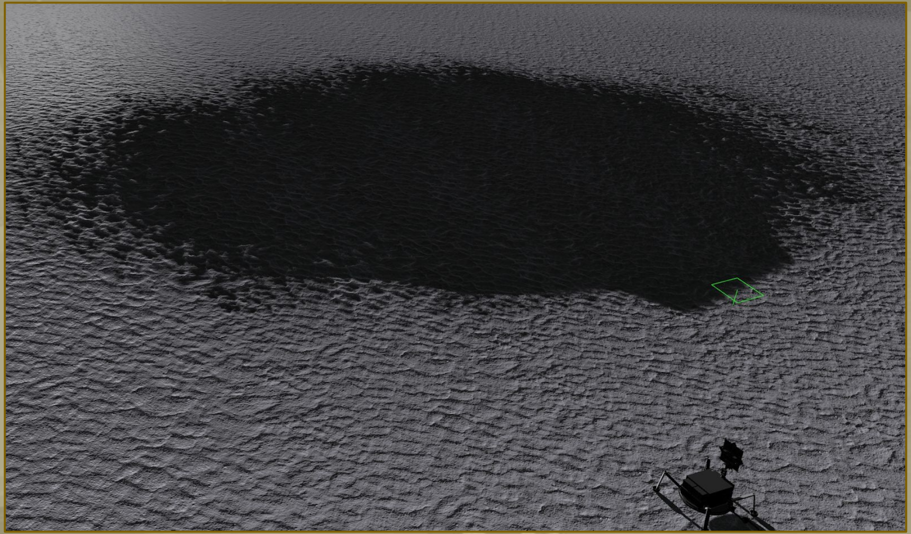
Deliver simulated camera images to computer vision algorithms

Illumination

- Lander lights
- Sun direct light
- Jupiter indirect light
- Starlight
- Terrain-reflected light





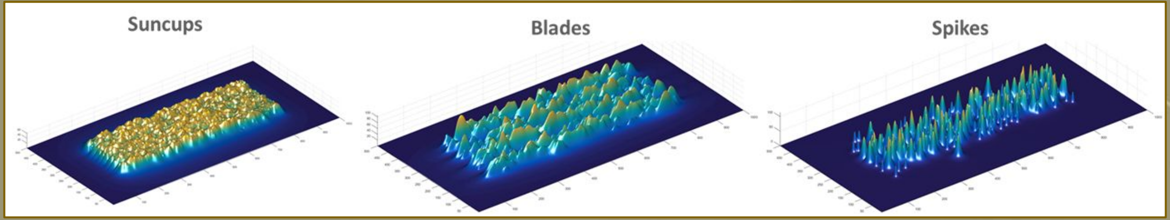


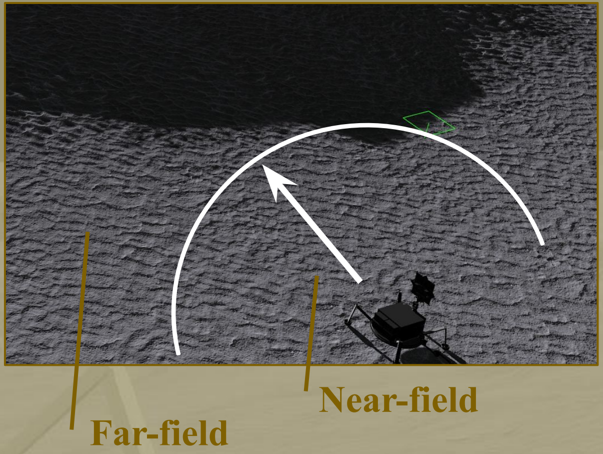
Shadows

- Only Sun casts shadows
- Includes eclipses

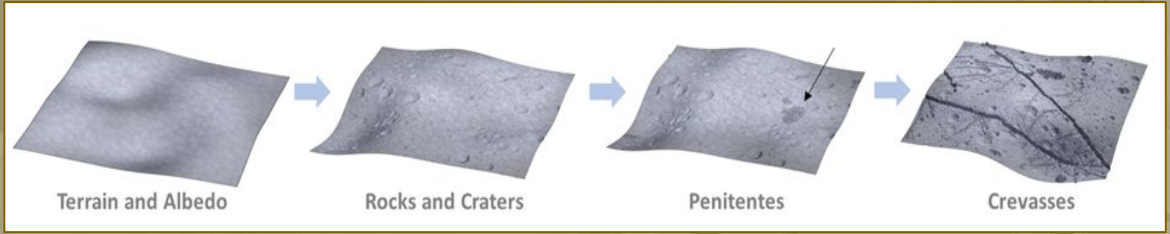
SURFACE GEOMETRY

PENITENTES: fractal noise perturbation + analytical models





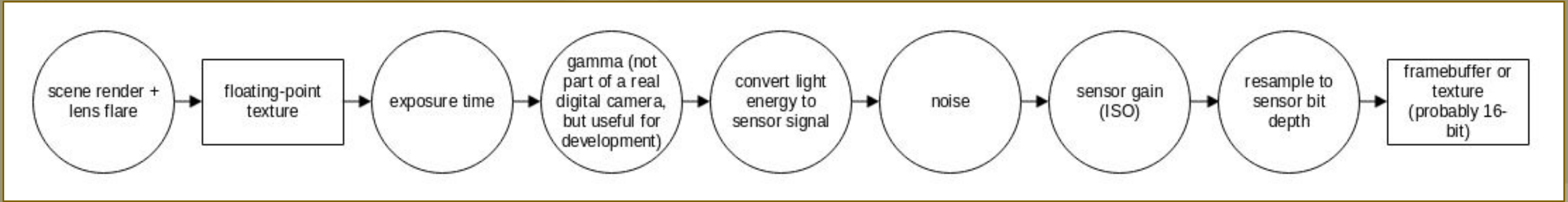
Far-field terrain generation



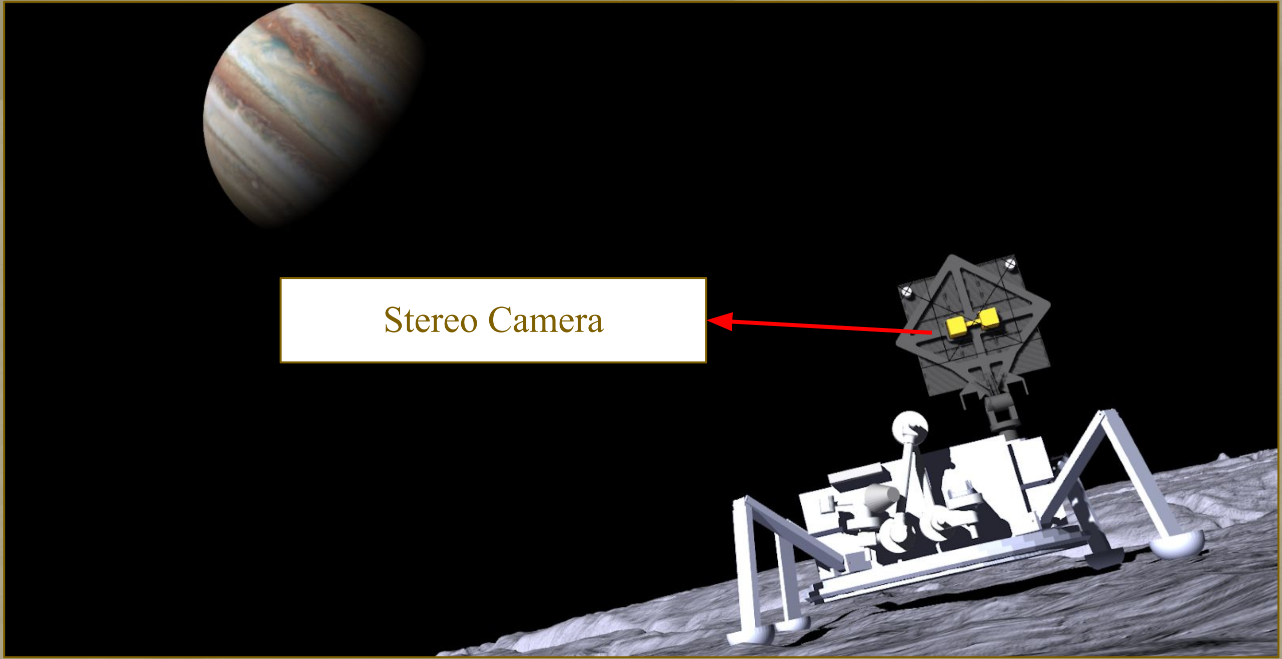
Near-field: digital elevation models built from laser scanning data

CAMERA SIMULATION

Digital camera simulation pipeline:

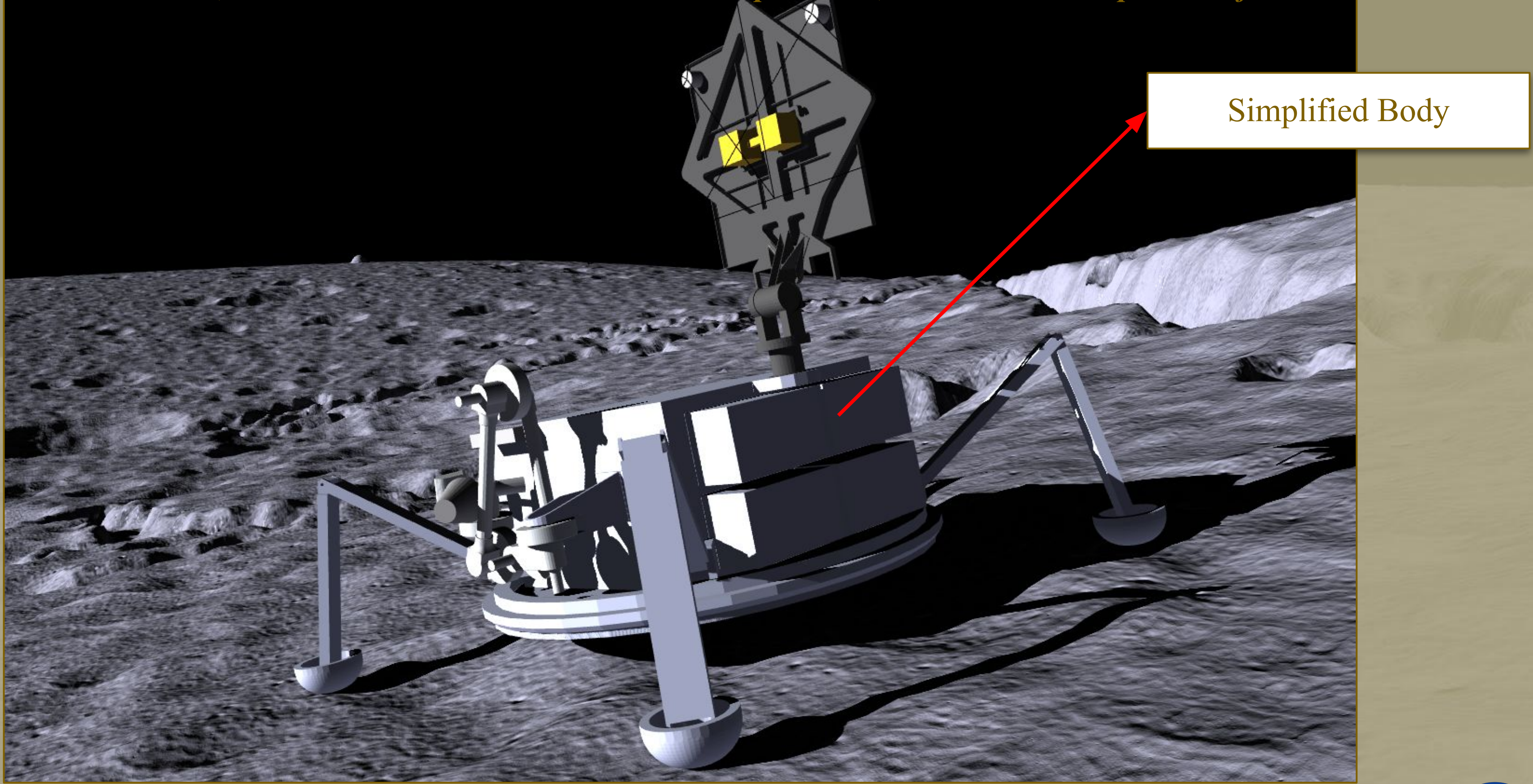


- Scene is rendered to a floating point texture
- A shader is applied to simulate digital camera properties
- Output is sent to Gazebo



EUROPA LANDER SYSTEM DESCRIPTION

Catanoso et. al., "OceanWATERS Lander Robotic Arm Operation", 2021 IEEE Aerospace Conference



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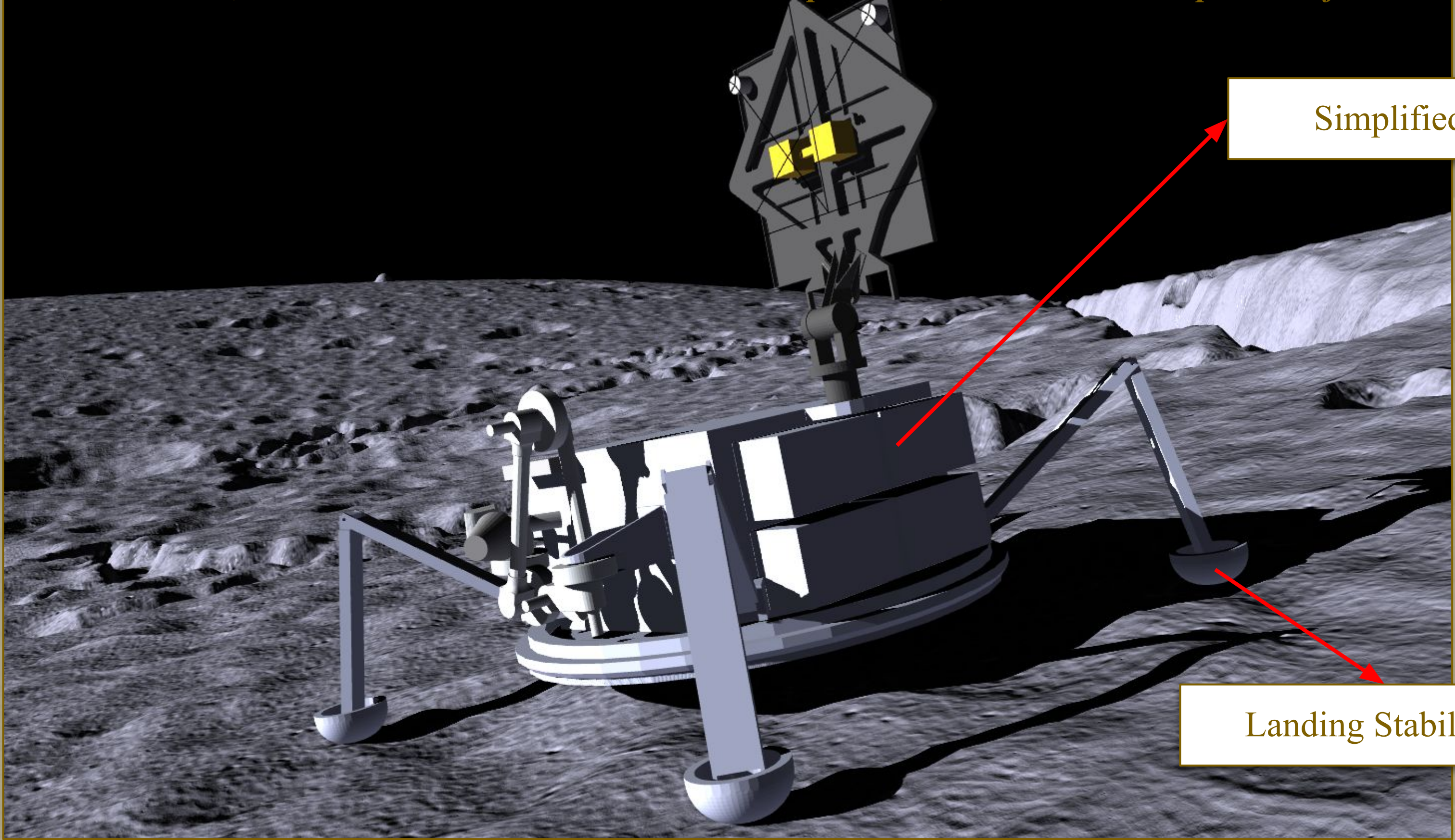

Simplified Body

Landing Stabilizers

EUROPA LANDER SYSTEM DESCRIPTION

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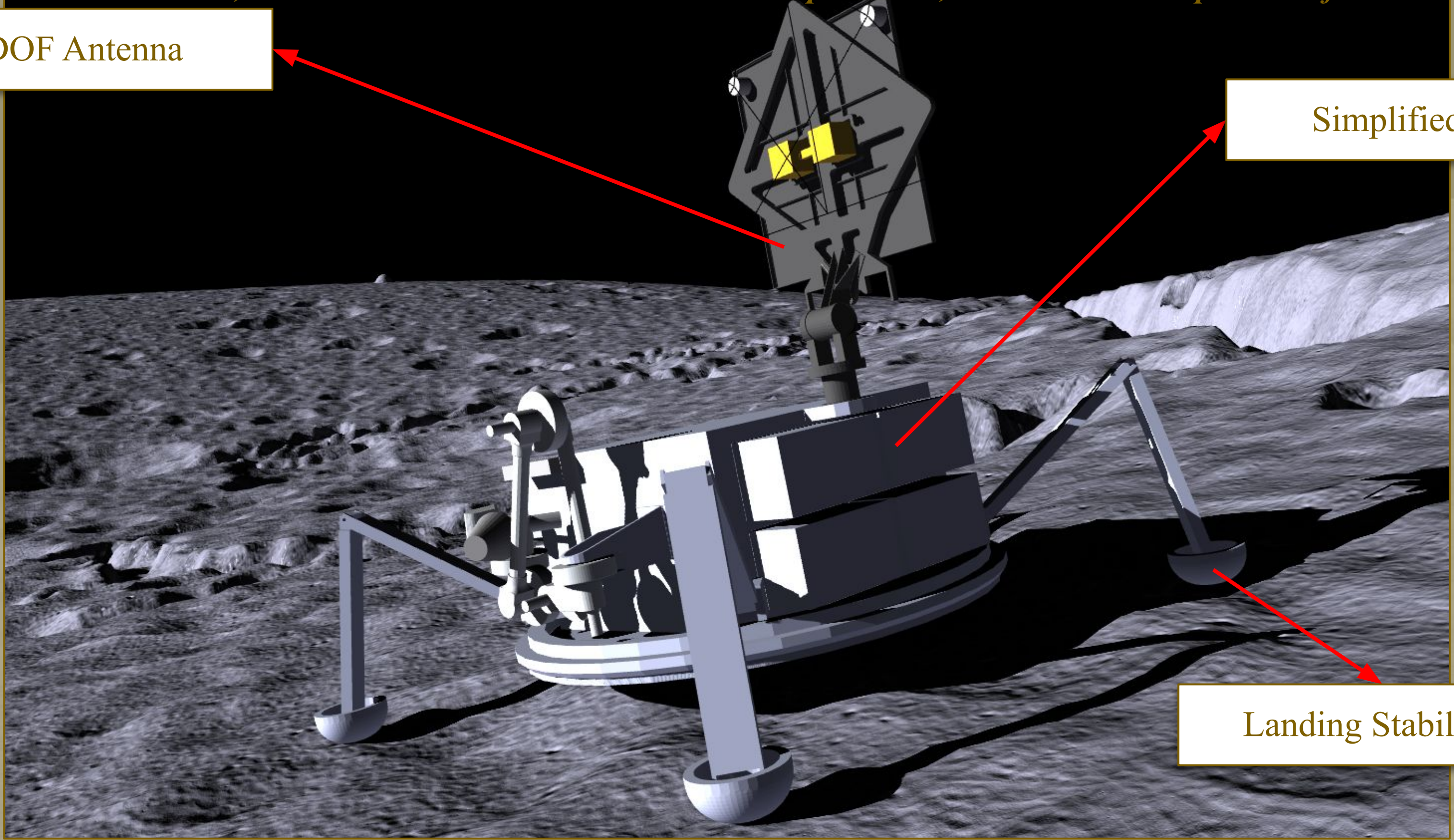

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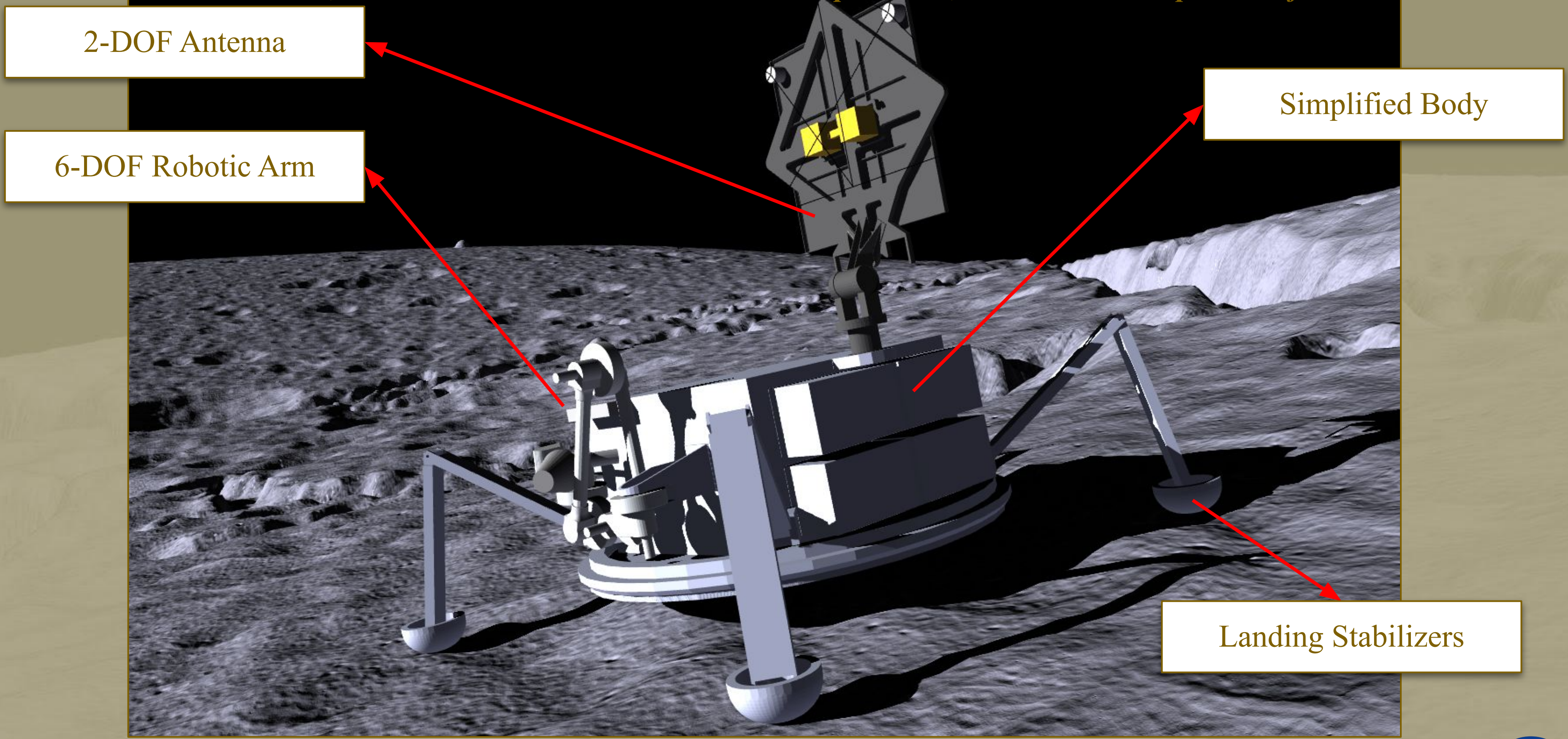

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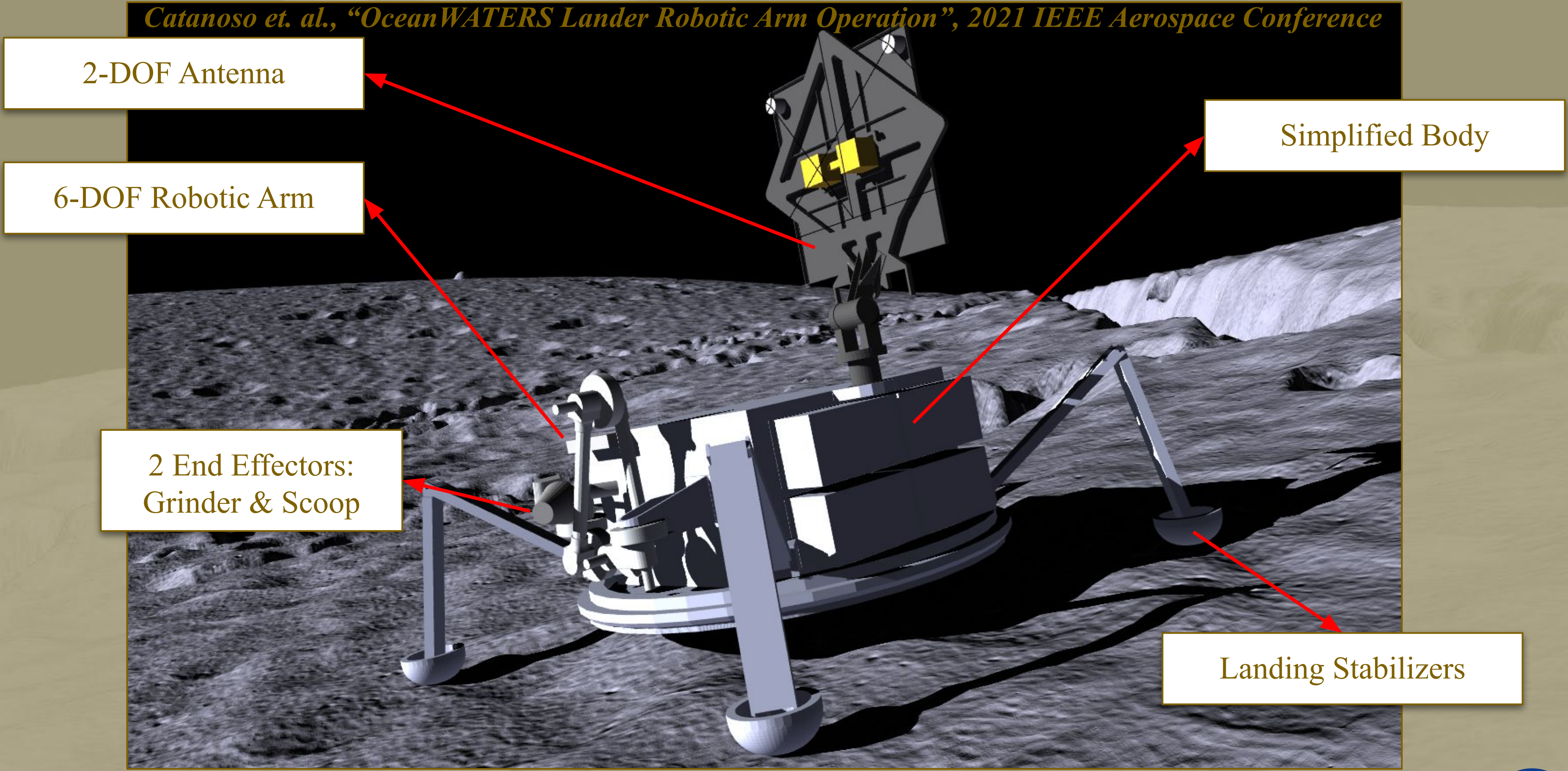

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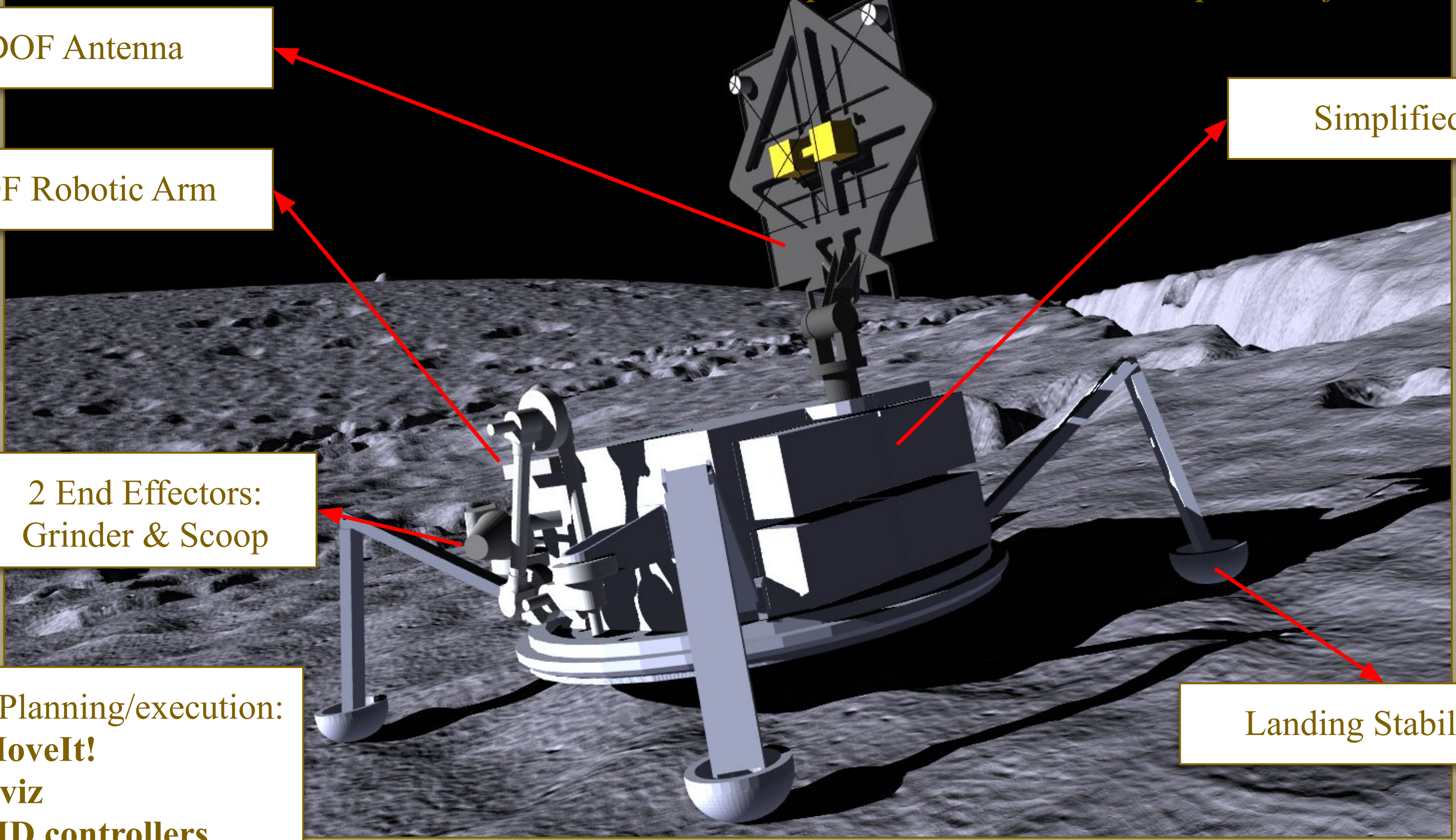
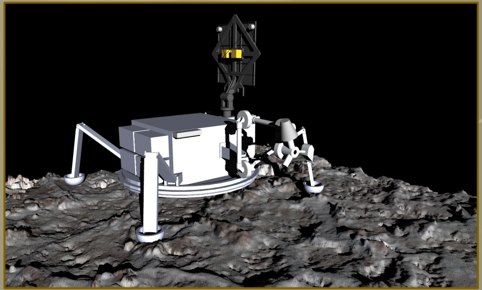
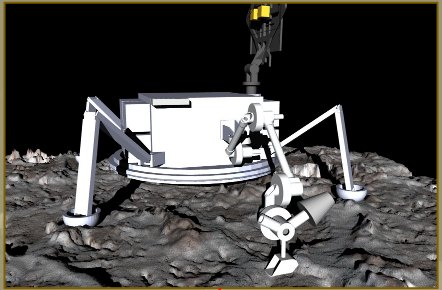


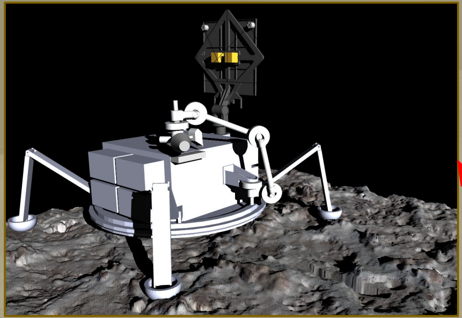
Motion Planning/execution:

- **MoveIt!**
- **Rviz**
- **PID controllers**

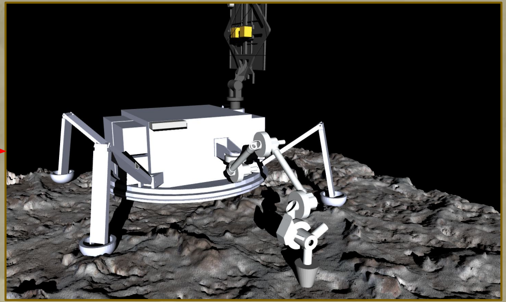
MODES OF OPERATION

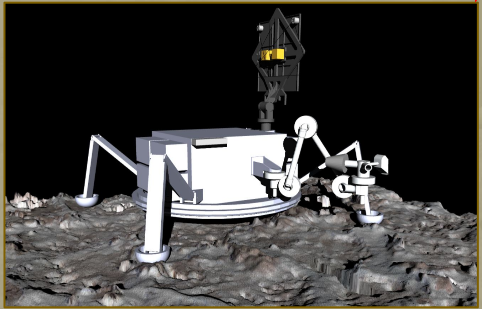


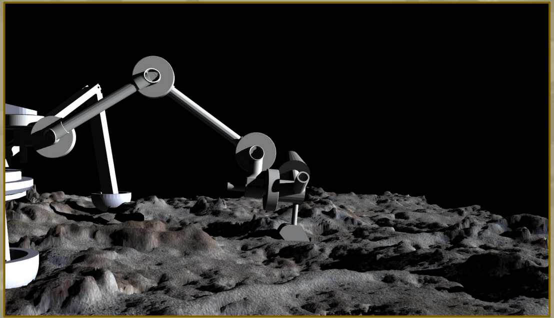


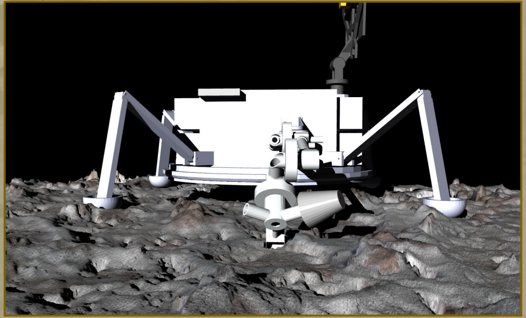


Name	Planned movement
Unstow	Unstow arm
Guarded_move	Perform a guarded move
Grind	create a Trench grinding solid ice
Dig_circular	Collect sample with circular motion
Dig_linear	Collect sample with rasping motion
Deliver_sample	Sample delivery and discard
Stow	Stow arm









Catanoso et. al., "OceanWATERS Lander Robotic Arm Operation", 2021 IEEE Aerospace Conference

OceanWATERS Lander Robotic Arm Operation

LANDER/SURFACE INTERACTION MODELING

Discrete Element Method (DEM) → Models physical interactions at a particle level, taking into account elastic forces, normal and rolling friction, plastic deformation of the particles and cohesion

Run simulations in EDEM** commercial software, varying set of parameters → Embed data in lookup table → Include it in Gazebo

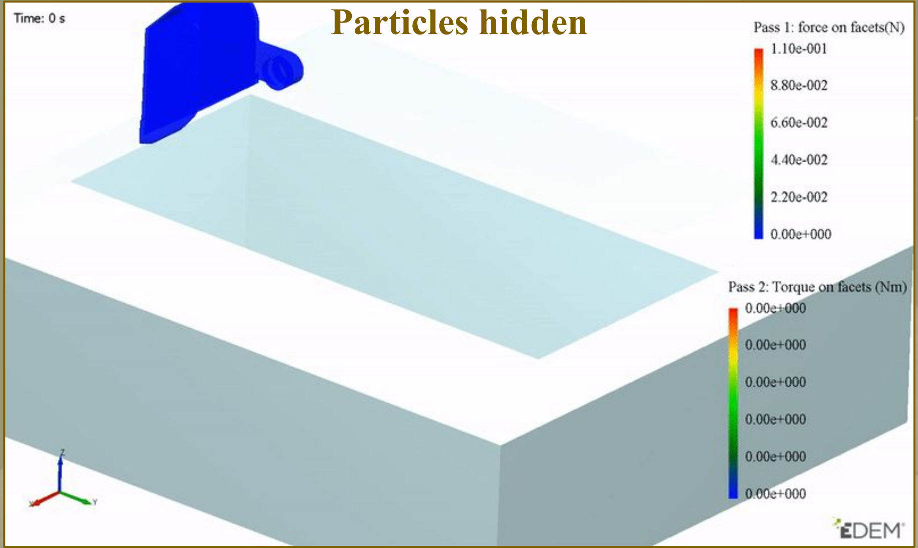
User runs customized simulations on demand

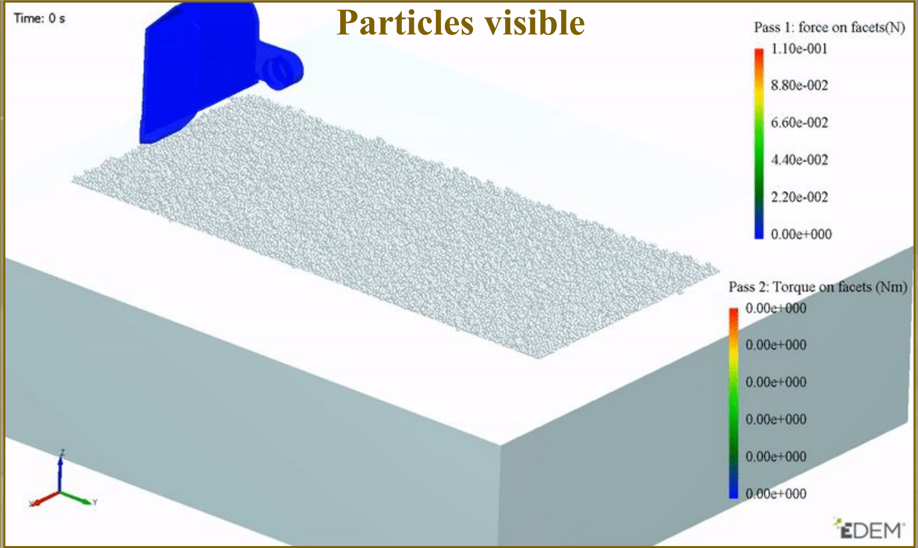
Include in OceanWATERS open source DEM solution

→ Embed data in lookup table

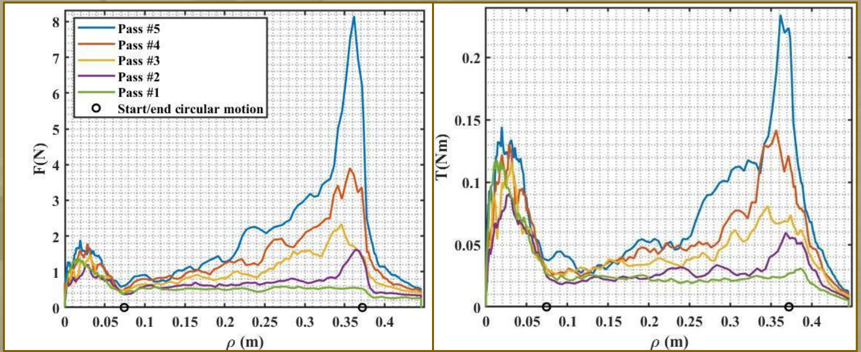
→ Parallel DEM-Gazebo simulation

LOOKUP TABLE SIMULATIONS





- **Terrain types: ice, snow, sand**
- **Sample collection:**
  - Circular-linear-circular
  - Multiple passes
  - Increasing depth between passes
- ***Catanoso et. al., "Analysis of Sample Acquisition Dynamics Using Discrete Element Method", 2020 IEEE Aerospace Conference***



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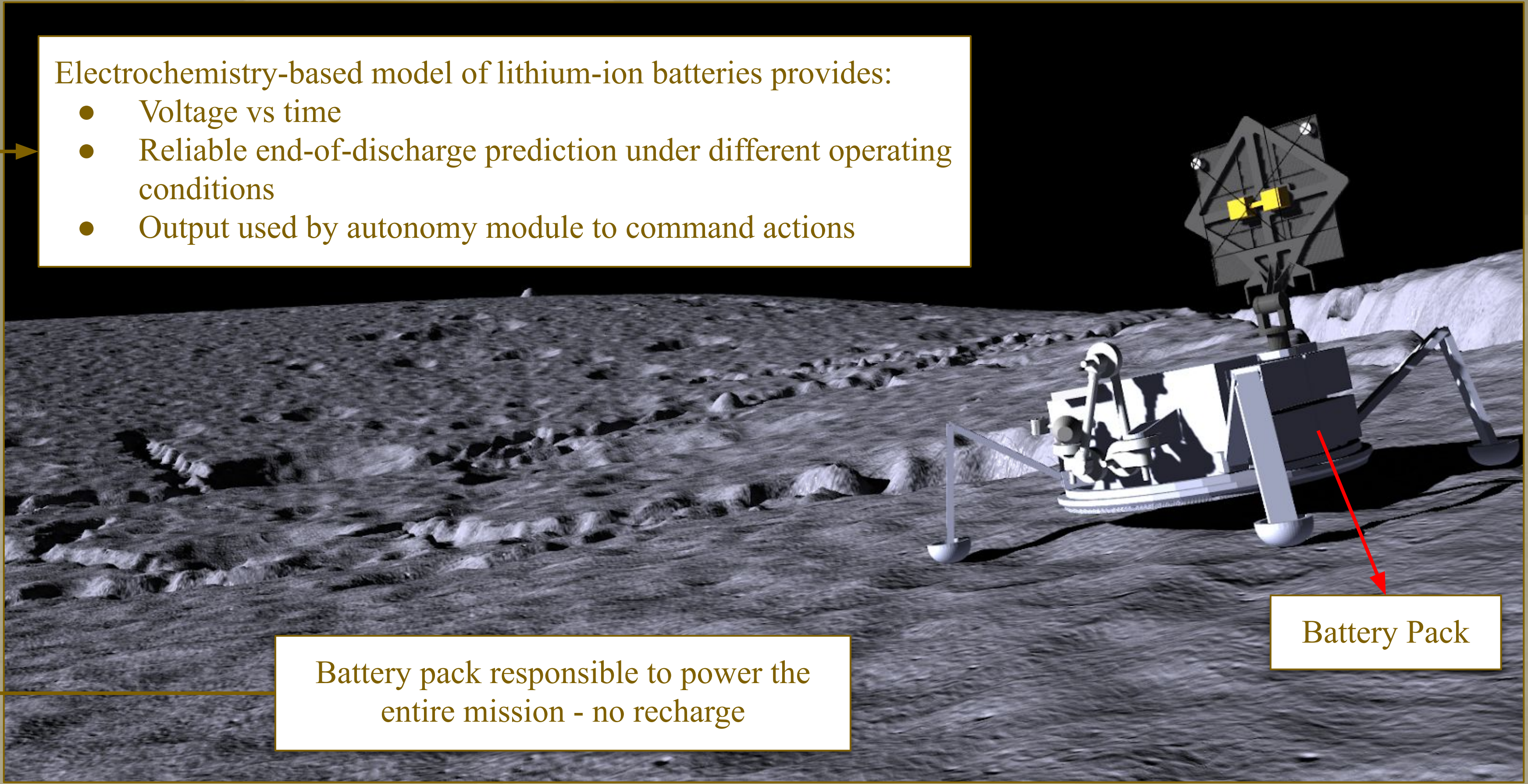
POWER MODELING

Electrochemistry-based model of lithium-ion batteries provides:

- Voltage vs time
- Reliable end-of-discharge prediction under different operating conditions
- Output used by autonomy module to command actions



Battery pack responsible to power the entire mission - no recharge

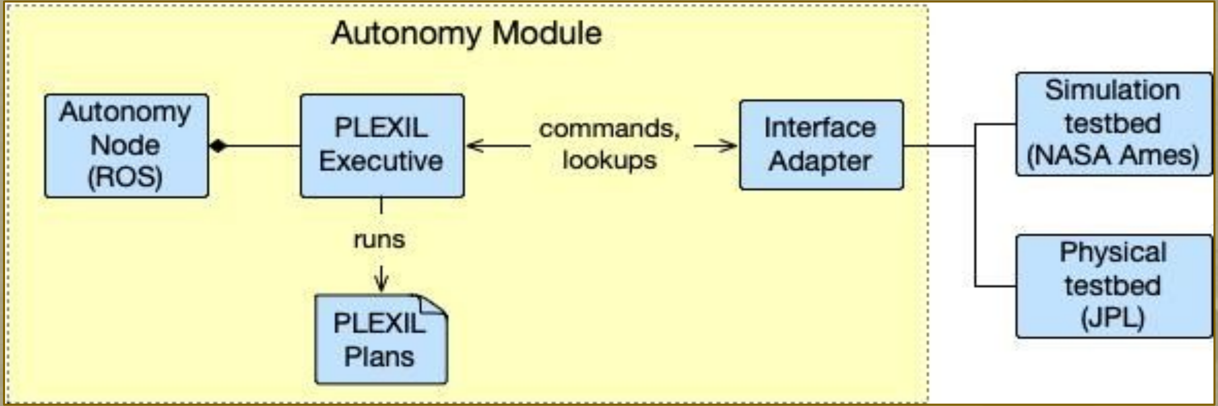
AUTONOMY MODULE

Autonomy module incorporated in OceanWATERS is just a reference

Includes basic autonomy capabilities that exercise the testbed

Based on PLEXIL, a language implementing a sequence of plans to be executed by the lander

Provides example of API for users' autonomy module integration



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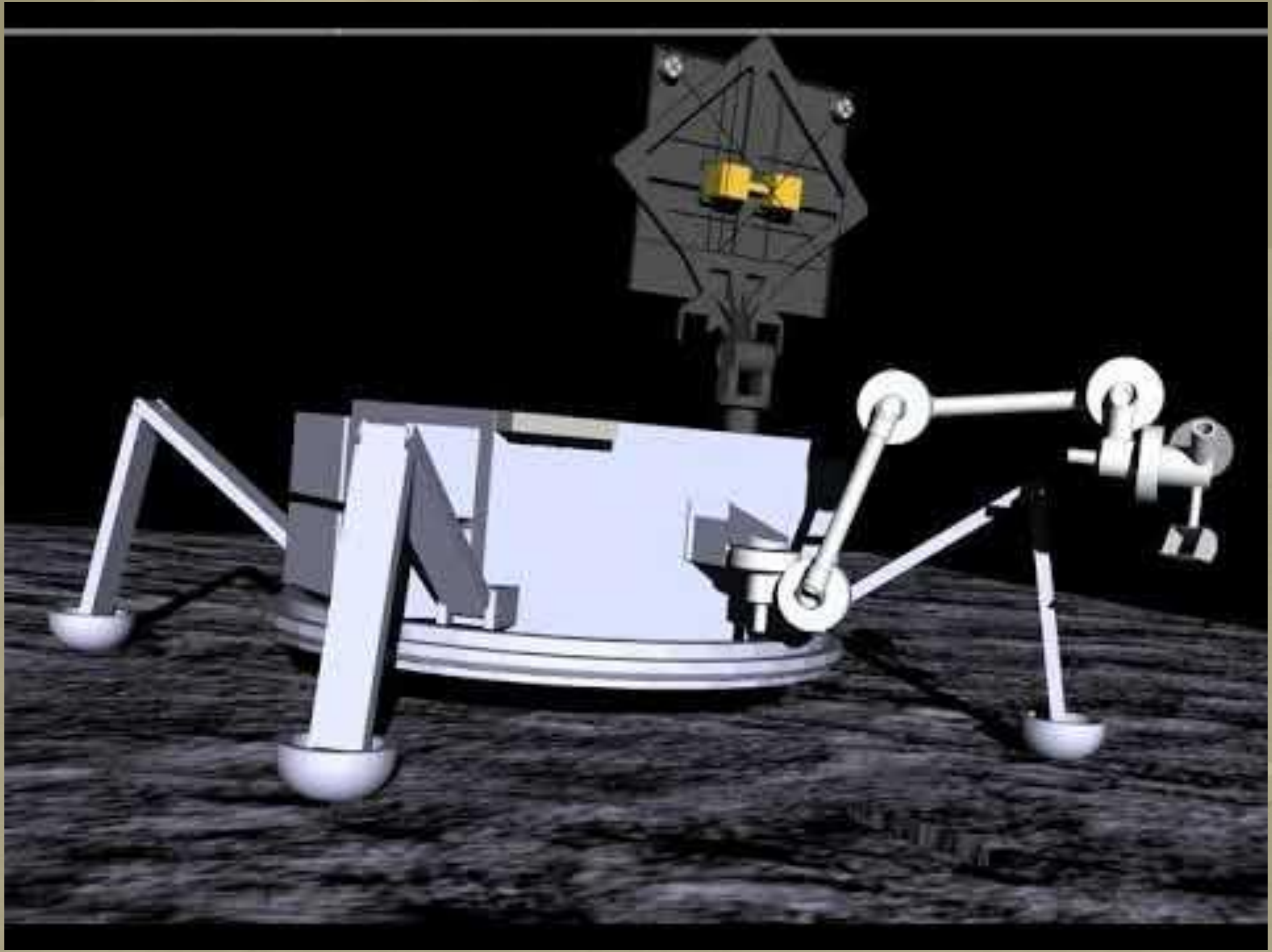

CONCLUSION

- OceanWATERS: an ocean worlds simulation testbed to test performance of autonomy algorithms under injected faults for surface exploration missions
- The testbed currently provides surface terramechanics modeling, as well as illumination and surface reflectance modeling, with simulated lander image sensor data and articulation telemetry.
- The testbed implements a multi-process architecture utilizing ROS as middleware and Gazebo to generate environment “ground truth”. A reference autonomy module has been implemented to exercise the system and provide an example of interfacing to the simulator via the API.

FUTURE WORK

- Development of fault injection/system state interrogation facility
- In surface visualization include visual properties of salt, sulfuric acid, etc.
- Include drilling force feedback using discrete element method (DEM) simulation
- Integrate open-source DEM software in OceanWATERS for user customization of sample collection strategy

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ACKNOWLEDGEMENTS

The OceanWATERS Team

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  Michael Dalal[2]
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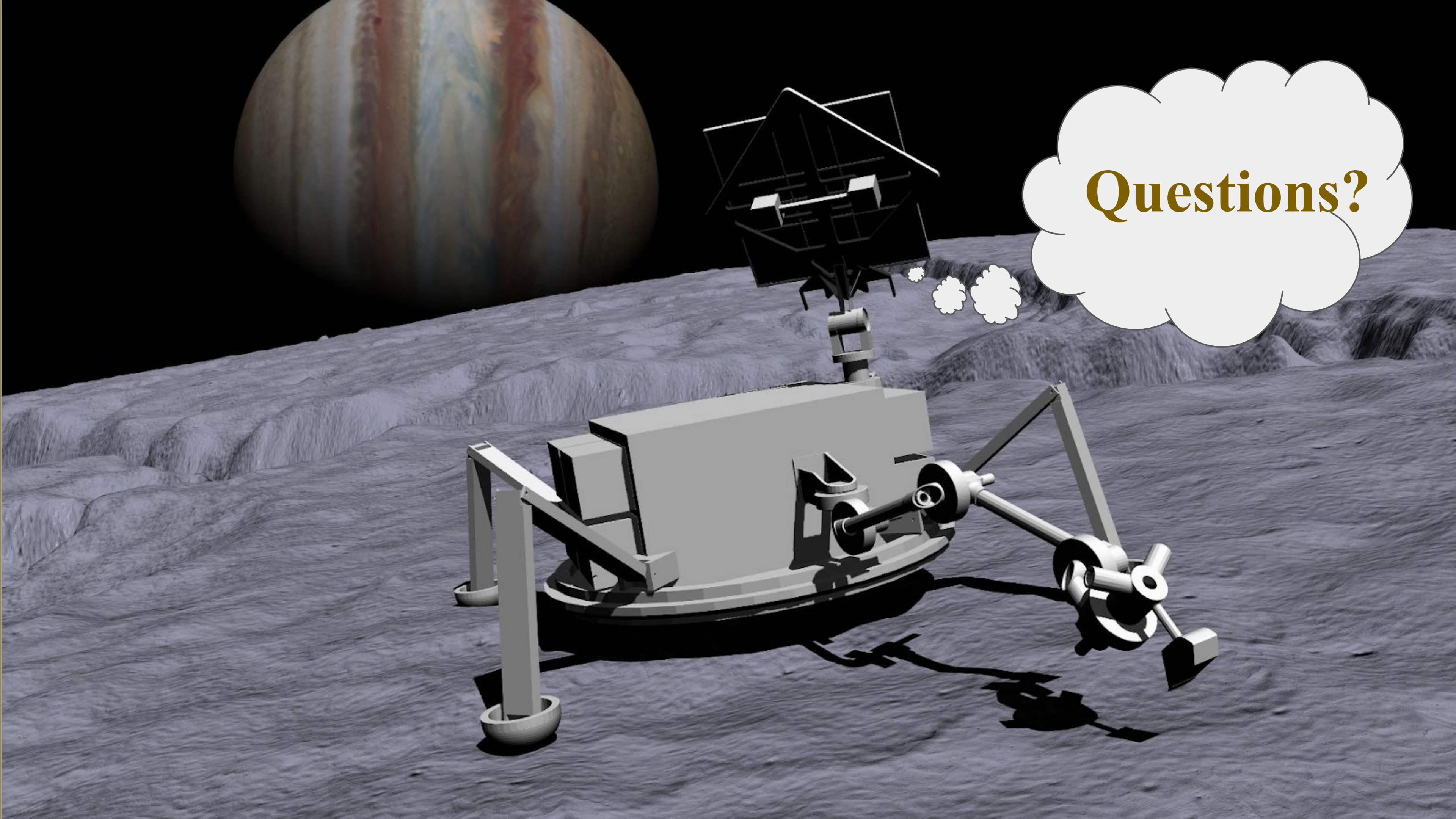
Questions?

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