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Celestial and Spaceflight
Mechanics Laboratory

Exploring Small Body Surfaces with Landed Pods

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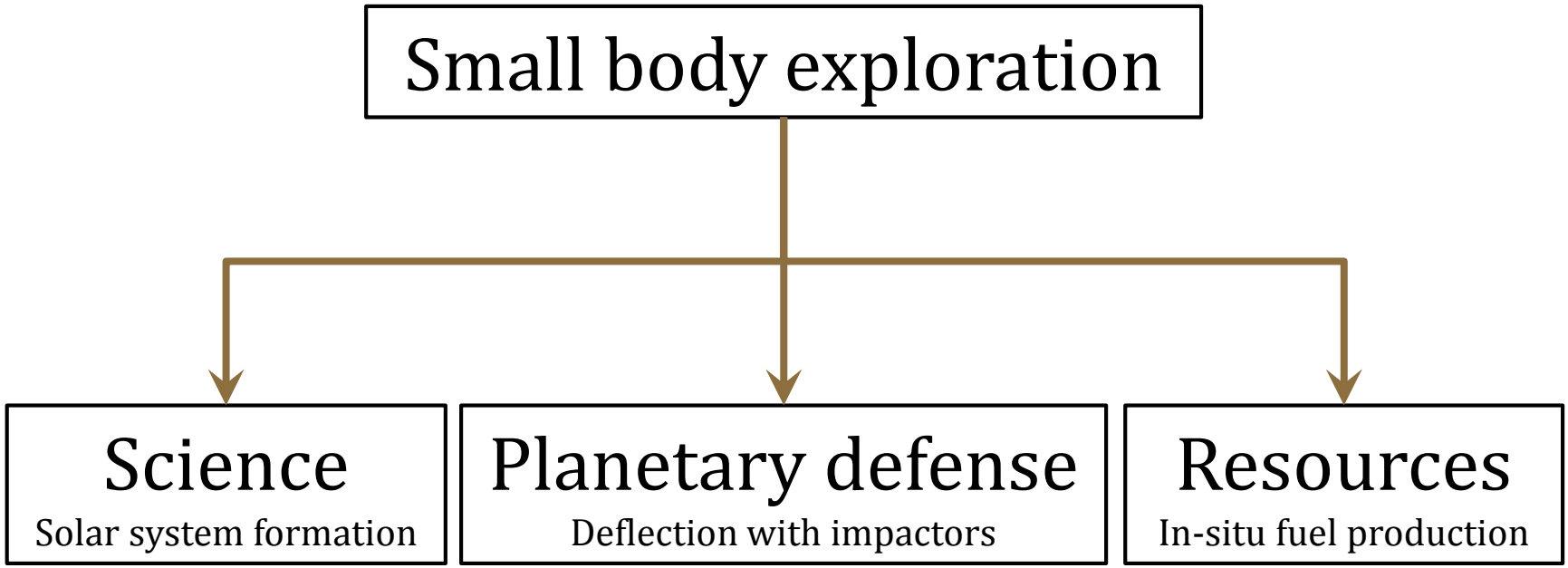
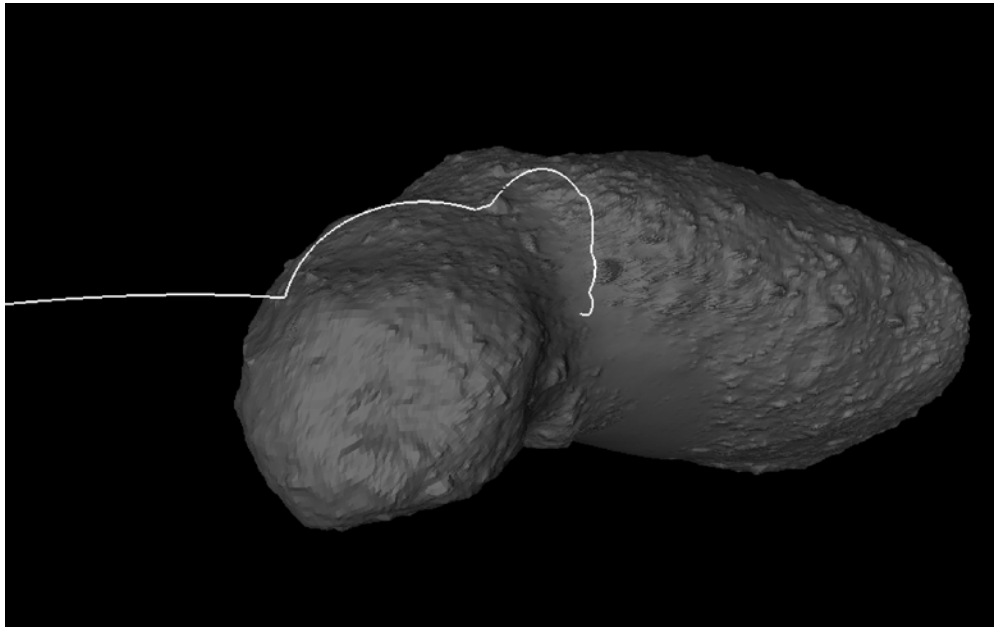
Introduction

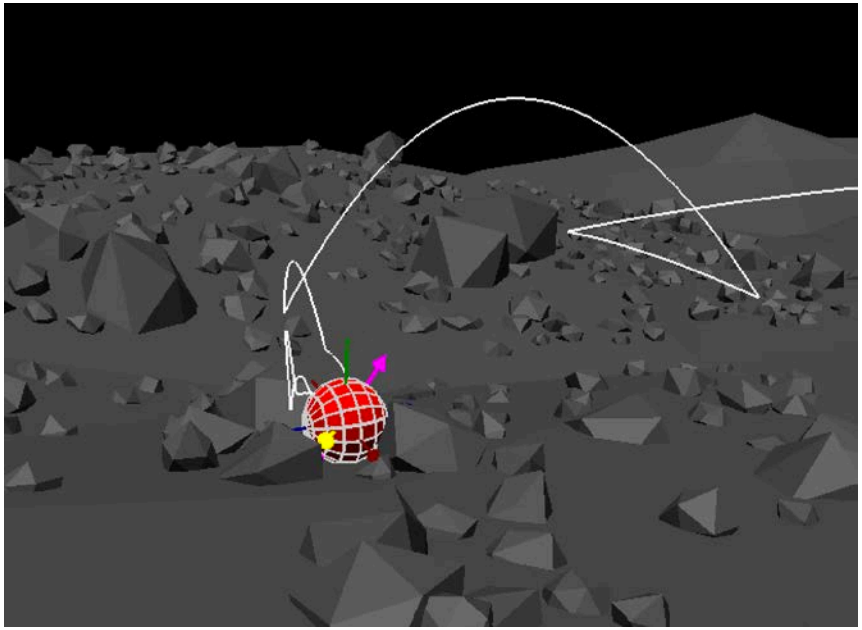


→ Increase mission return with **lander** and **surface mobility** operations

Contents

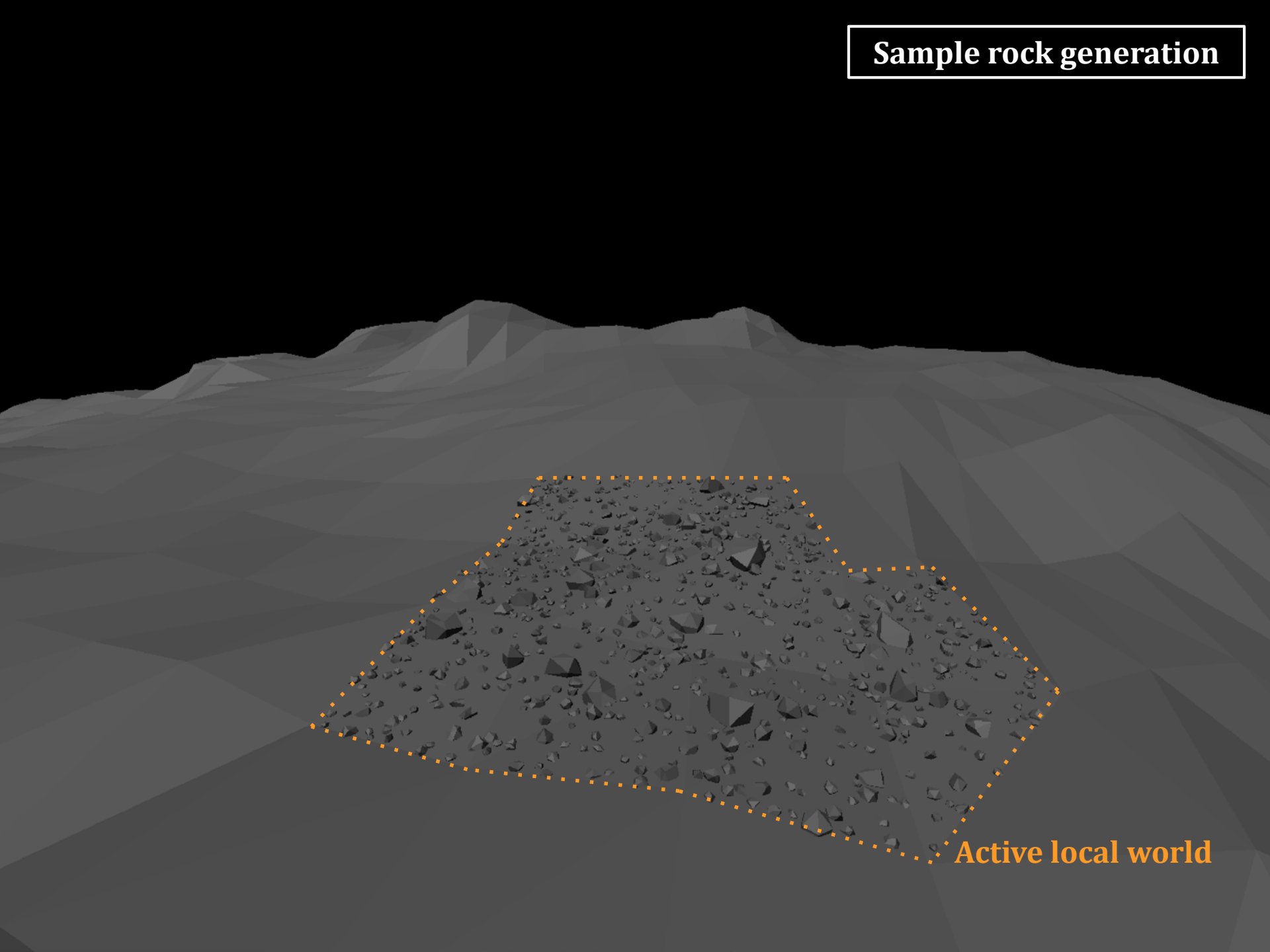
- Simulating lander motion
- Deployment
- Mobility operations
- Results and applications





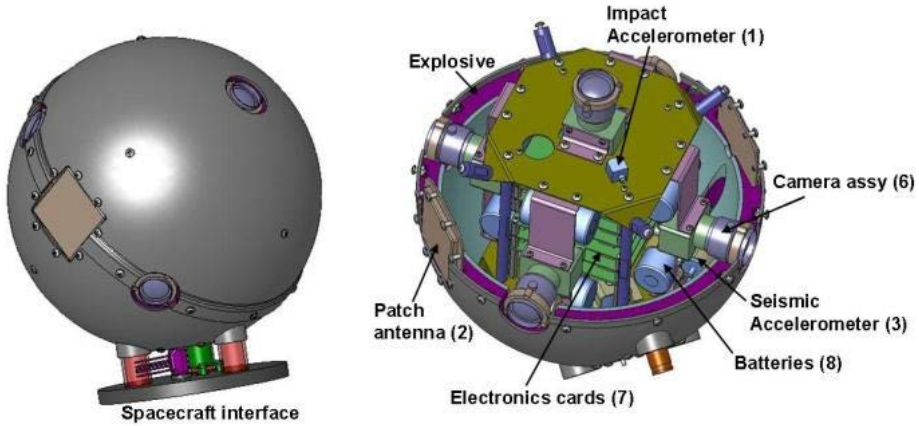
Simulating Lander Motion

- *SAL* software package, developed for *BASiX* mission to 1996 FG3
- Captures interaction at 3 scales:
  - Gravity and coarse body shape
    → constant-density polyhedron
  - Rocks and boulders on surface
    → recreated following Hayabusa observations
  - Granular surface
    → contact dynamics model with normal, friction, and rolling resistance forces and torques
- Integrated visualization engine


Sample rock generation
Active local world

Simulating Lander Motion

- Landers modeled as spherical pods
  - Proposed for *BASiX* mission to 1996 FG3

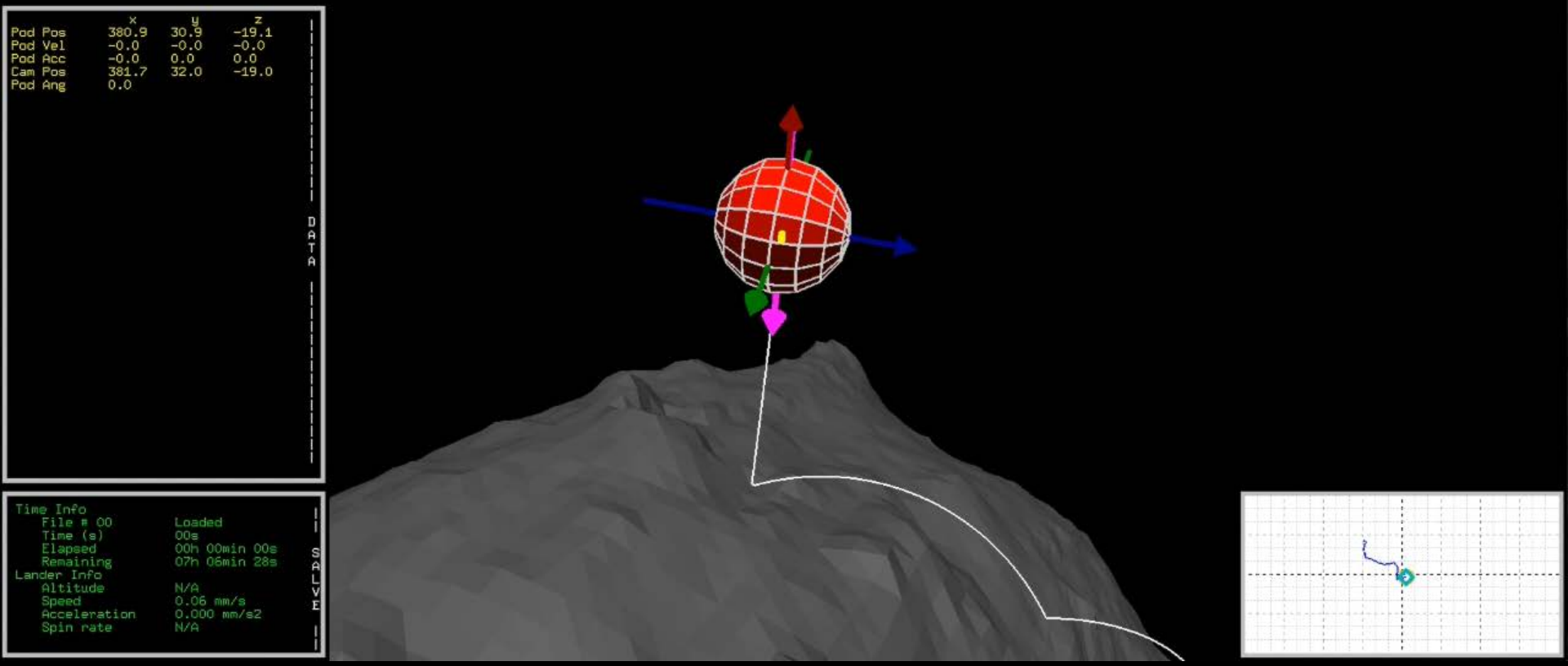


Source: S. Roark et Al.

  - Mass ~5kg, diameter ~0.25m
- Monte Carlo runs with variation of:
  - Release conditions
  - Interaction coefficients

  → Hardware and mission constraints

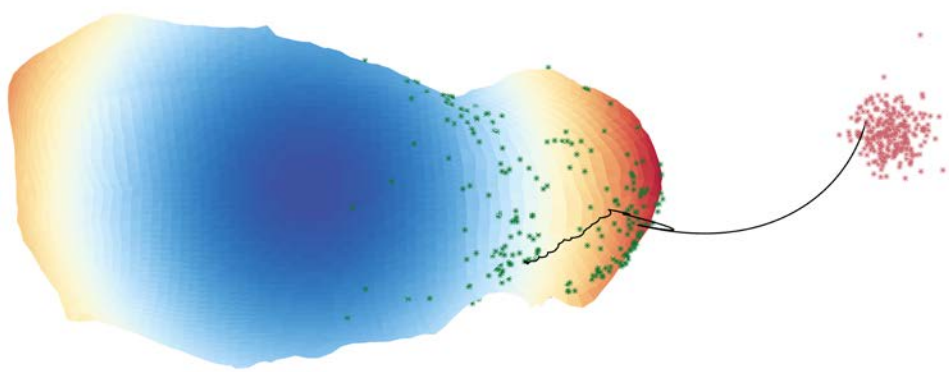
Sample deployment to Itokawa

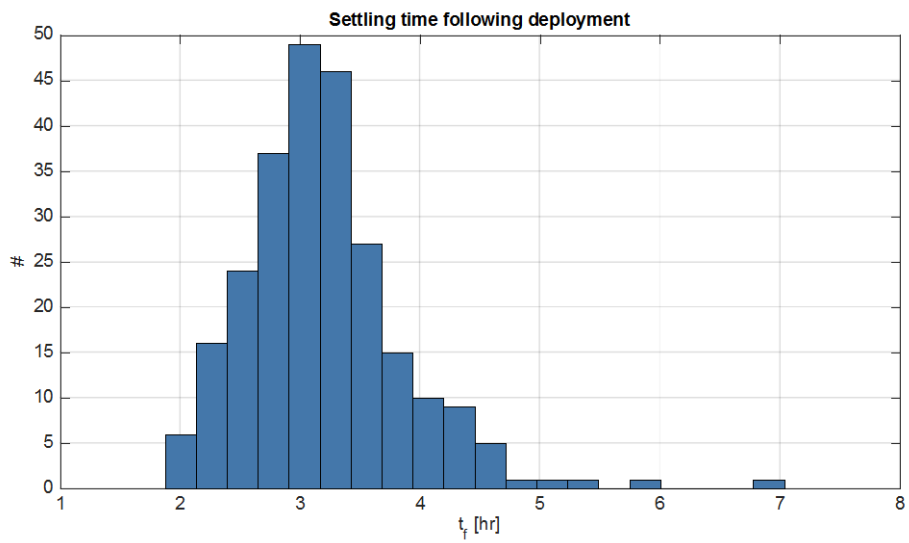


https://youtu.be/4CmuyQMe_So

Deployment

- Prove feasibility of deployment strategy
- Collisions with rocks cause surface dispersion
  - → Justifies inclusion of high-resolution rock model
- Energy dissipation governed by e and C_{RR}
- Settling statistics:

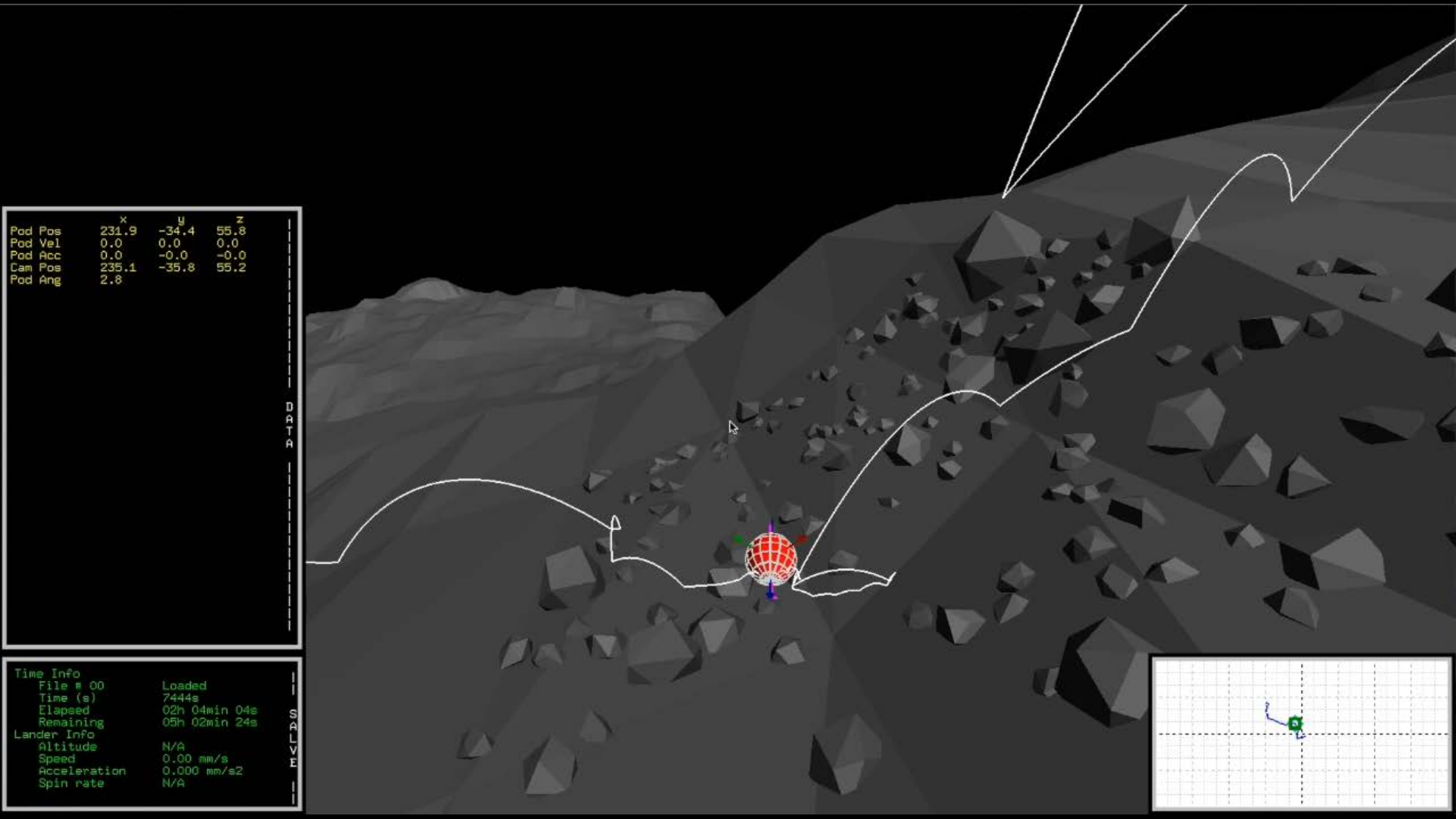




Mobility Operations

- Pods equipped with reaction wheel
  - Low-energy spin-up
  - Mechanical brake provides impulse
    - *E.g.* Ω_{pod} 1rpm ≈ Ω_{RW} 100rpm ≈ H_{RW} 0.2Nm·s
  - Spin transferred to velocity by friction
  - Impact with rock initiates "hopping" arc
- Simulations with *SAL*
  - Impulse from single 0.5kg wheel
  - Monte Carlo analyses to study dynamics

Sample hopping operations

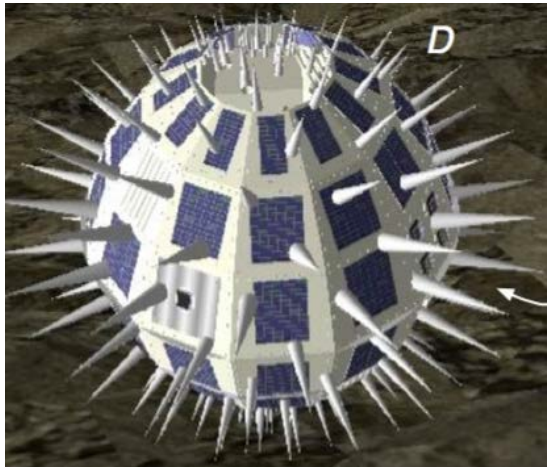


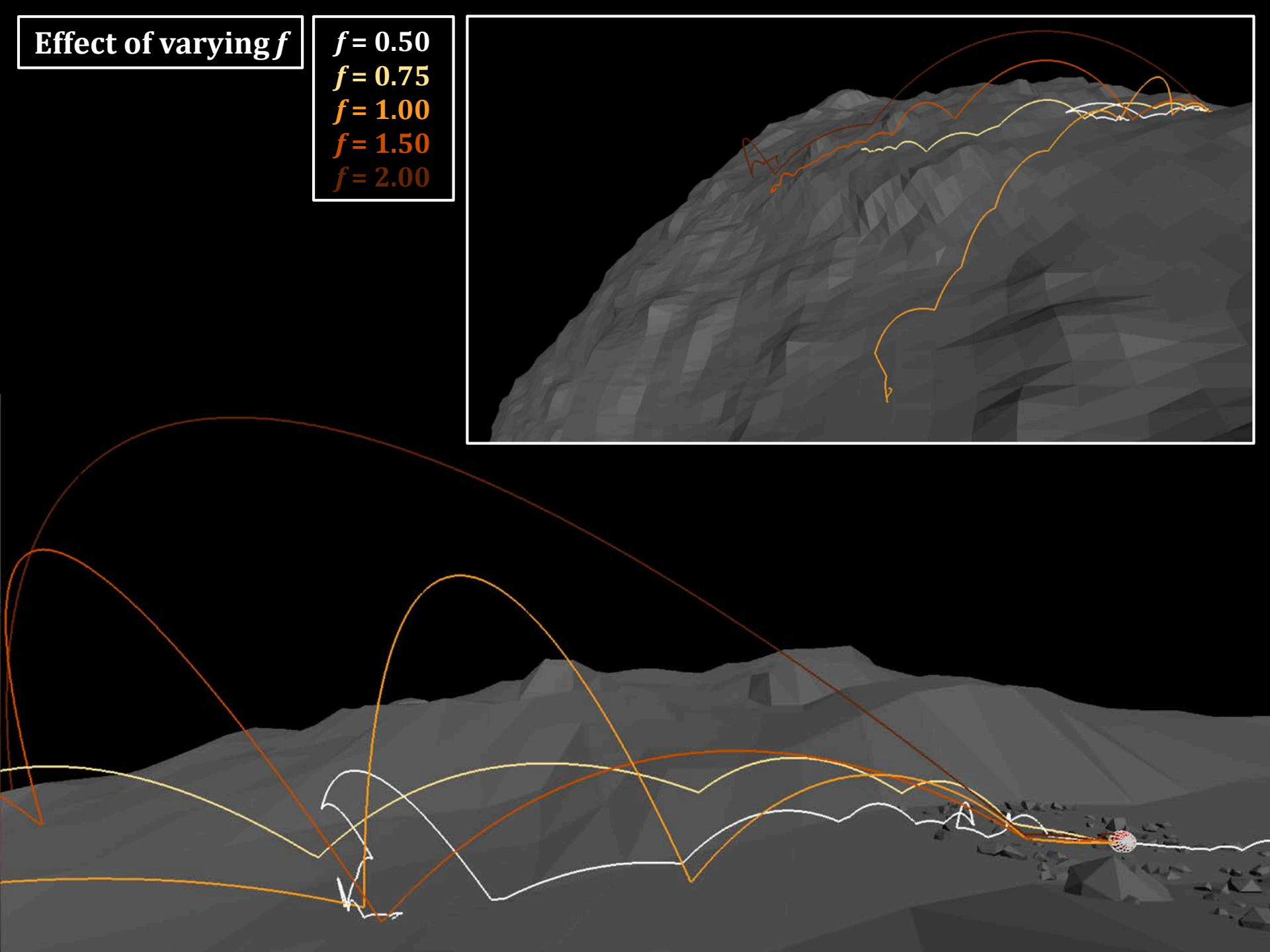
https://youtu.be/RGlDthbbBxo

Results and Applications

- Coefficient of friction *f*
  - Magnitude determines synchronization time
  - Greater *f* yields
    - → Shorter synchronization time
    - → Fewer intermittent collisions
    - → Greater control over velocity direction
  - 'Rough' pods will have greater control over hopping direction
    - → *E.g*. spikes and friction strips
    - → Comply with other interaction constraints (instrumentation, getting stuck, *etc*.)

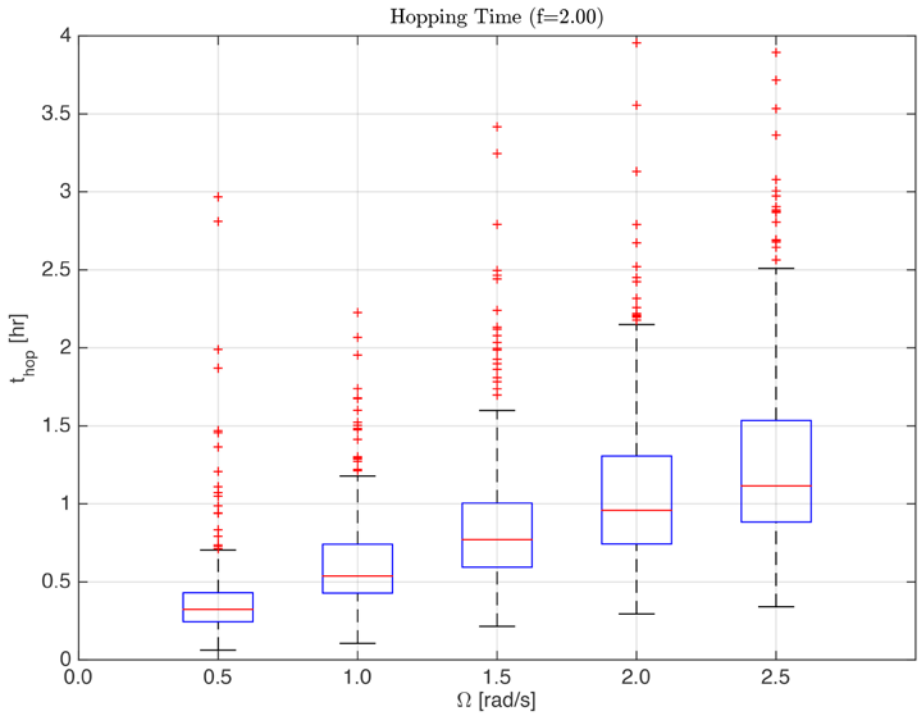
Source: M. Pavone et Al.

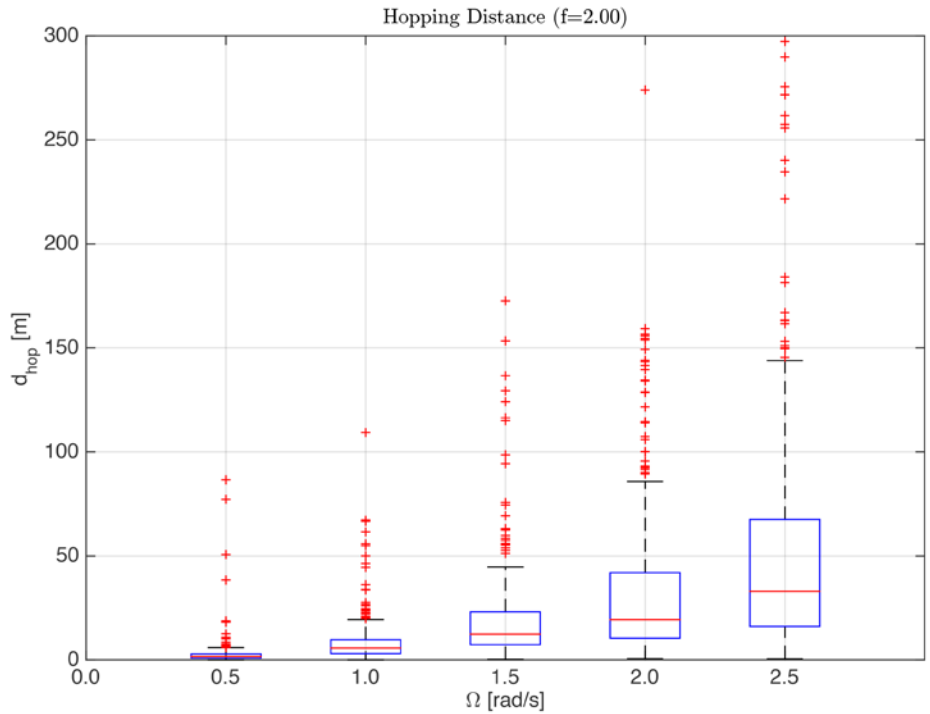



Effect of varying *f*
f = 0.50
f = 0.75
f = 1.00
f = 1.50
f = 2.00

Results and Applications

- Magnitude of reaction wheel impulse





→ Hop scales with impulse magnitude

Conclusions

- High-fidelity small body lander simulations
  - Prove feasibility of landing strategy
  - Generate trajectory characteristics
  - Establish hardware requirements
- Surface mobility with reaction wheels
  - Variability due to surface rocks
  - High *f* provides greater control over direction
  - Hop scales with impulse magnitude
- Low-cost, low-risk surface mobility operations

Thank you for your attention!

Special thanks to the IPPW sponsors

References

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