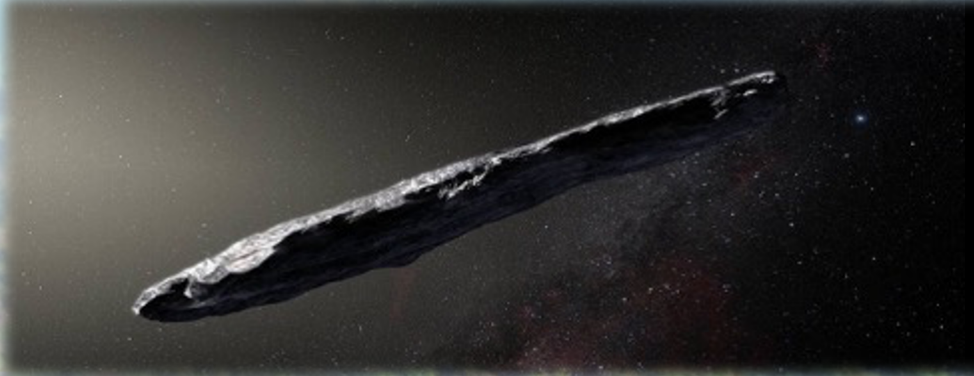
RPC 2020



Virtual Research Presentation Conference

Autonomous Approach and Landing on Small Unexplored Bodies with SmallSats

Principal Investigator: Issa A. Nesnas (347)
Co-Is: Shyam Bhaskaran, Daniel Lubey (392), Saptarshi Bandyopadhyay, Benjamin Hockman, Benjamin Morrell (347), and David Bayard (343)
Consultant: Andrew Johnson
Team: Jacopo Villa (347/U. of Colorado), Sandro Papais (347 student), Reza Karimi (392), Alan Osmundson (347-student), Ben Jarvis (347-student), Michele Bersani (347-student)

Program: Topical RTD

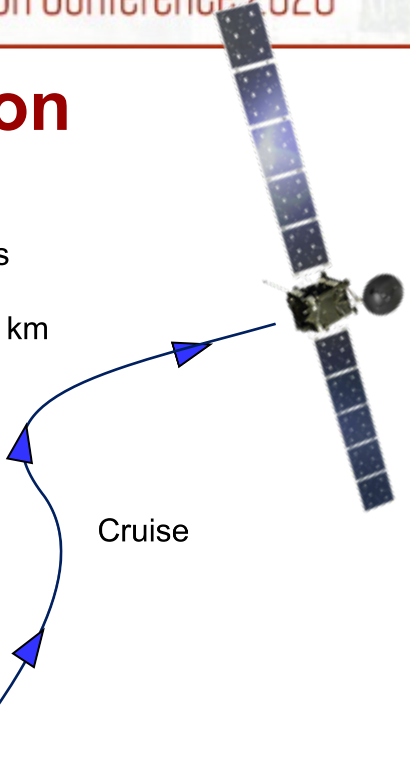
Assigned Presentation # RPC-180

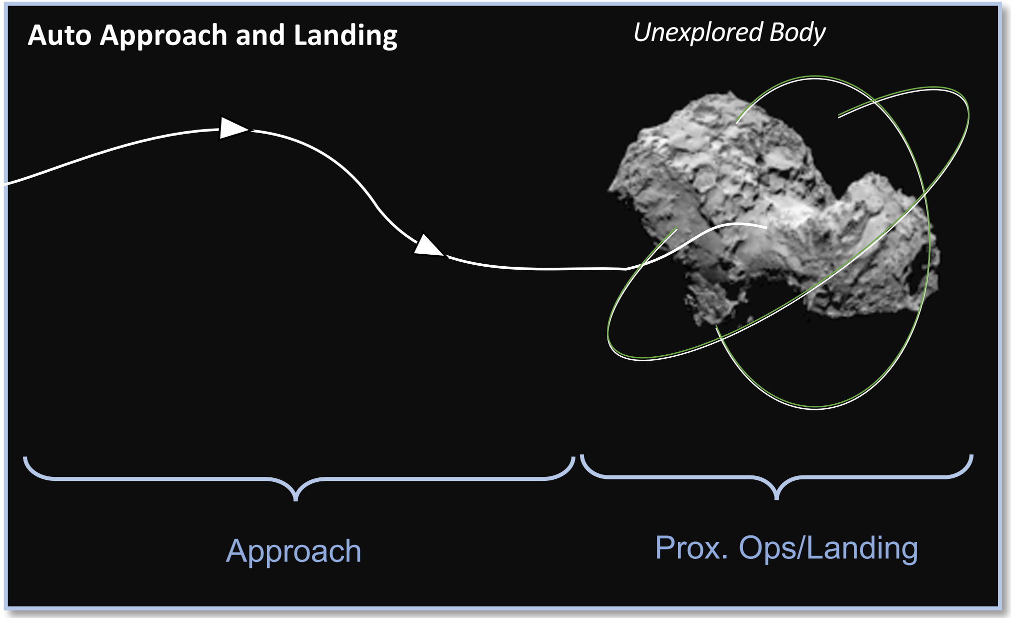
Jet Propulsion Laboratory
California Institute of Technology

Introduction

Abstract

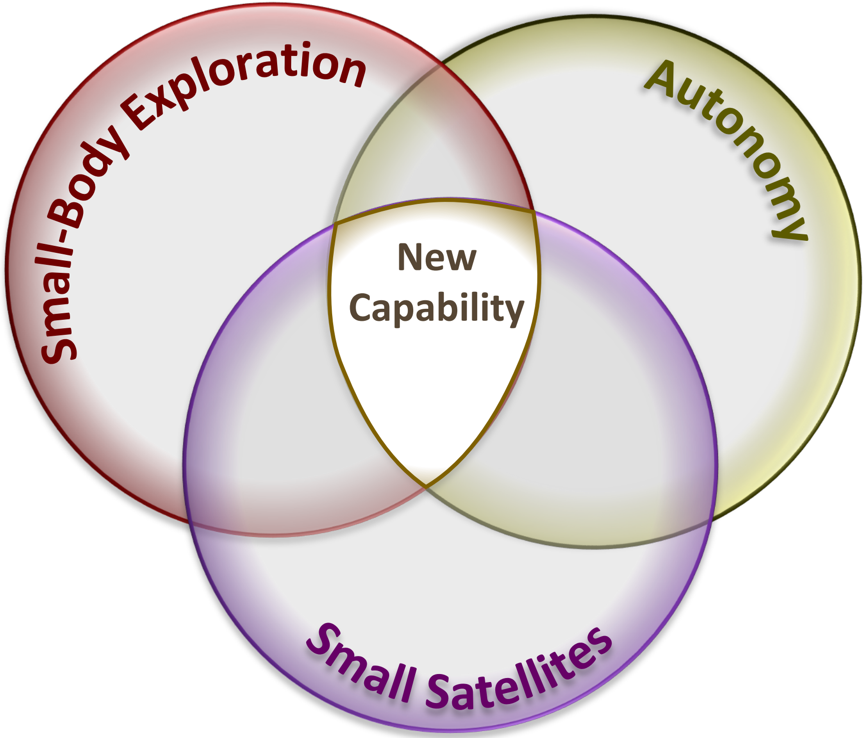
Focuses on autonomous functions to enable approach from 1000s of km down to landing on an unexplored body





Why?

- Enables greater access to diverse small bodies for *science* and *planetary defense*
- Can substantially *advance autonomy* using SmallSats and Near-Earth Objects
- Leverages increasing launch opportunities
- Shares challenges that would enable future missions (e.g. KBOs, interstellar)
  - Motion and shape not known *a priori*
  - Rugged surface
  - Dynamic interaction on surface

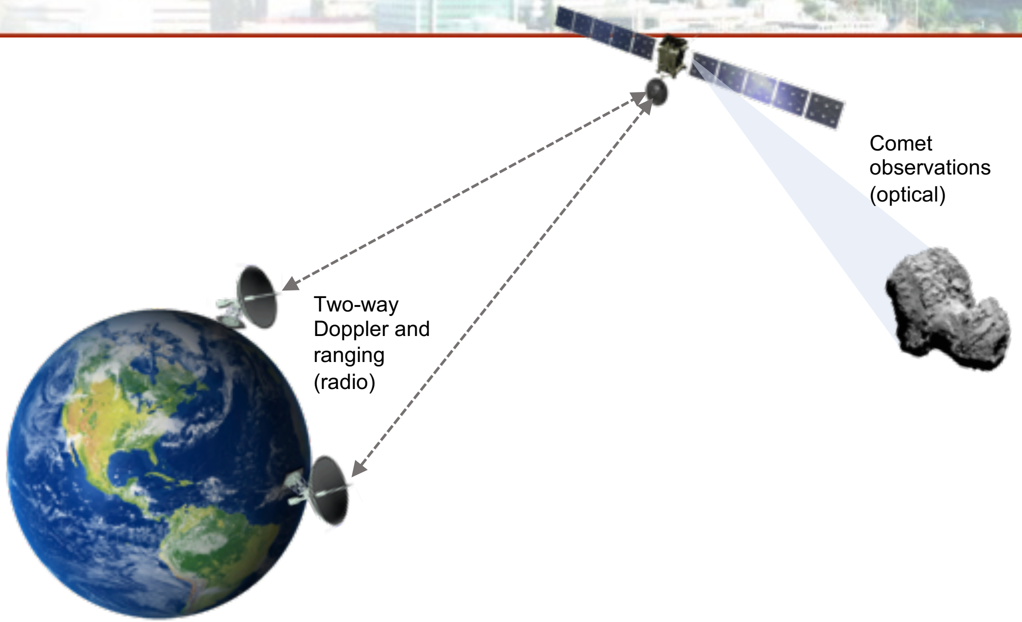


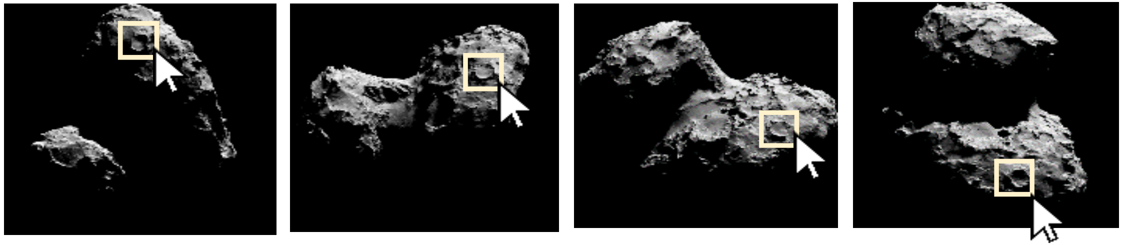
Synergy

State of the Art

Heavily relies on ground

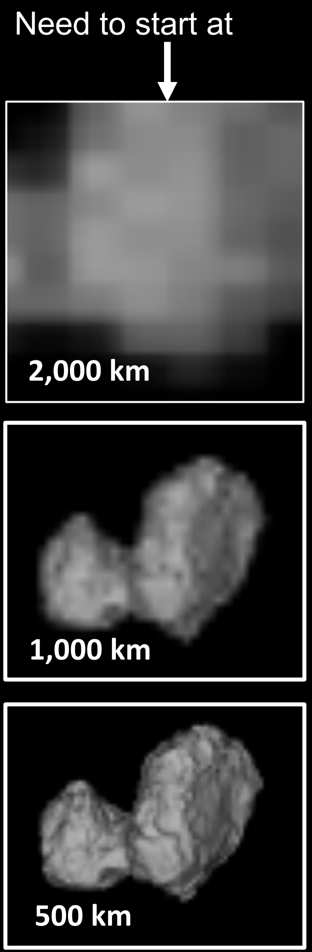
- Constrained by communication availability
- Relies on Deep Space Network (DSN) for ranging and velocity estimation
- Uses optical measurements of bodies (centroids and landmarks)
- Heavily relies on ***operators*** for approach, touching or landing





Manual landmark correspondence

Challenges



Estimate

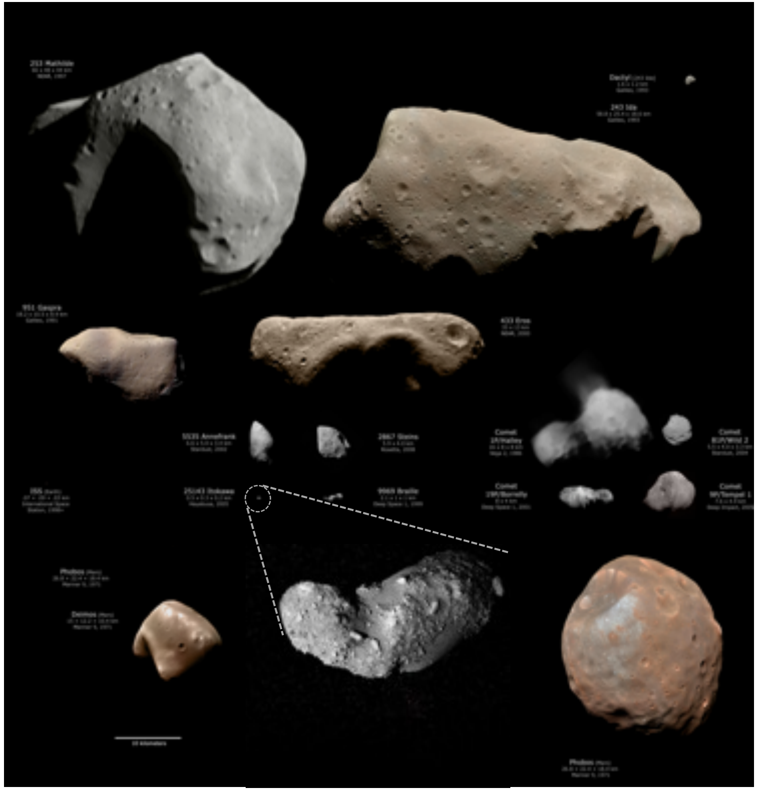
- Orbits (throughout)
- Rotation rate
- Center of rotation
- Rotation axis
- Shape
- Hazards and safe landing sites

Relevance

Allows greater access to small bodies, which are:

- Abundant
- Disparate
- Diverse *(in composition and origin)*
- Relatively unknown

Knowledge (as of 10/2019)	**#**
Ground	**>850,000**
Flybys	**25**
Rendezvous	**7**

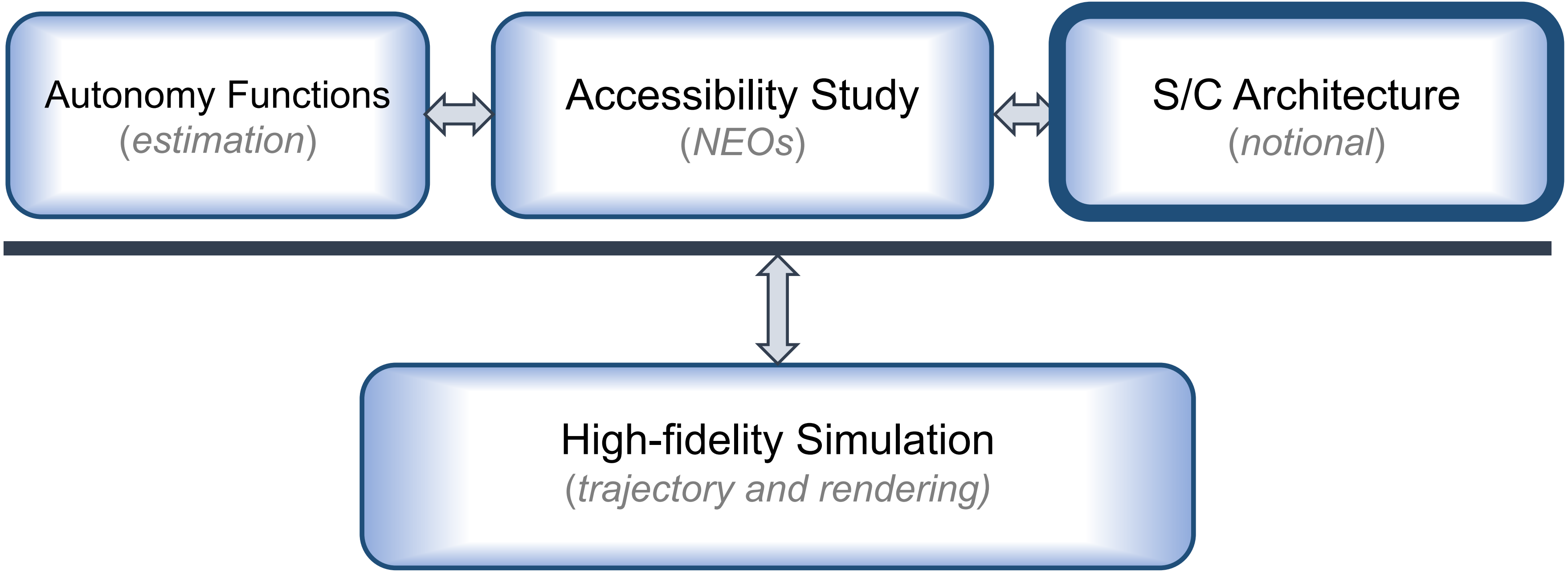


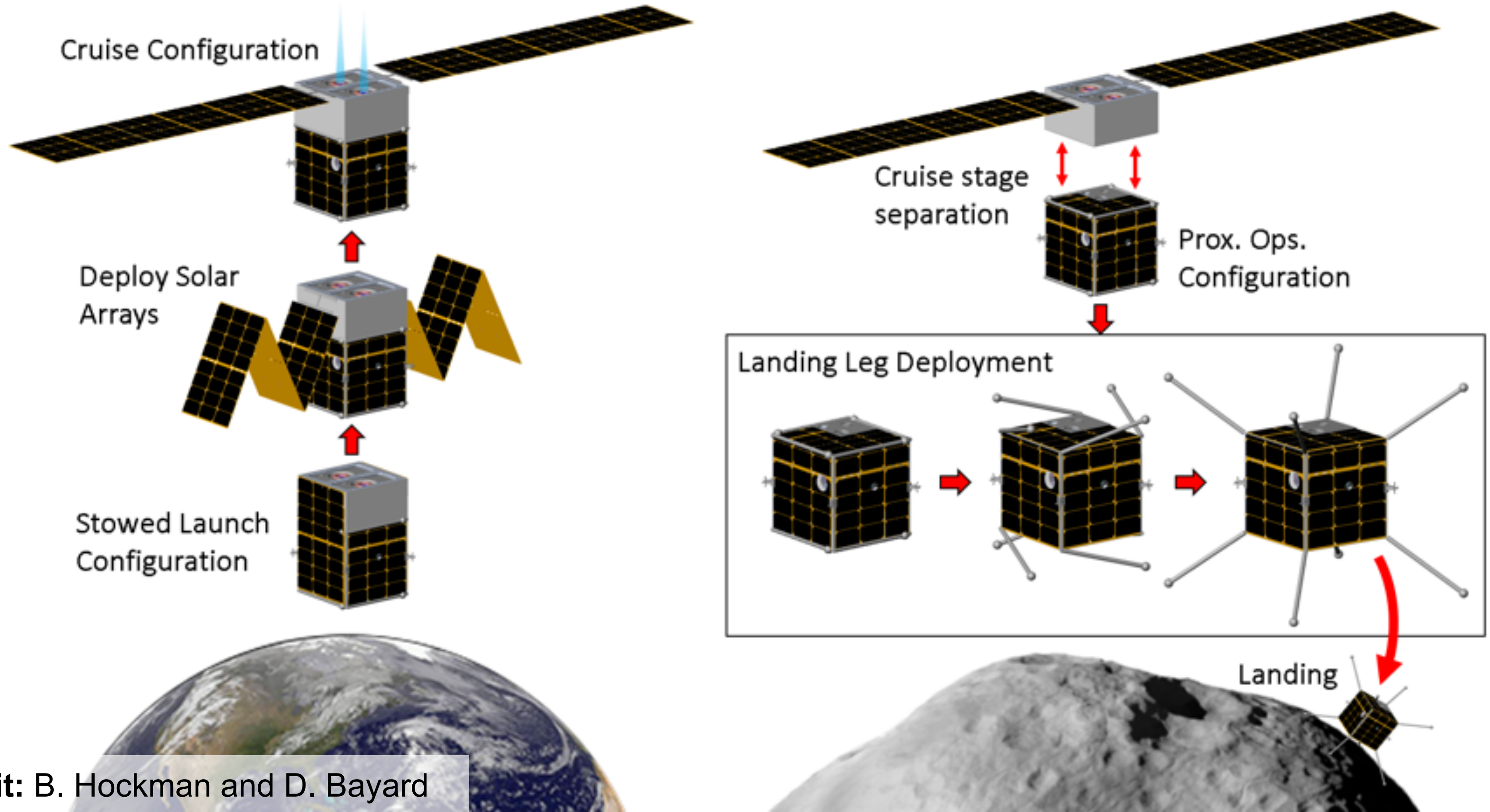
Feedforward Applicability

Near-Earth objects, comets, asteroids, interstellar objects, small moons, ocean worlds, tran

Small Bodies are diverse and relatively unknown

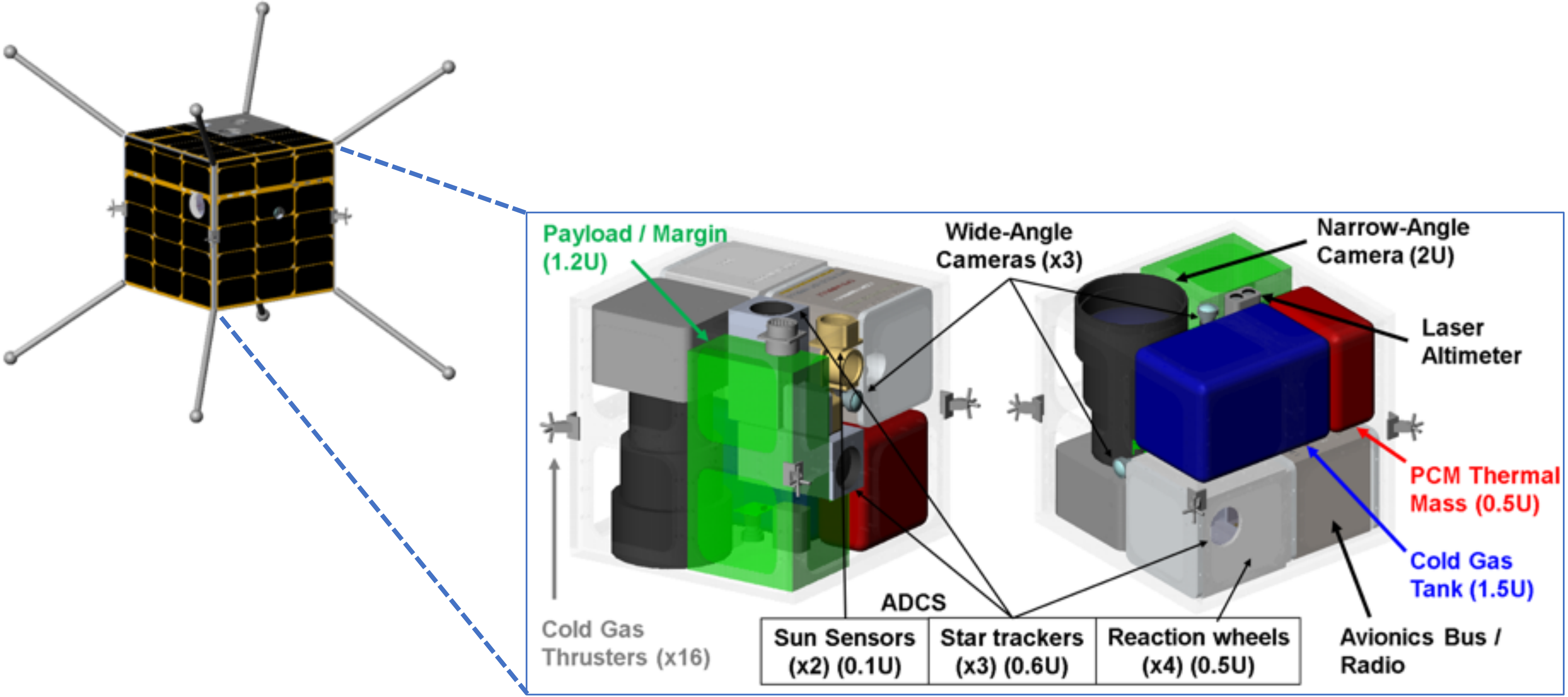
Methodology





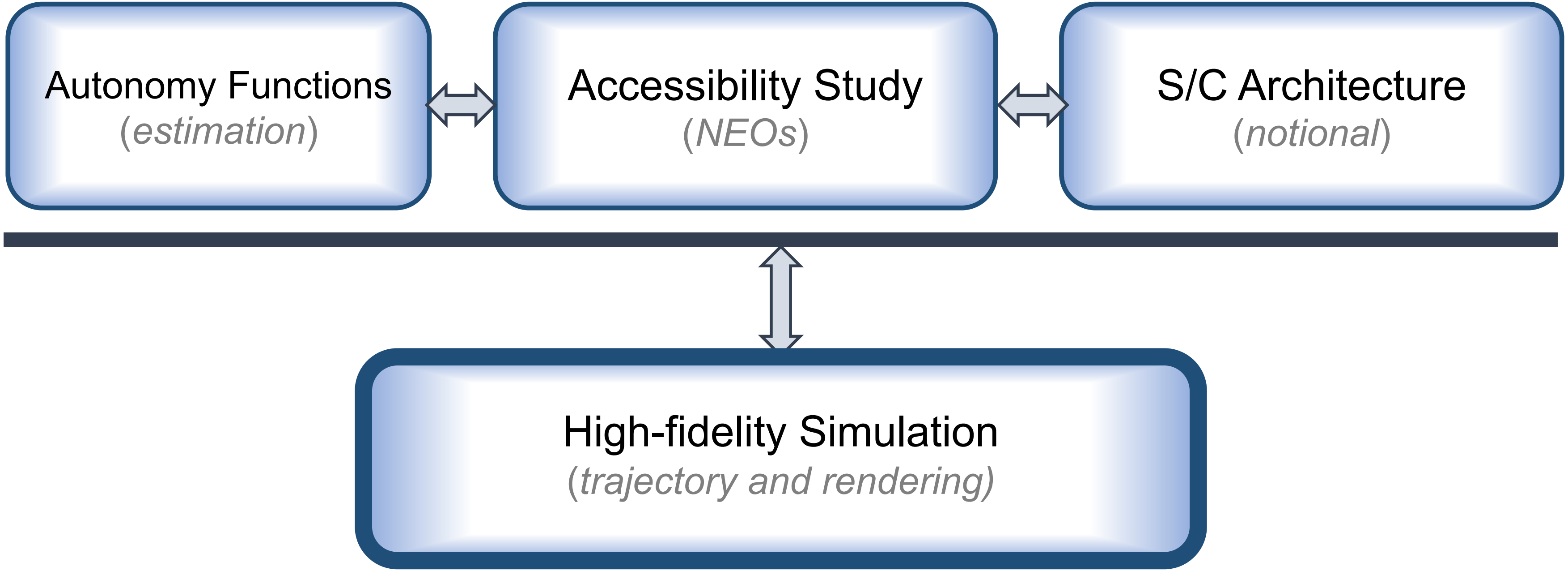
Credit: B. Hockman and D. Bayard

Notional SmallSat Architecture



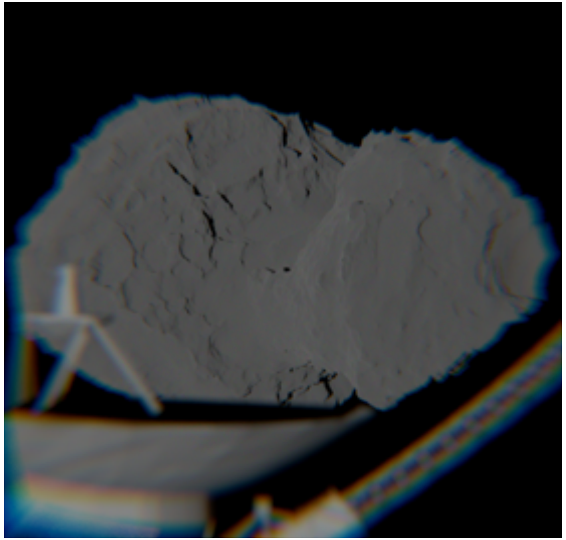
Credit: B. Hockman, S. Papais, and D. Bayard

Methodology



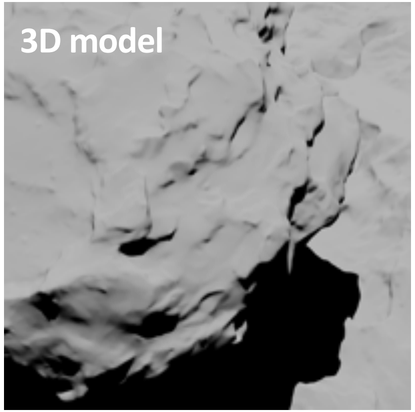
High-Fidelity Rendering

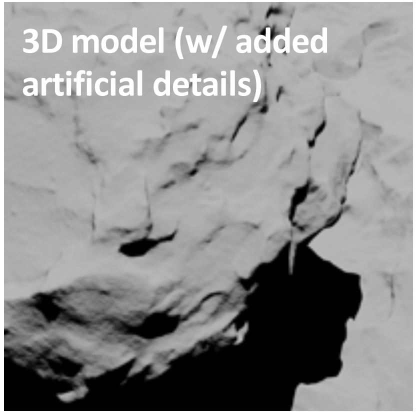
Using state-of-the art tools from gaming industry

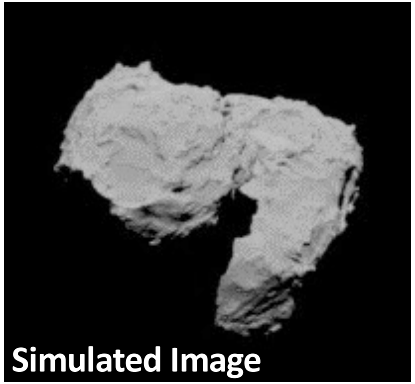


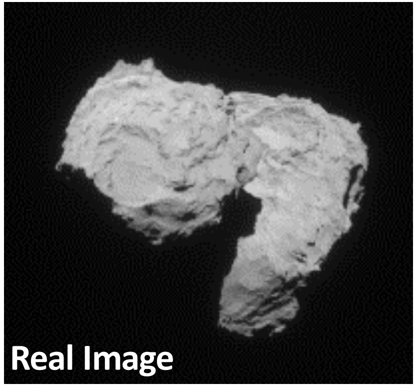
Exaggerated optical effects

Distortion, depth of field, chromatic aberration (models: exposure time, motion blur, read noise, dark current, and dynamic range)





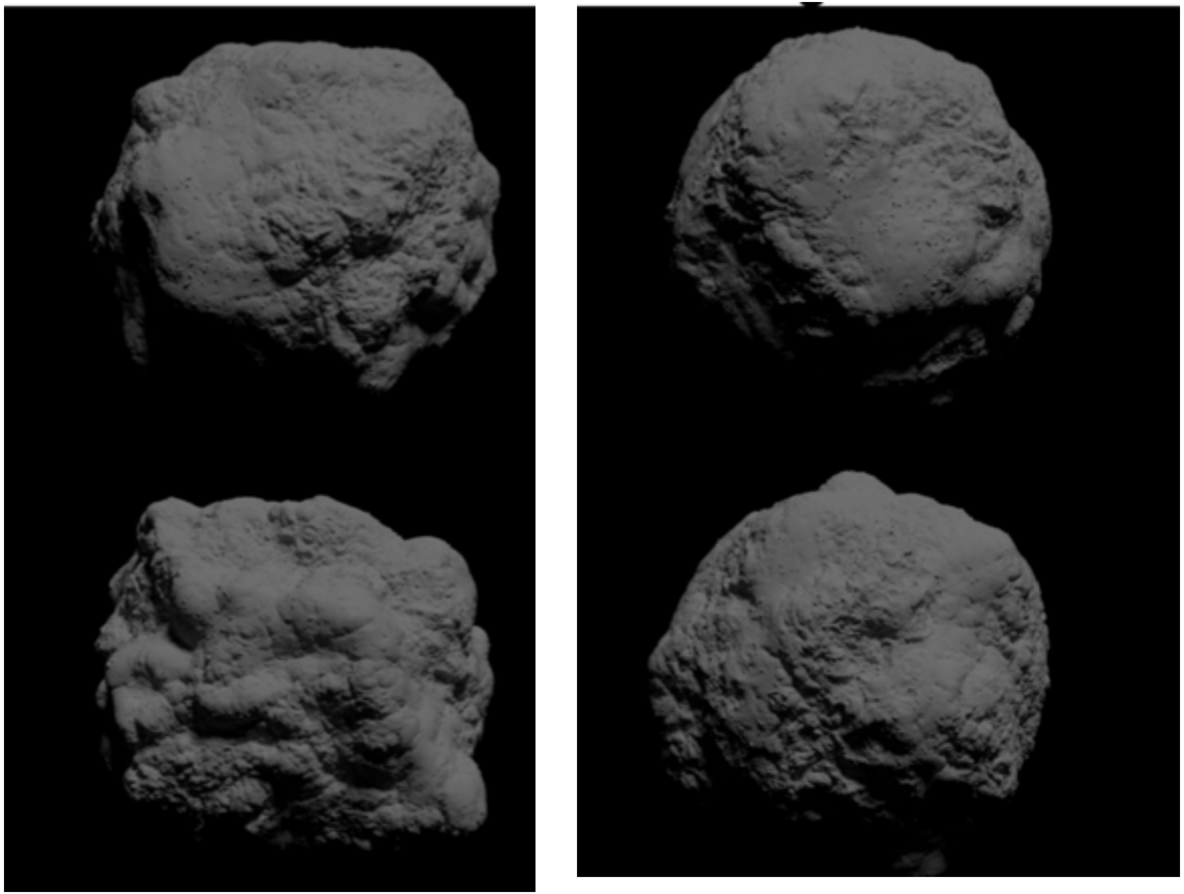




Credit: J. Villa

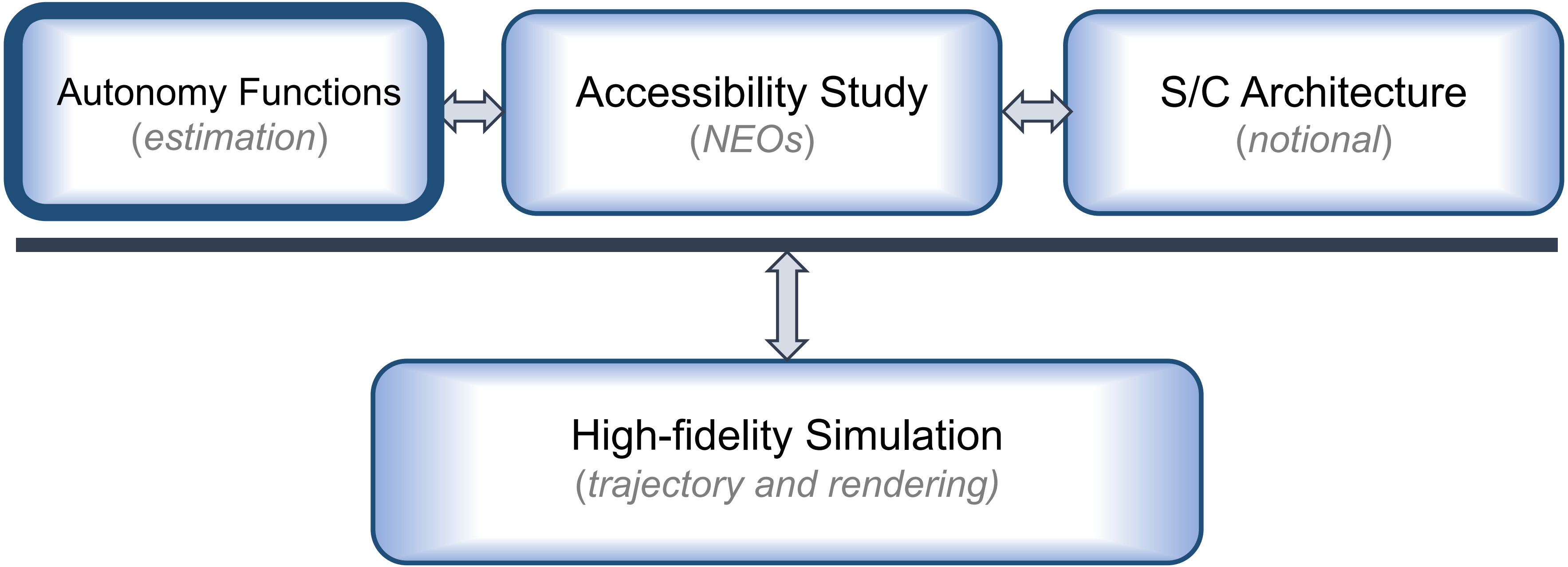
Artificially-generated Bodies

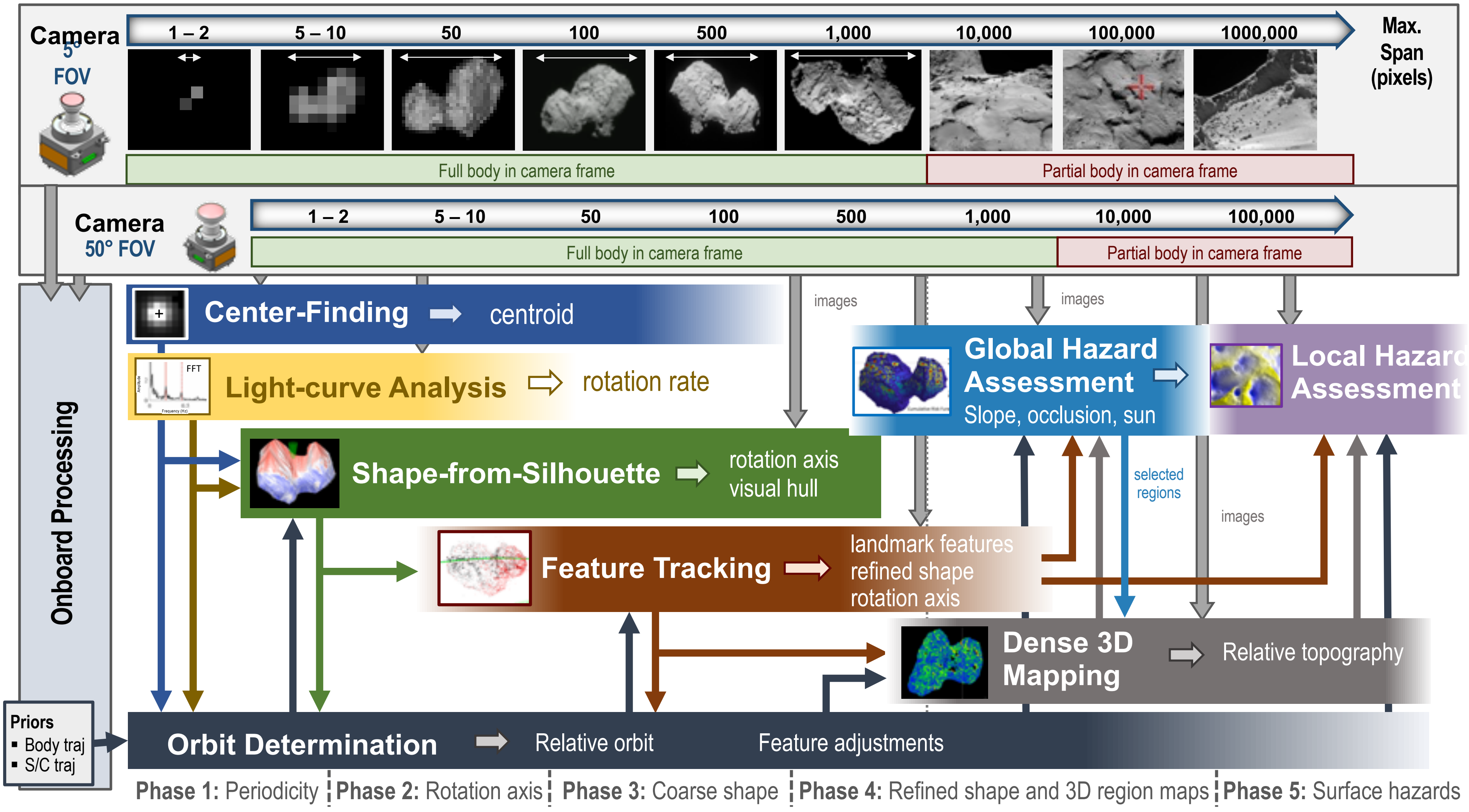
For testing and training



Credit: J. Villa

Methodology

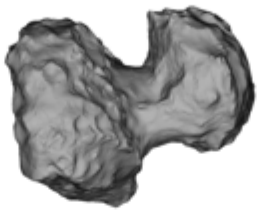




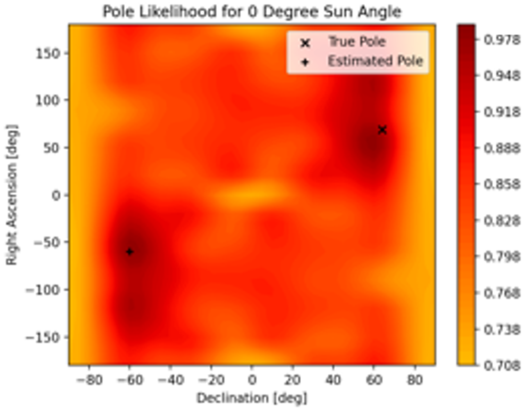
Camera
5° FOV
1 – 2
5 – 10
50
100
500
1,000
10,000
100,000
1000,000
Max. Span (pixels)
Full body in camera frame
Partial body in camera frame
Camera
50° FOV
1 – 2
5 – 10
50
100
500
1,000
10,000
100,000
Full body in camera frame
Partial body in camera frame
Onboard Processing
Center-Finding
centroid
images
images
FFT
Light-curve Analysis
rotation rate
Global Hazard Assessment
Slope, occlusion, sun
Local Hazard Assessment
Shape-from-Silhouette
rotation axis
visual hull
selected regions
images
Feature Tracking
landmark features
refined shape
rotation axis
Dense 3D Mapping
Relative topography
Priors
Body traj
S/C traj
Orbit Determination
Relative orbit
Feature adjustments
Phase 1: Periodicity
Phase 2: Rotation axis
Phase 3: Coarse shape
Phase 4: Refined shape and 3D region maps
Phase 5: Surface hazards

Pole and Shape from Silhouette

- We use a multi-hypothesis pole estimation using ray-casting
- Once candidate poles are identified, we carve a voxel shape

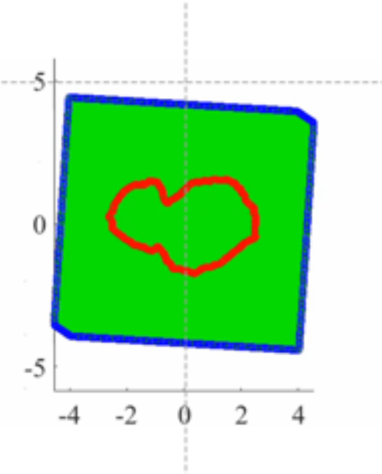


True Shape

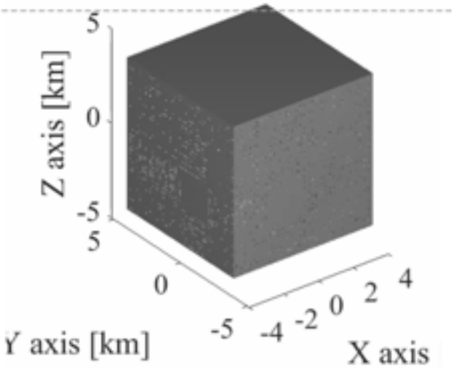


Candidate Poles

Image stream



Body Silhouette

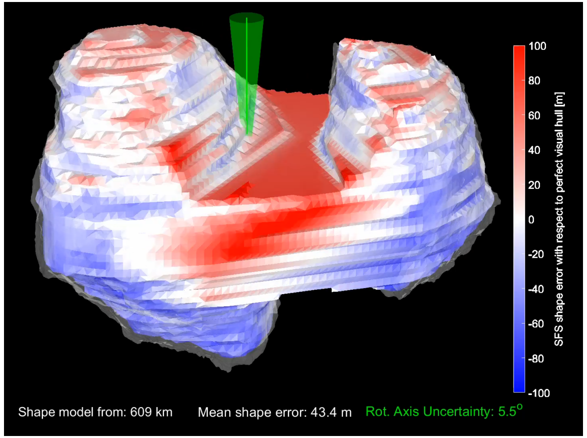


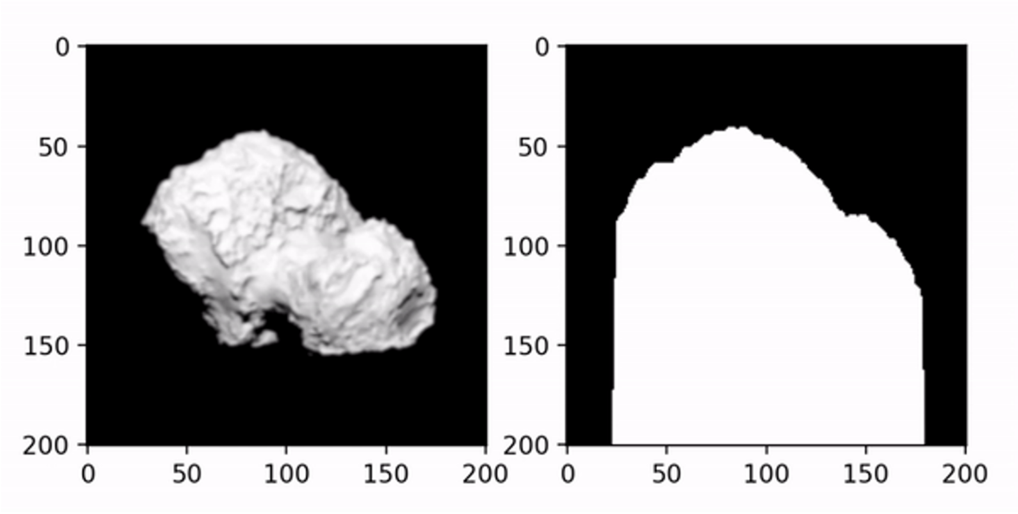
Voxel Carving

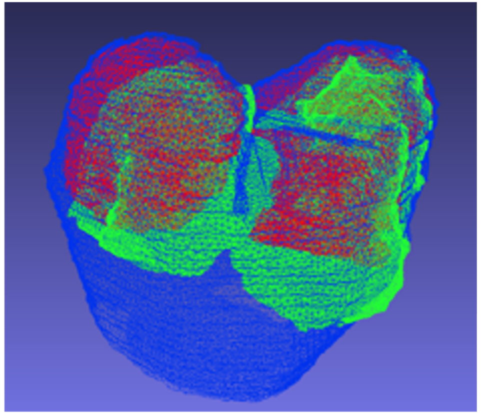
Credit: S. Bandopadhyay, A. Osmundson, B. Hockman, B. Morrell

Shape from Silhouette

- Limit: convex hull
- Handling different sun angles
- Handling shadows

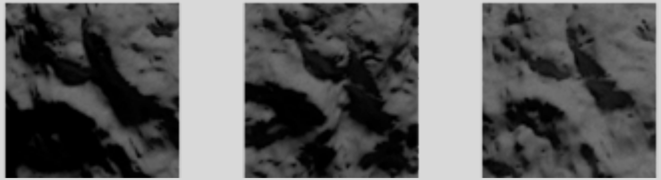






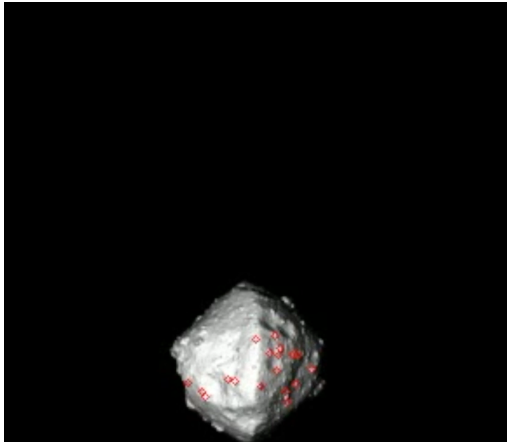
Credit: A. Osmundson, S. Bandopadhyay, B. Hockman, B. Morrell

Tracking Surface Features


Same feature at different times

Features change due to:
- Perspective
- Light and shadows
- Large scale

Other challenges
- Features similarity
- Re-identification after full revolution

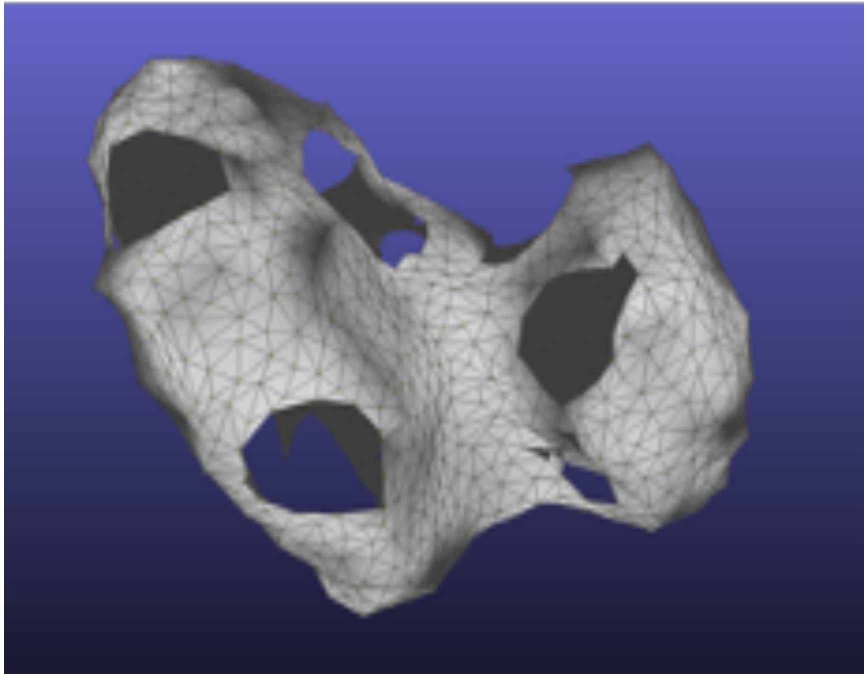


Compared different approaches
- **Optical flow:** LKT
- **Feature descriptors:** SIFT (local histogram)
SURF (wavelet)
AKAZE, BRISK, ORB (binary)

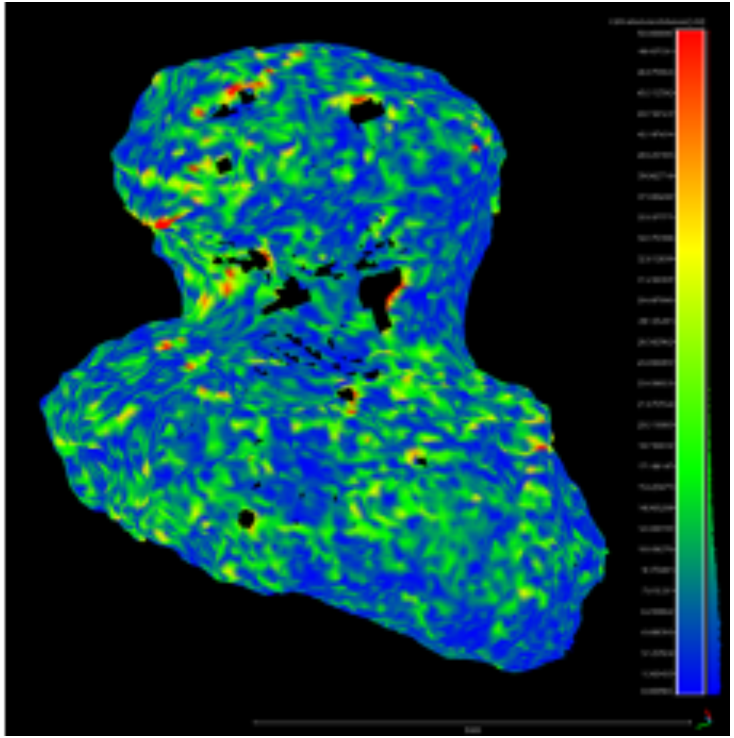
Findings
- Current trackers do not handle such features well
- Trade-off between long tracks and low drift

Credit: B. Morrell

Shape from Features



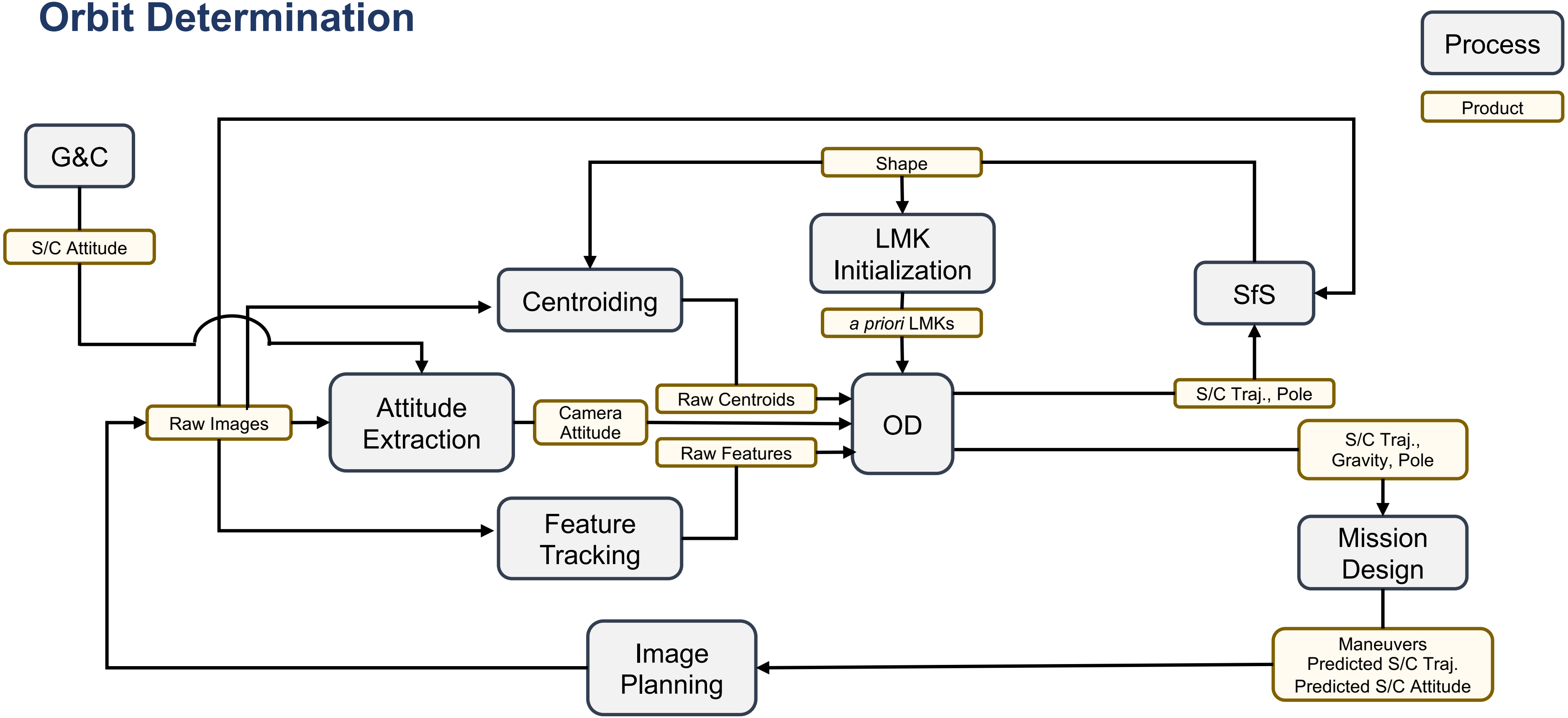
Coase Shape
(from 400 features)



Fine shape
(fuses multiple point clouds)
Error < 10s of meters

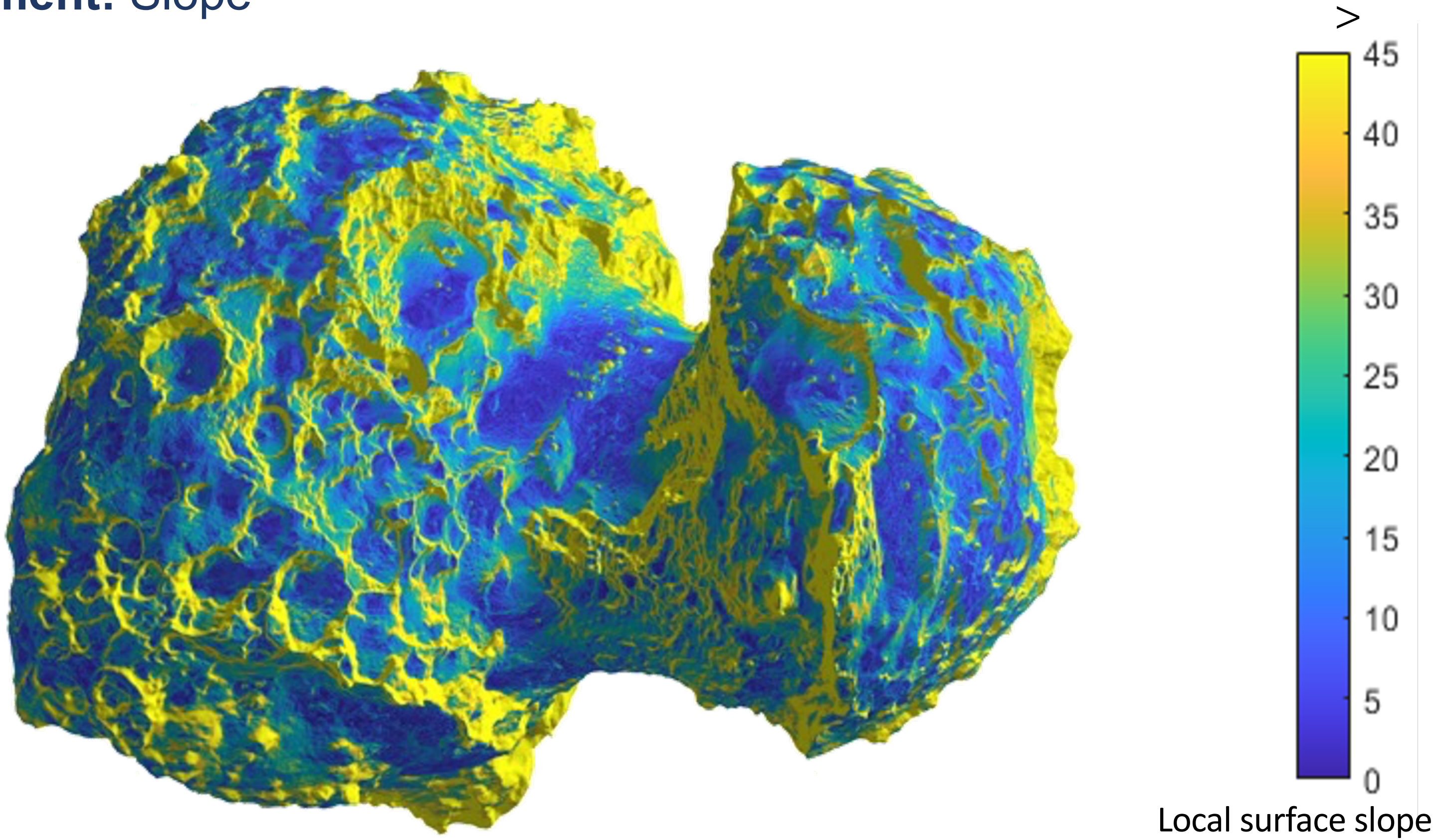
Credit: B. Morrell , B. Jarvis

Orbit Determination



Credit: D. Lubey, S. Bhaskaran

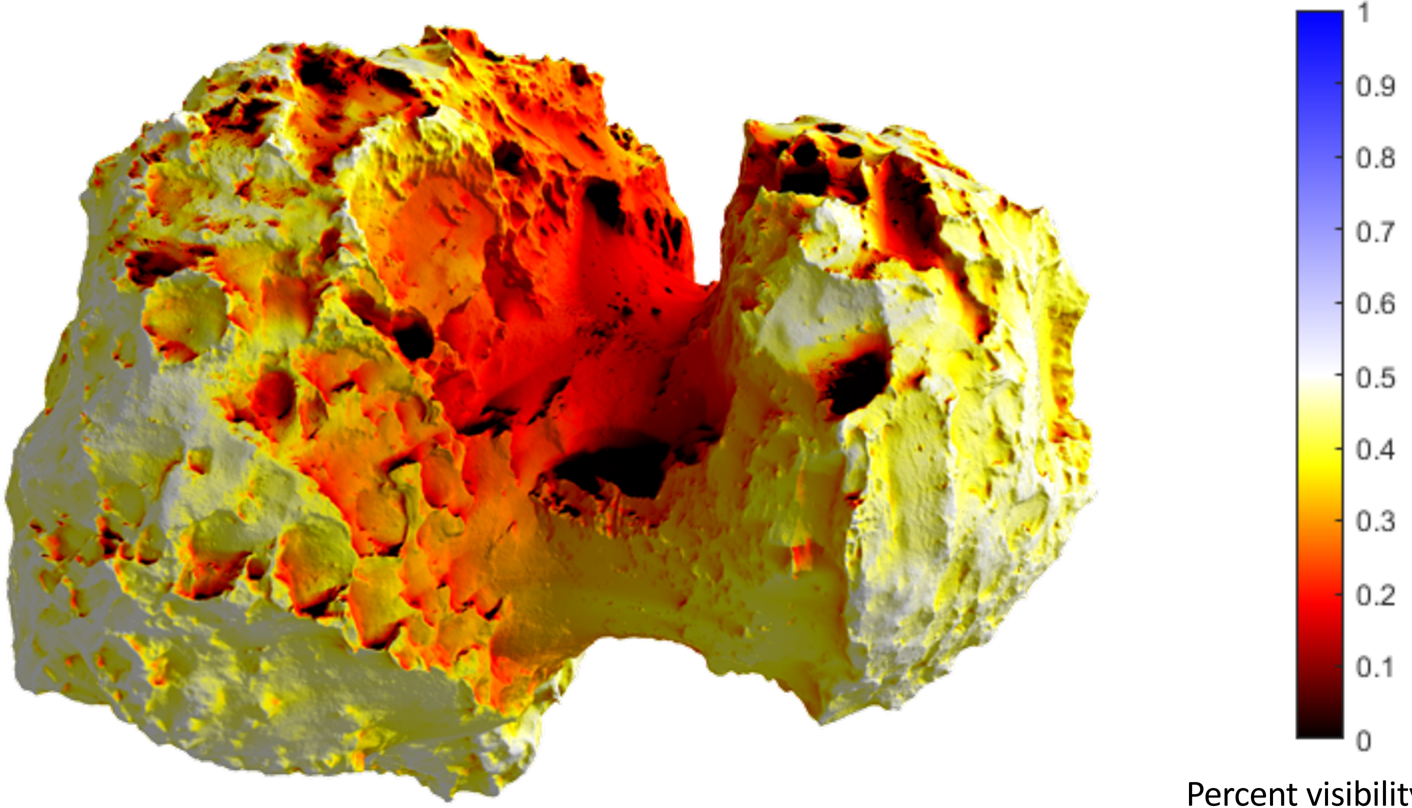
Hazard Assessment: Slope



Local surface slope
(capped at 45°)

Credit: B. Hockman

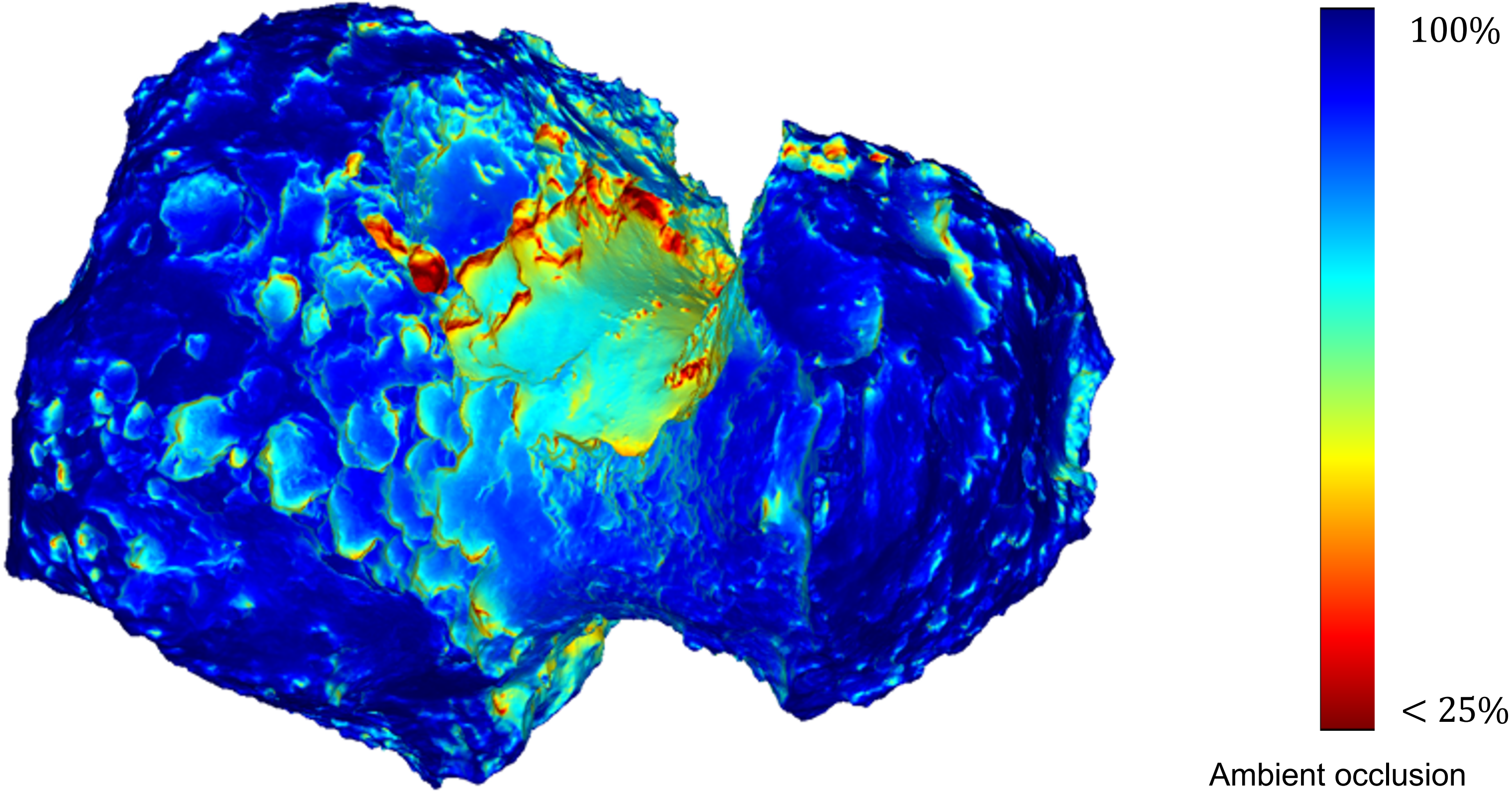
Hazard Assessment: Diurnal visibility *(for solar power and comm)*



Percent visibility of Sun at 0° latitude

Credit: B. Hockman

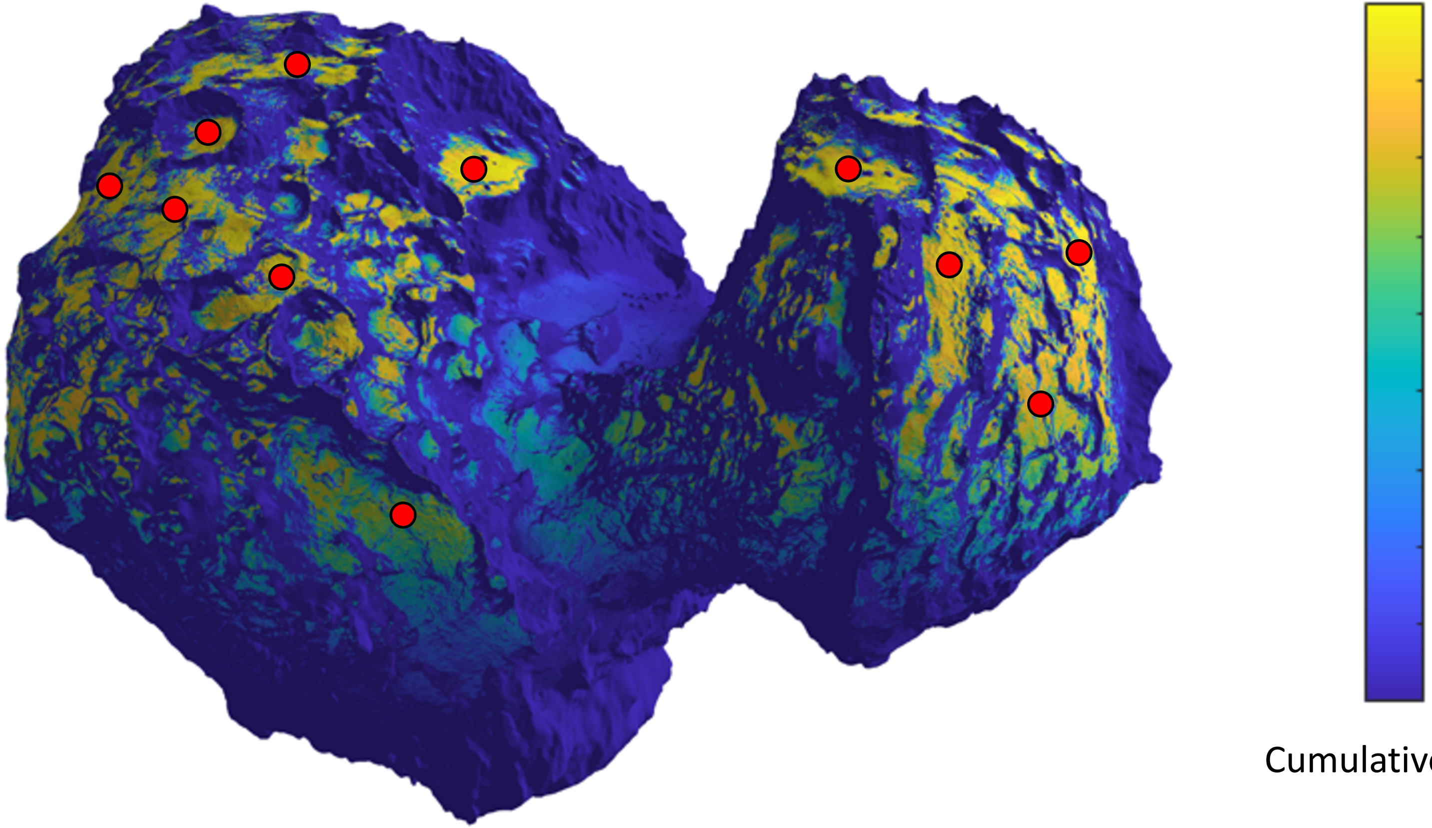
Hazard Assessment: Ambient occlusion *(sky visibility thermal proxy)*



Ambient occlusion map of Comet 67P

Credit: B. Hockman

Hazard Assessment: Ambient occlusion *(sky visibility thermal proxy)*



Credit: B. Hockman

Summary

- Investigated accessibility of NEOs using autonomous SmallSat
- Developed (1) an perception-rich *estimation pipeline*, (2) a notional *spacecraft architecture* for landing , and (2) high-fidelity *simulation tools*
- Simulated two end-to-end autonomous approach experiments
- Initial results indicate promise but further refinement of the pipeline and tools is needed
- Developing, maturing, and assessing performance of key capabilities
- Testing on a range of bodies

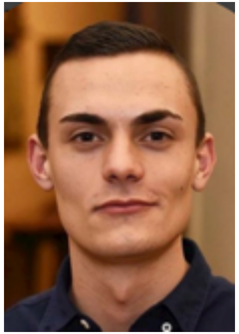
Publications and References

- B. Morrell, J. Villa, S. Bandyopadhyay, D. Lubey, B. Hockman, S. Bhaskaran, D. Bayard, and I.A. Nesnas, “Automatic Feature Tracking on Small Bodies for Autonomous Approach,” AIAA ASCEND 2020
- J. Villa, S. Bandyopadhyay, B. Morrell, B. Hockman, A Harvard, S. Chung, S. Bhaskaran, I. A. Nesnas, "Optical Navigation for Autonomous Approach of Small Unknown Bodies," 43rd Annual AAS GNC Conf, Breckenridge, Colorado, 2020
- S. Papais, et al., “Architecture Trades for Accessing Small Bodies with an Autonomous Small Spacecraft,” IEEE Aerospace Conference, Montana 2020

Meet the Team


Saptarshi Bandopadhyay (Co-I)


David Bayard (Co-I)


Michele Bersani (student intern)


Shyam Bhaskaran (Co-I)


Ben Hockman (Co-I)


Ben Jarvis (student intern)


Andrew Johnson (consultant)


Reza Karimi


Dan Lubey (Co-I)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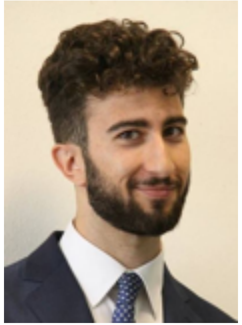
Sandro Papais (student intern)


Jacopo Villa (student intern)