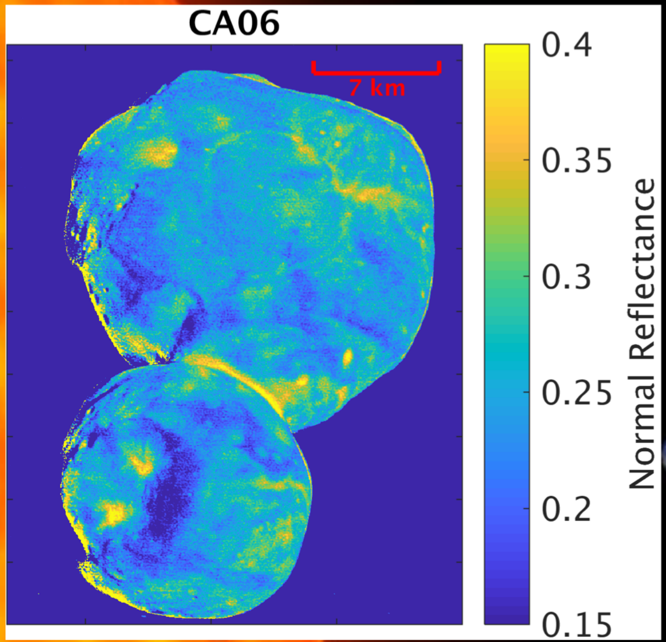
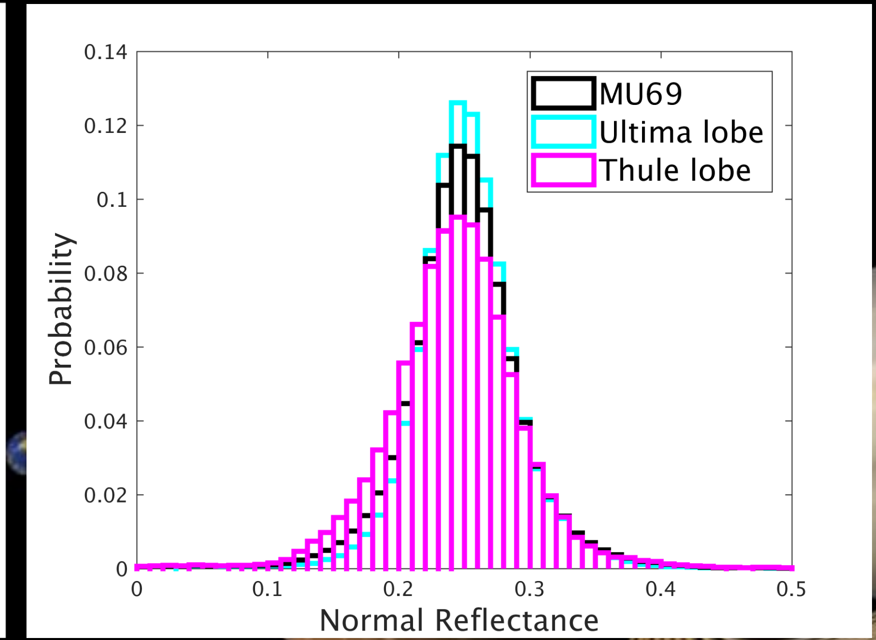
Jet Propulsion Laboratory
California Institute of Technology

Arrokoth (2014 MU69) Photometry

Hofgartner J. D., et al.





New Horizons spacecraft flew by cold classical Kuiper belt object Arrokoth (2014 MU69) on 01/01/2019, possibly the most primitive object ever explored by a spacecraft

Geometric Albedo: $0.21^{+0.05}_{-0.04}$ **at 550 nm**

Bond Albedo: 0.062 $\pm$ **0.02**

Geometric albedo is greater than the median but consistent with a distribution of cold classical Kuiper Belt Objects

Similar normal reflectance distributions of the two lobes is consistent with co-formation and co-evolution

Hofgartner et al., Photometry of Kuiper Belt Object (486958) 2014 MU69 from New Horizons LORRI, Icarus, in revision

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Cryohydrologic Landforms May Exists Within Complex Craters on Ceres

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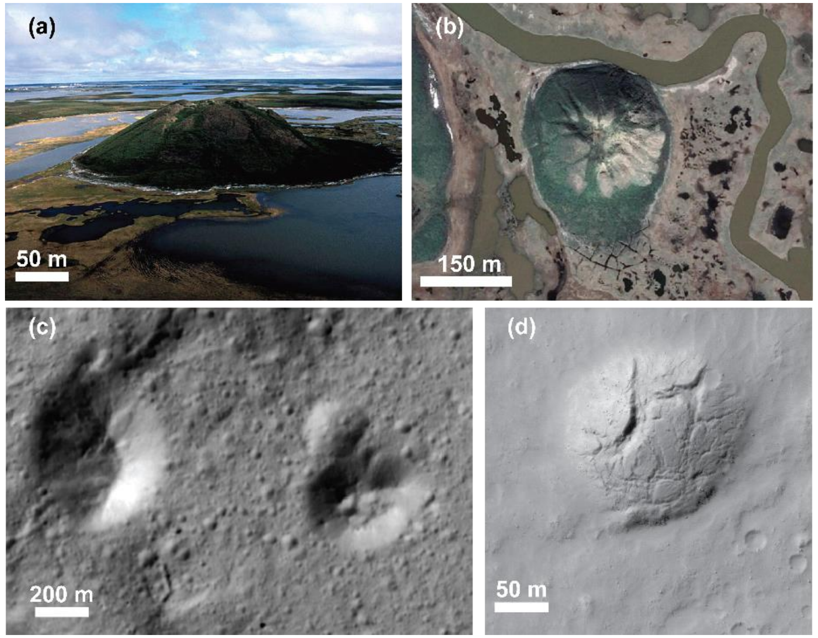
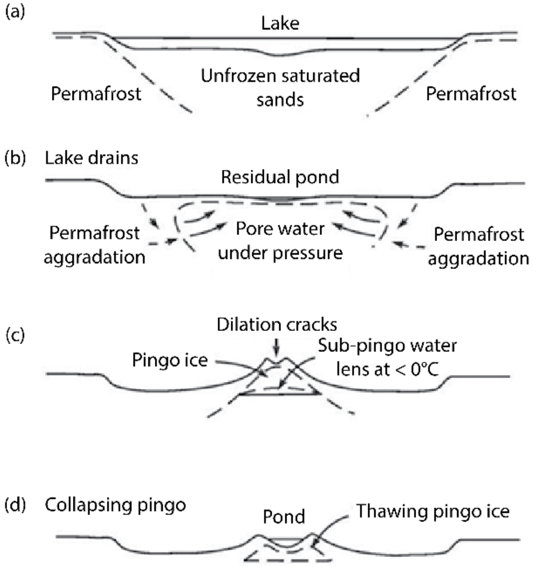
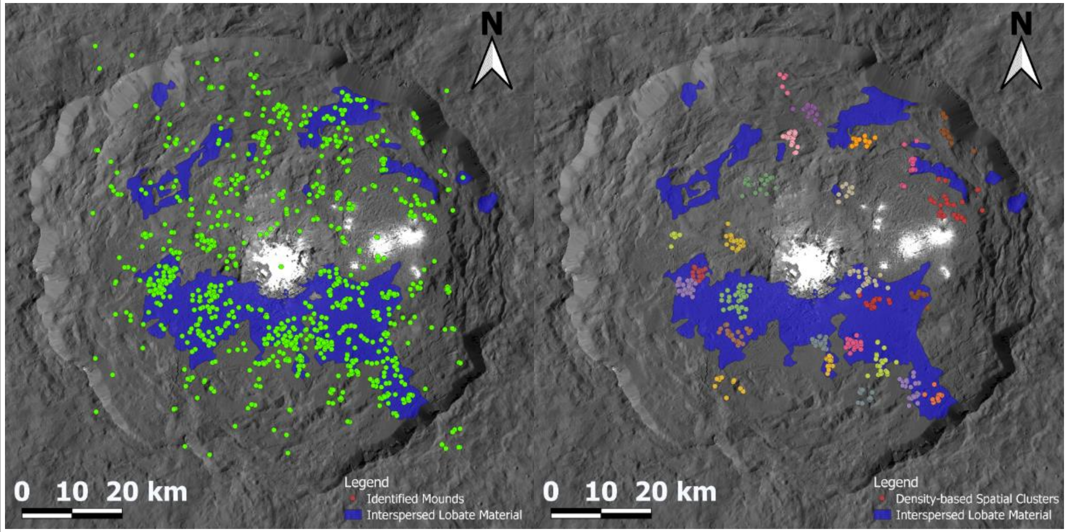
- Pingos are abundant landforms in periglacial terrains on Earth
- Numerous pingo-like morphologies are seen on Mars, and now Ceres
- Determining their nature is paramount to understanding the hydrologic processes, resources, and astrobiological potential of these planets



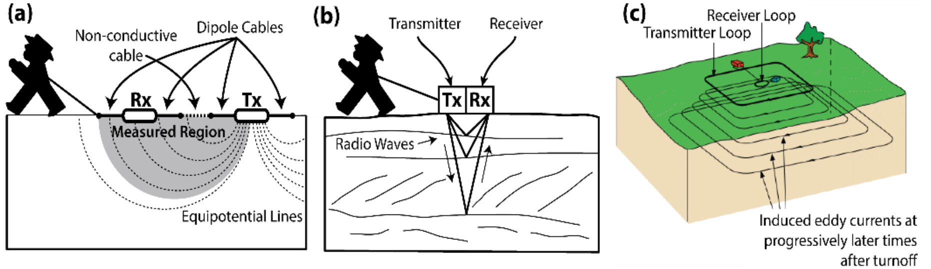
- On Earth, a pingo is an ice-cored hill formed in permafrost environments by the injection and freezing of pressurized groundwater



Adapted from Mackay [1998]



- Using mapping and machine learning we identified over 1,000 small intra-crater mounds on Ceres
- They often cluster by morphology and favor impact melt units



- Future landed investigations are needed to determine their nature
- Geophysical studies of terrestrial pingos will help prepare us for exploring alien ground ice

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- Member of the Solar System Dynamics (SSD) Group and CNEOS at JPL.
- Developed the JPL Small-Body Mission-Design System (https://ssd.jpl.nasa.gov/?mdesign)
- Implementing new version of the impact monitoring system Sentry.
- Support NHATS updates and maintenance.
- Operational support: orbit determination system, Small-Body Database, fireball reports.

Research interests:

- Orbital mechanics, numerical integration methods, N-body systems, mission design, uncertainty propagation, orbit determination.

Background:

- PhD in Aerospace Engineering from the Technical University of Madrid, Spain.
- Postdoctoral researcher at JPL and Princeton University, collaborated with IAS.

BRIDGE to the stars: A mission concept to an interstellar object

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Motivation

In this concept study, we propose *Bridge:* a flyby mission of an interstellar object (ISO) as it passes through our Solar System.

ISOs have the potential to address high-priority topics such as: the **chemical, physical, & biological differences between stellar systems**, as well as the **processes that shape solar system evolution** throughout the universe. Studying ISOs thus can aid in constraining solar system formation scenarios.

Science Goals

A. Can prebiotic chemical ingredients be dispersed between stellar systems and the interstellar medium?

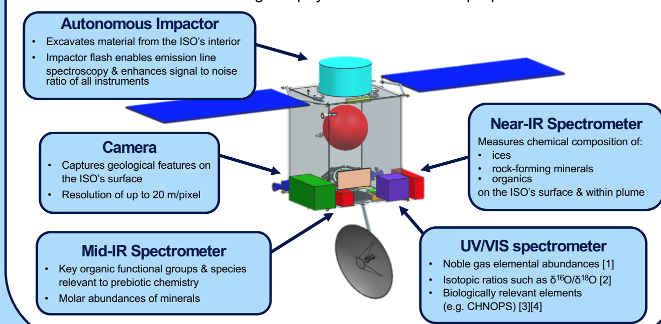
B. Do interstellar objects form via the same processes that created objects within our solar system?

Science Objectives

1. **Determine whether the ISO formed in an environment with chemical composition similar to our solar system.**
2. **Determine whether the ISO contains prebiotic ingredients.**
3. **Determine if processes in extrasolar systems lead to bodies similar to those found in our solar system.**

Instruments

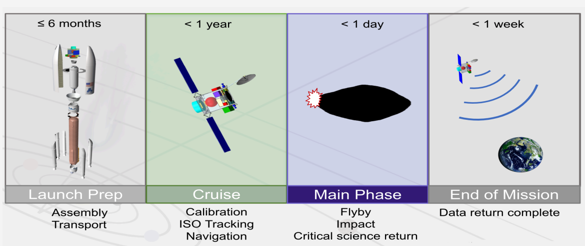
The target ISO's properties and trajectory will only be known a few months before launch, requiring an instrument suite capable of characterizing a variety of objects with a wide range of physical and chemical properties.



Mission Design

Missions to ISOs pose unique challenges:
Since ISO's travel with large heliocentric velocities, spacecraft must be designed/built for an as-yet undiscovered target

- **We utilize a flyby/intercept mission architecture for Bridge.**
- Spacecraft stored until viable ISO selected (3-5 years)
- Target selection criteria:
  - ✓ Inner solar system interception within 0.7-2 AU from Sun
  - ✓ Relative encounter velocity of <70 km/s



Cost Breakdown

Fits comfortably within New Frontiers ~$1B cost cap

Cost Summary (FY 2019)	Reserves	Cost (M)
Project Cost	**43%**	**$973.1**
Launch Vehicle Capability (penalty)	0%	$22
Development cost (Phase A-D)	**46%**	**$930.1**
Phase A		$4.0
Phase B		$86.8
Phase C/D		$817.3
Operations Cost (Phase E-F)	**15%**	**$43.0**

Policy Recommendations

To enable a mission to an ISO, the community will need to advocate for two specific changes to future NASA AO's.

1. **Long-term spacecraft storage**
   - *Bridge waits in ground storage until discovery of a suitable ISO (~0 to 7yr).*
   - *Under current NASA guidelines, it's not permitted to propose a spacecraft that explicitly requires ground storage [5]*

✓ **Recommendation 1: Modify the New Frontiers AO to allow for multiple years of pre-planned spacecraft storage.**

2. **Rapid/responsive launch capabilities**
   The ability to launch in response to an ISO discovery greatly increases the percent of reachable ISOs.

✓ **Recommendation 2: NASA HQ should investigate rapid launch capabilities for future missions.**
(detection-to-launch turnaround time 3 to 6 months)

References: [1] Almandos and Raineri (2007), *Atoms* 5, 12. [2] Hutsemékers et al. (2008), *A & A* 490, L31 - L34. [3] Robert et al. (2016), *Planetary and Space Science* 124, 94 - 104. [4] McClintock et al. (2015), *Space Sci Rev* 195, 75 -124. [5] NASA. (2016) Announcement of opportunity: New Frontiers 4.

Acknowledgements: We would like to thank L. Lowes and J. Armijo for their coordination of the PSSS program, R. Wessen for leading the A-Team sessions, A. Nash and Team X for their expertise. We'd like to thank NASA Planetary Science Division, & NASA's Radioisotope Power System program for financial support of the program.

Themis Family Tour: Journey into a differentiated, ice- and organic-rich asteroid

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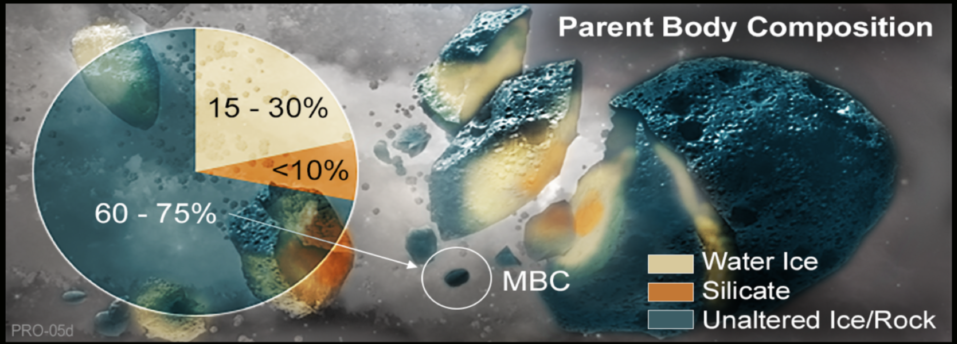
1. JPL, California Institute of Technology 2. LASP, University of Colorado 3. Georgia Institute of Technology 4. Planetary Science Institute 5. APL, John Hopkins University

Goal: The Oracle Mission would reveal physical and chemical processes of internal evolution in large icy planetesimals by studying multiple members of the Themis family with rendezvous at 24 Themis and flybys of multiple family members (including at least one known active asteroid)

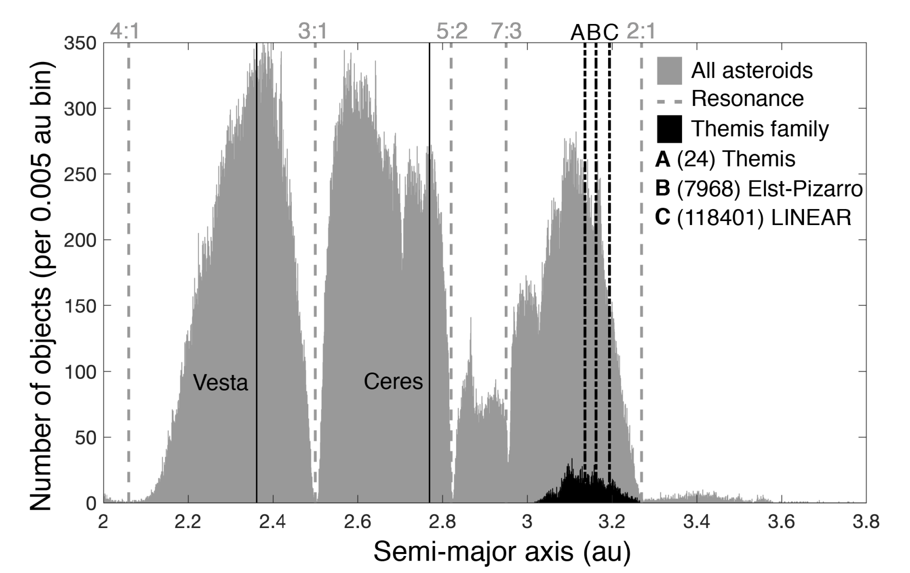
Proposed Instrumentation: Camera, IR Spectrometer, Gamma Ray and Neutron Spectrometer, Magnetometer, radiometer, Mass spectrometer, Radar



Meech and Raymond (2020)

Key Questions:

1. Did evolved, ice-rich protoplanets form in situ?
2. Via what processes did the interiors of ice-rich protoplanets evolve, and did they undergo significant ice/rock fractionation?
3. What processes occur on the surfaces of Themis family members, and how do they compare to those surfaces of comets?
4. Where and how were water and organics distributed throughout the Themis parent body?
5. Is the 3 micron absorption on Themis' surface from surficial water ice?
6. Does exogenic organic contamination play a large role on the surfaces of asteroids?

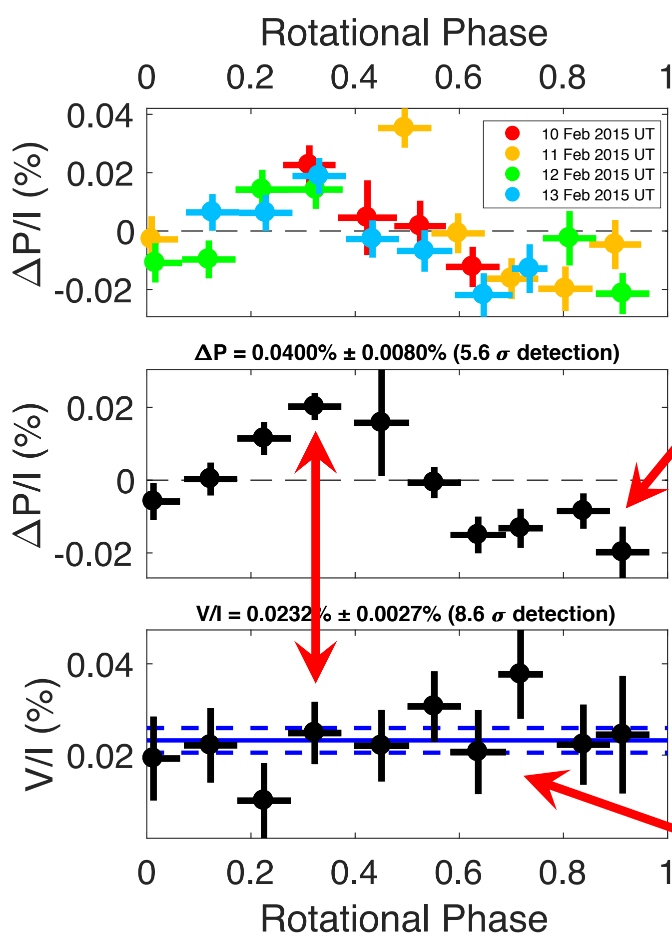


Histogram of asteroids from the IAU Minor Planet Center catalog. Themis family members from the PDS archive.

Rotation-Resolved Linear and Circular Polarimetry

Sloane Wiktorowicz, The Aerospace Corporation

(7) Iris, N. Hem., 2015



Large ΔP (spots), strong V but weak ΔV (const. metals?)

Weak ΔP (featureless), strong V and strong ΔV (varied metals?)

$V_{mean} >> 0$

(7) Iris, S. Hem., 2017