Ross (née, CAESAR)

PSDS3 Workshop

Beau Bierhaus[1], Josh Hopkins[1], Ben Clark[1,2], Robert Jedicke[3], Michael Ravine[4], Driss Takir[5]

[1]Lockheed Martin, [2]Space Science Institute, [3]University of Hawaii, [4]Malin Space Science Systems, [5]SETI

18 March 2018

LOCKHEED MARTIN

CAESAR Renamed for Mary Ross

- Our mission was originally named CubeSat Asteroid Encounters for Science And Reconnaissance (CAESAR)
- A comet mission selected for New Frontiers Phase A is also named CAESAR
- To avoid confusion, we changed our mission name to Ross
- Mary G. Ross was an engineer at Lockheed from 1942-1973, and one of the first American Indians in aerospace engineering
  - She worked on P-38 aerodynamics, Constellation aeroelasticity, Polaris hydrodynamics, the Agena rocket, and interplanetary trajectory design to Mars and Venus
  - We honor her trailblazing role and her contributions to orbital mechanics with this mission

Image courtesy of Society of Women Engineers National Records, Walter P. Reuther Library

Ross Mission Overview

Study objective

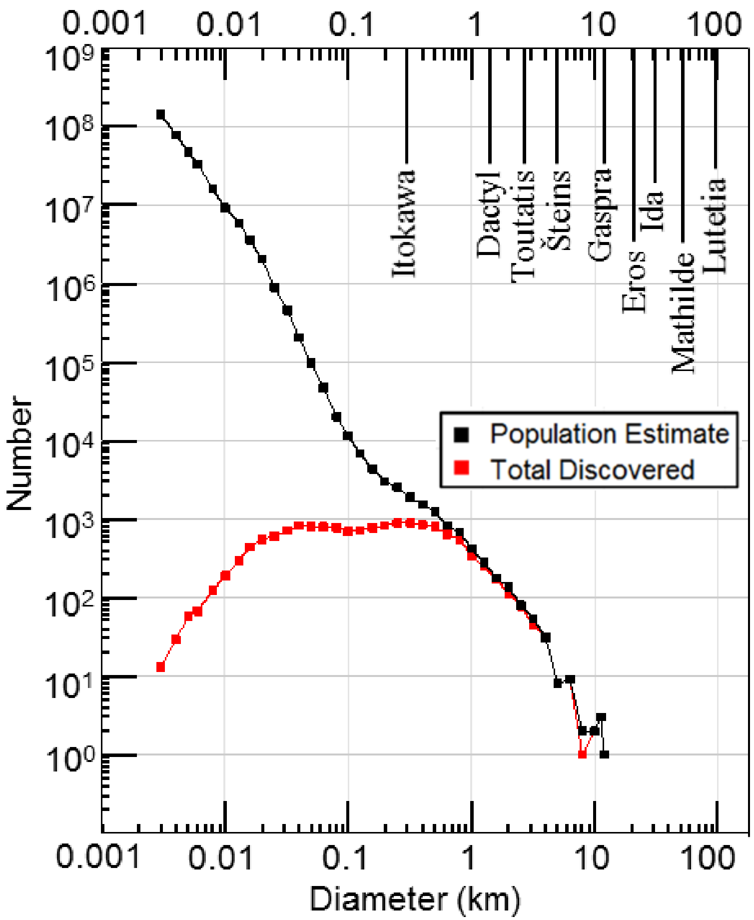
- **Demonstrate that a fleet of small, low-cost spacecraft provides an affordable means to explore an incredibly diverse small-body population via flybys**

Why flybys?

- **A well-planned and executed flyby on an unexplored object provides a wealth of information on multiple fundamental physical parameters**
- **Flybys provide an excellent balance between valuable data and implementation with small-scale spacecraft**

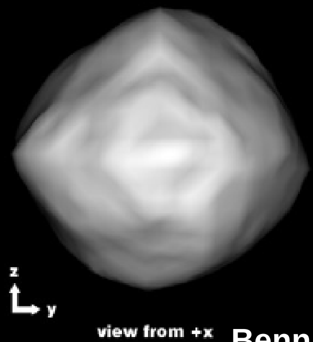
Numbers & Processes Matter

- ***Most objects in the solar system belong to a physical scale that has never been visited by spacecraft***
- **Small (< a few km) objects are . . .**
  - **The vast majority of planetary bodies (NEOs, MBAs, KBOs)**
  - **A window into early stages of planet formation**
  - **The greatest remaining unknown risk for Earth impact**
  - **Candidate targets for ISRU and / or human exploration**



Small asteroids are among the most numerous objects in the solar system

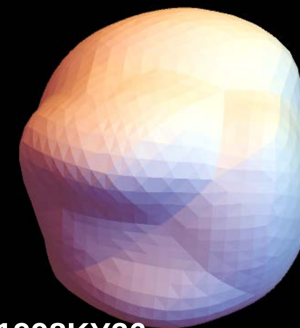
Why small NEOs?



Bennu

Ast. 153591

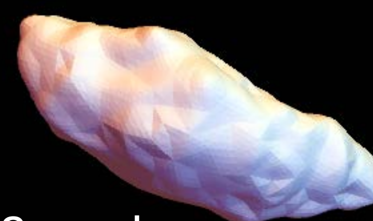
2008 EV5



1998KY26

Ra-Shalom

Itokawa



Geographos

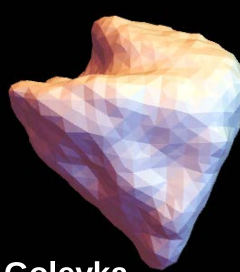
Bacchus

Castalia

1996HW1

1998ML14

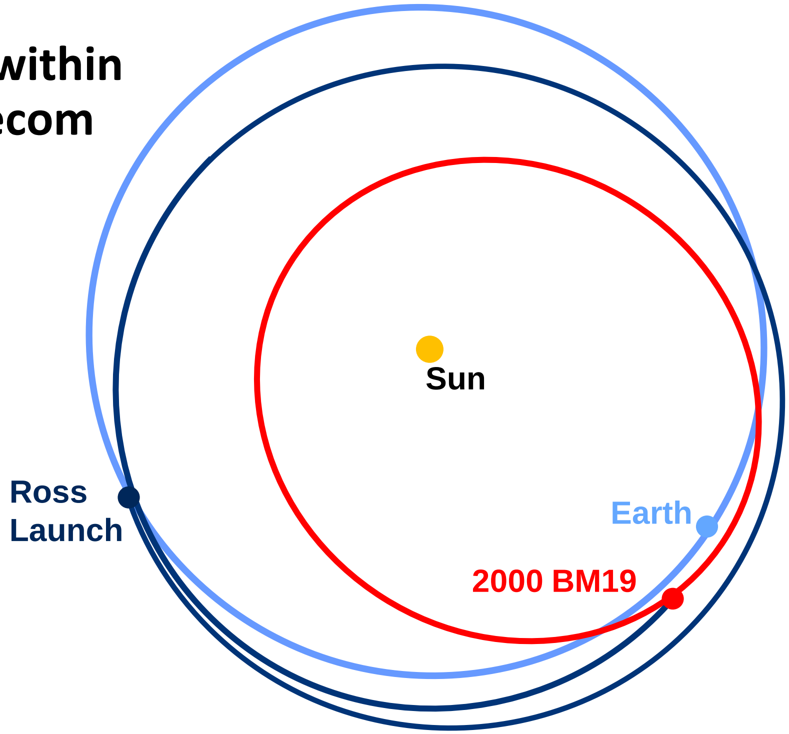
YORP



Golevka

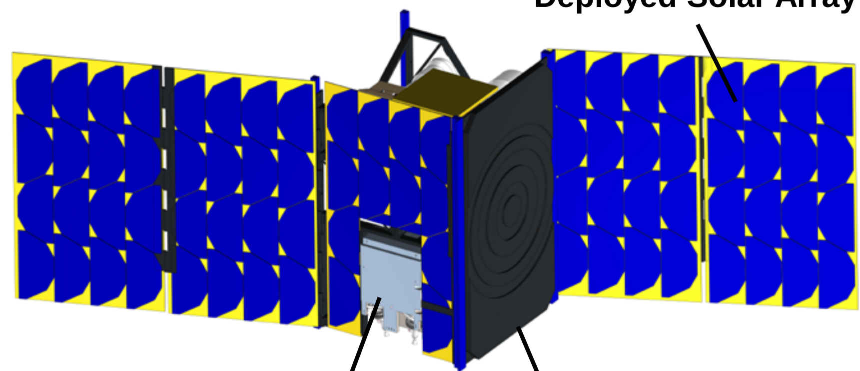
Mission Architecture

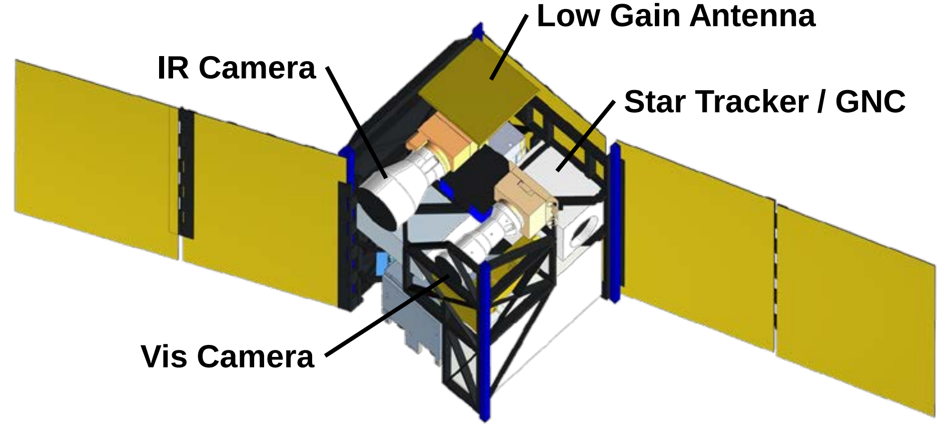
- Multiple identical CubeSats launch as secondary payloads on the same launch.
- Each CubeSat targets one flyby of a different NEO. Asteroid 2000 BM19 used as an example throughout this presentation.
- CubeSats reside in heliocentric orbit before encounter
  - Dozens of feasible targets with low ΔV
  - 1 year phasing orbit keeps spacecraft within ~0.7 AU of Earth, which simplifies telecom
- Feasible target selection considers:
  - Mission duration & ΔV
  - Encounter velocity & phase angle
  - Earth range at encounter
  - Max Earth & Sun range in cruise
  - Asteroid size, orbit determination
  - Science merit of target



Spacecraft Configuration

- **12U spacecraft, compatible with rail or tab dispensers**
  - **24 kg launch mass with margins**
- **Two science cameras**
  - **Malin ECAM visible**
  - **Malin IR3 microbolometer**
- **X-band telecom: IRIS v2 radio and high-gain + low gain patch antennas**
- **Green propellant propulsion system from VACCO**
- **Deployed, non-gimbaled solar arrays**



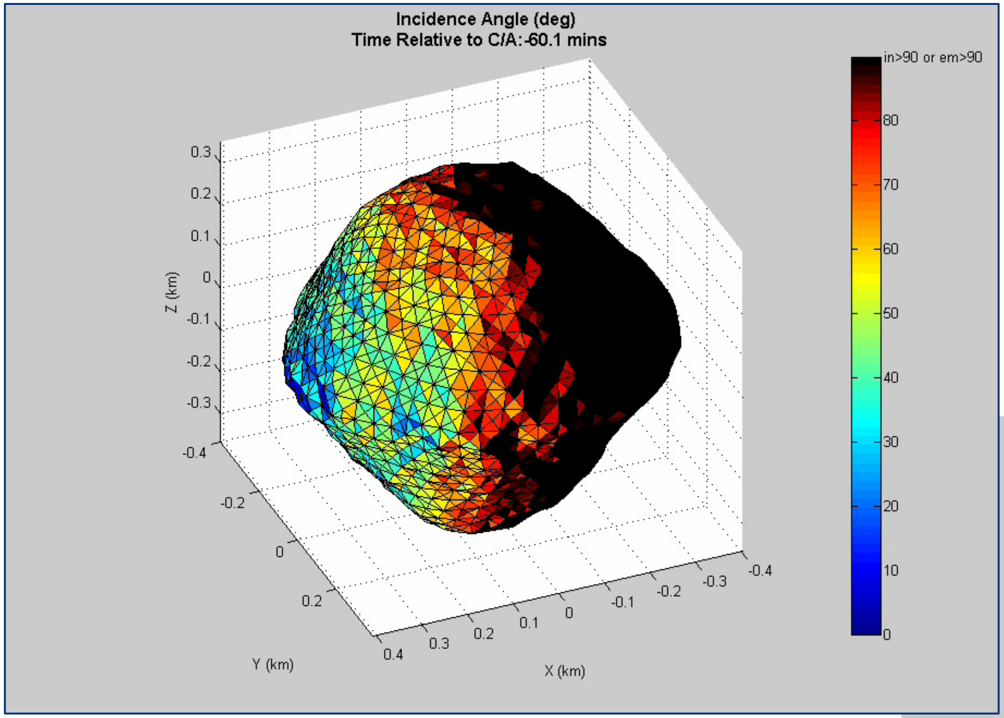


Overall Concept of Operations

- Simple, low-activity operations during cruise prior to encounter
  - Periodic system check-outs and status
- Observe target several hours before closest approach
  - science observations (next slides)
  - Refines ephemeris
- Update flyby timing based on point-source observations
- Conduct flyby observations (next slides)
- Data downlink after flyby observations end


Time (UTCG): 6 Mar 2023 21:20:02.410
Solar Phase Angle (deg): 62.207
BM19 Range (km): 808.364437
Earth Range (Au): 0.206875
Sun Range (Au): 0.979669
White box is VIS camera FOV
Red box is IR camera FOV
LOCKHEED MARTIN

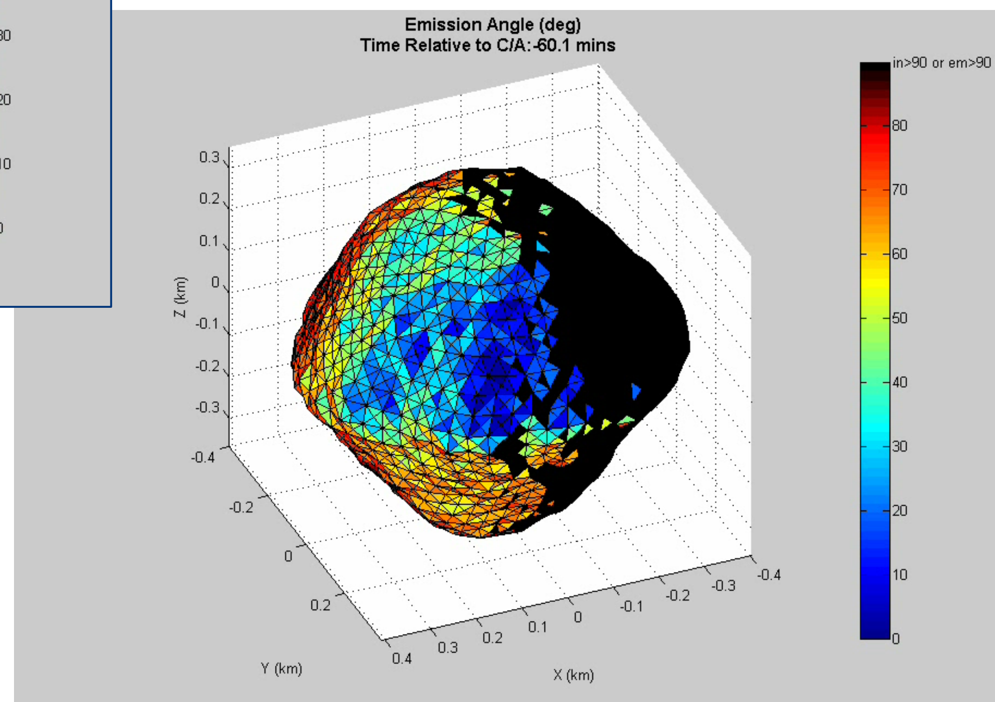
Shape Matters



Incidence angle animation

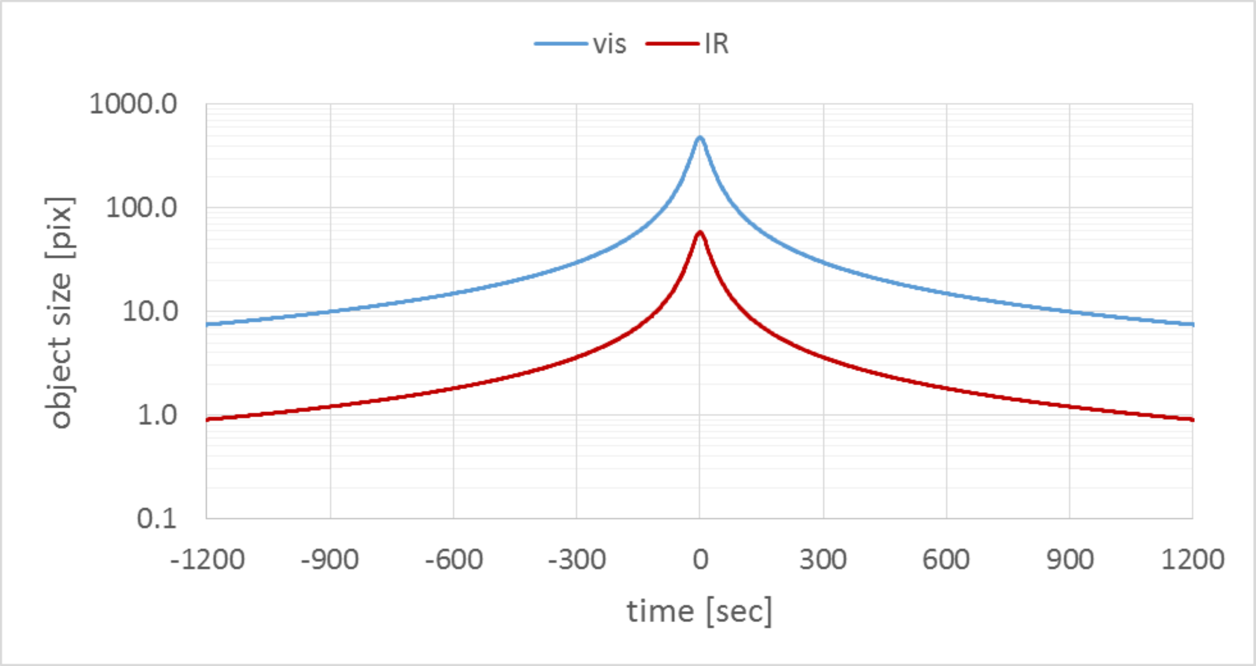
We developed tools to evaluate irregular shapes and optimize science-data acquisition

Emission angle animation



Encounter Performance (2000BM19)

474	pix	Maximum object size in pixels in visible
2.53	m/pix	Best pixel scale in visible
57	pix	Maximum object size in pixels in IR
20.90	m/pix	Best pixel scale in IR



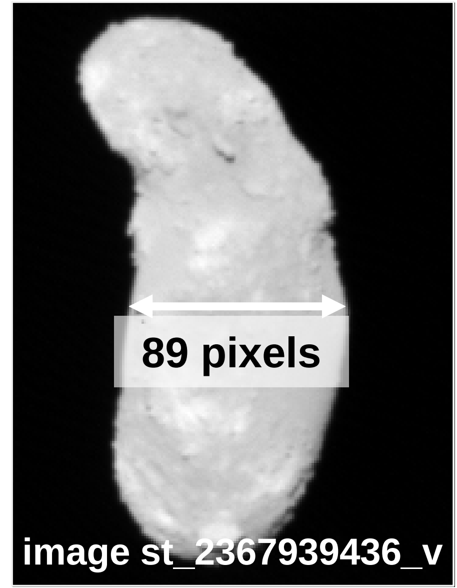
For a closest-approach distance of 125 km

How does this compare with existing asteroid data sets?

Itokawa

enveloping pixel dimensions of object: white box
height: 186 pixels
width: 97 pixels

height: 167 pixels
width: 111 pixels

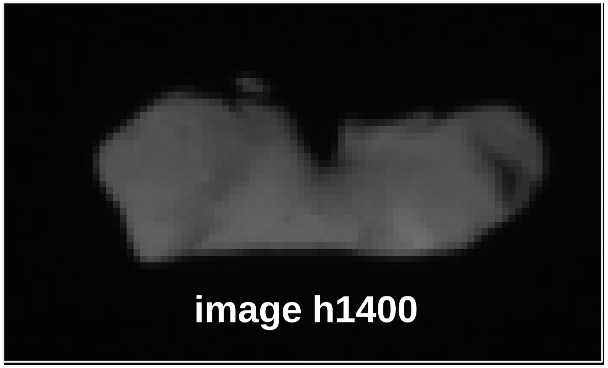


height: 224 pixels
width: 111 pixels

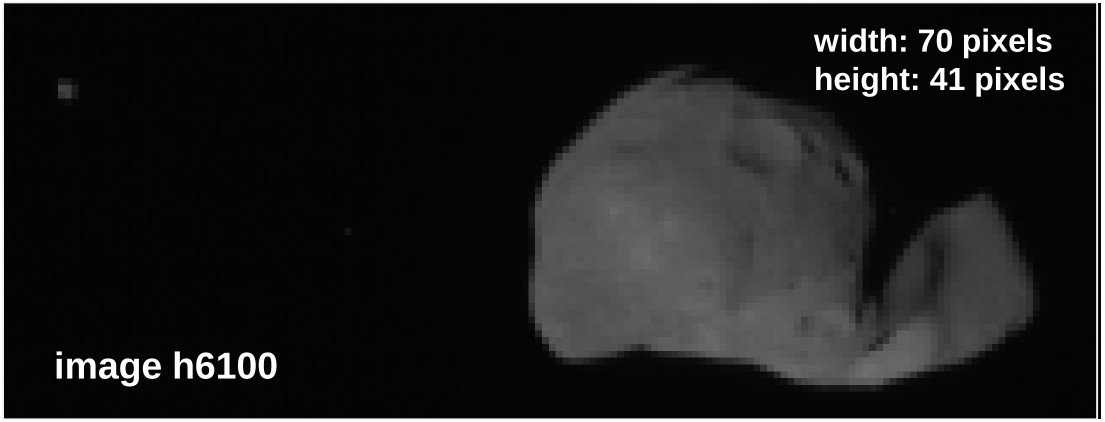
height: 154 pixels
width: 108 pixels

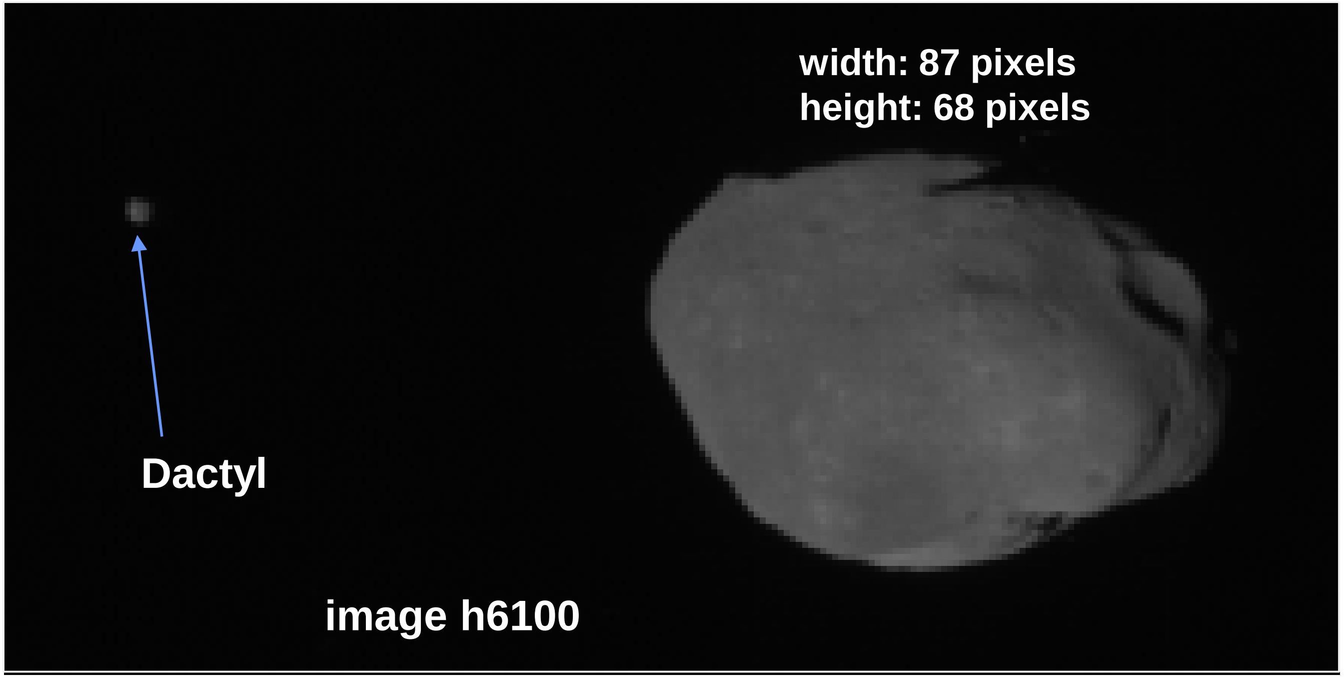
height: 156 pixels
width: 100 pixels

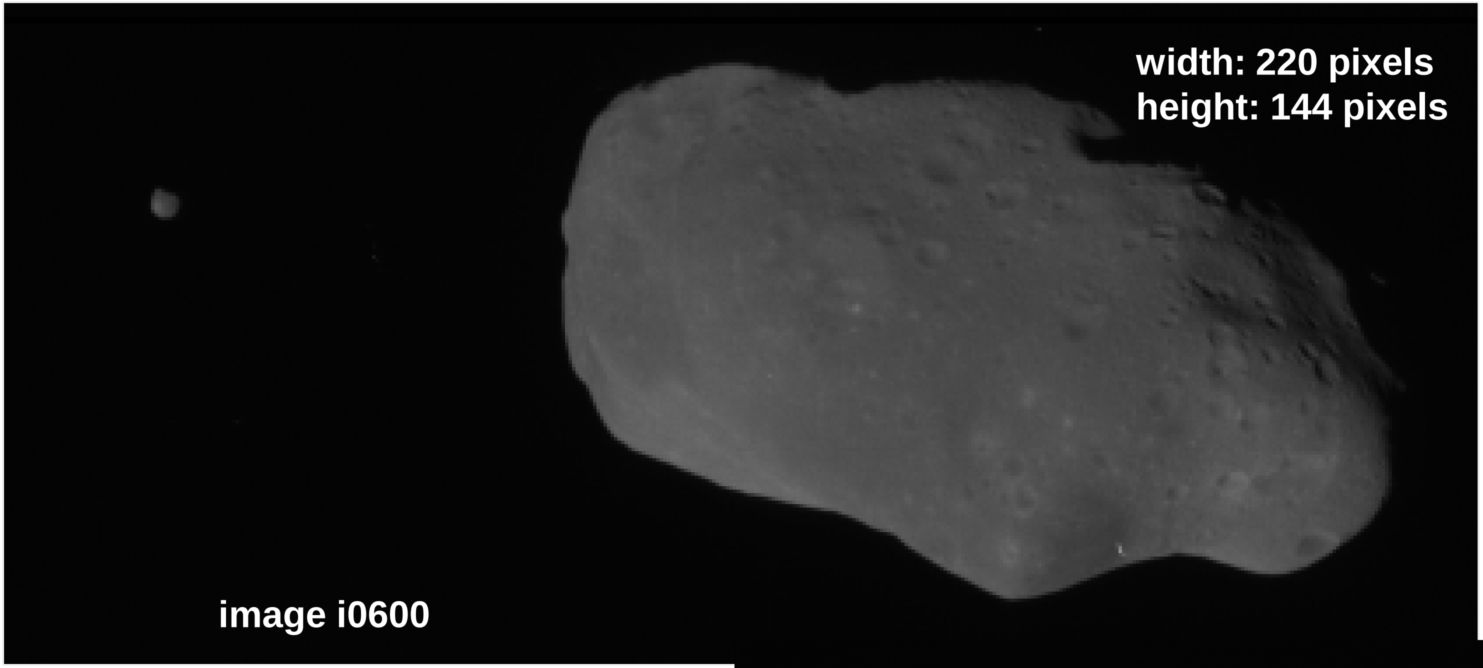
Ida (and Dactyl)

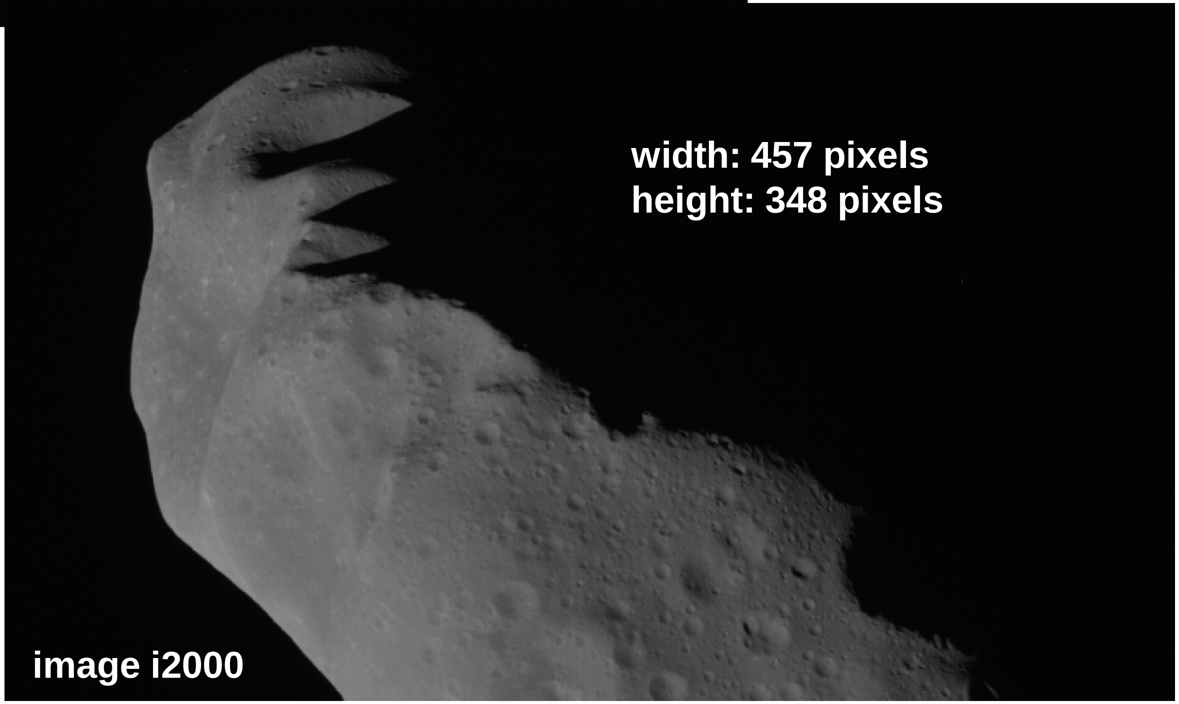


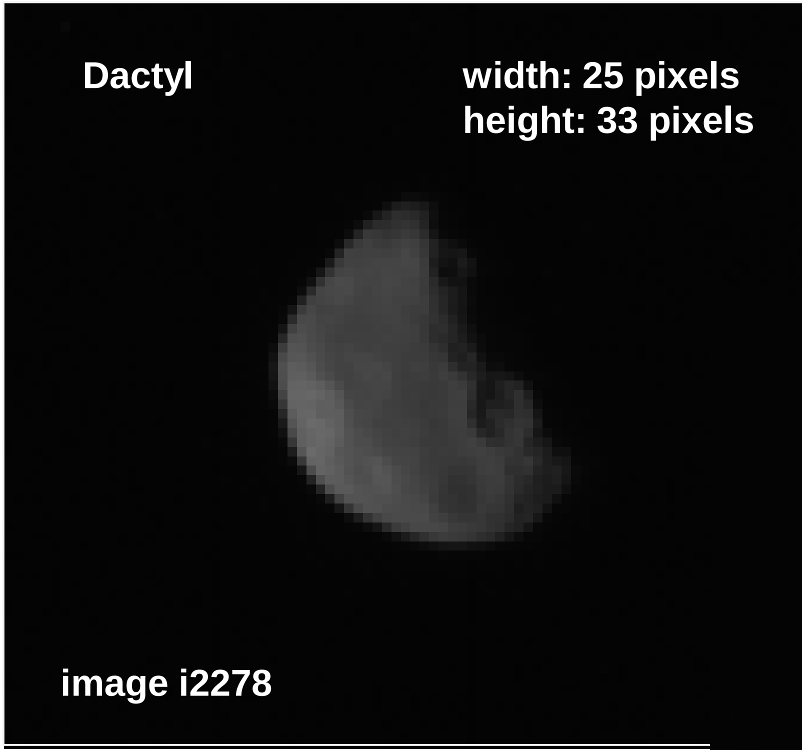
enveloping pixel dimensions of object
width: 58 pixels
height: 23 pixels

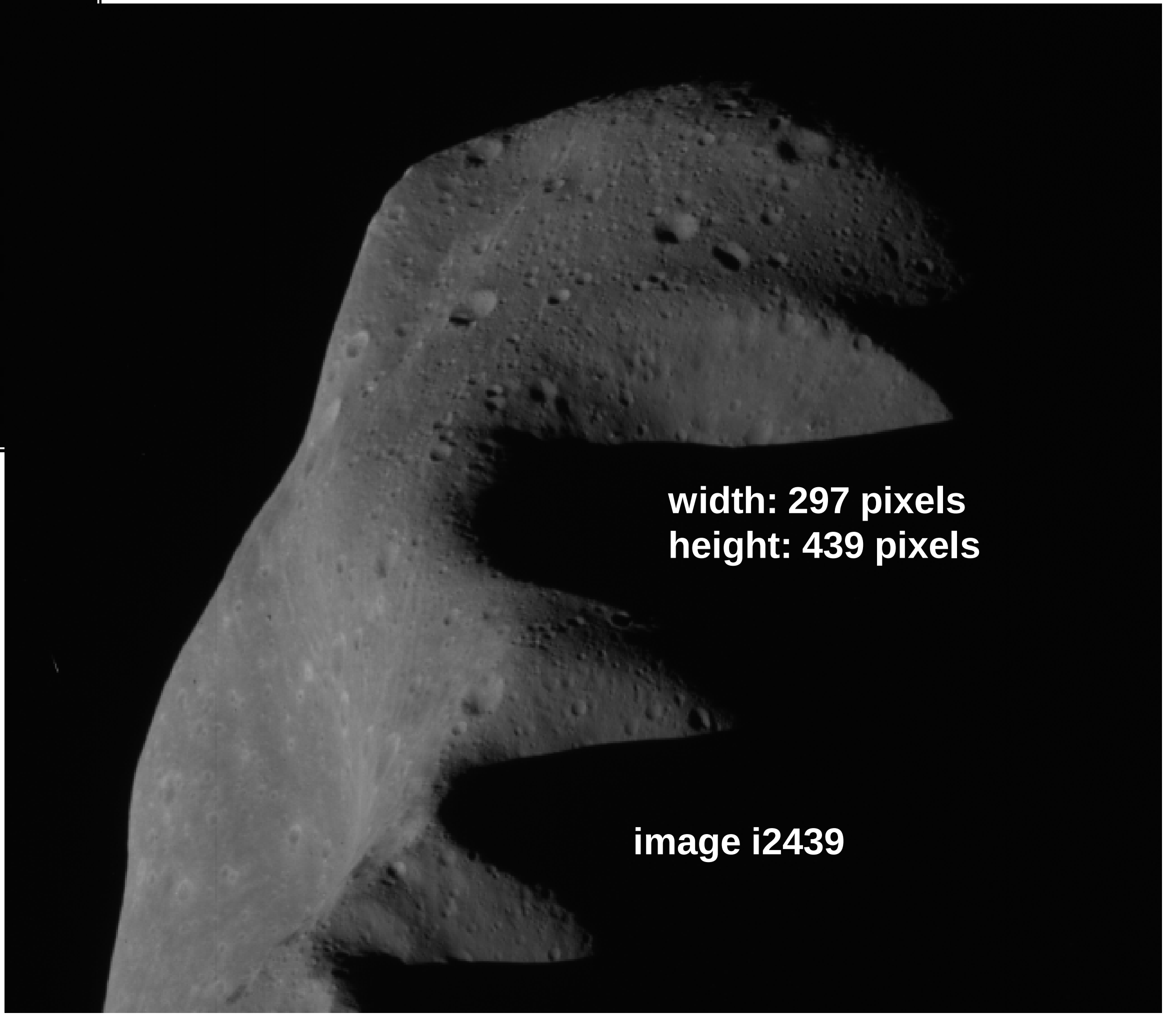





width: 220 pixels
height: 144 pixels
image i0600


width: 457 pixels
height: 348 pixels
image i2000


Dactyl
width: 25 pixels
height: 33 pixels
image i2278

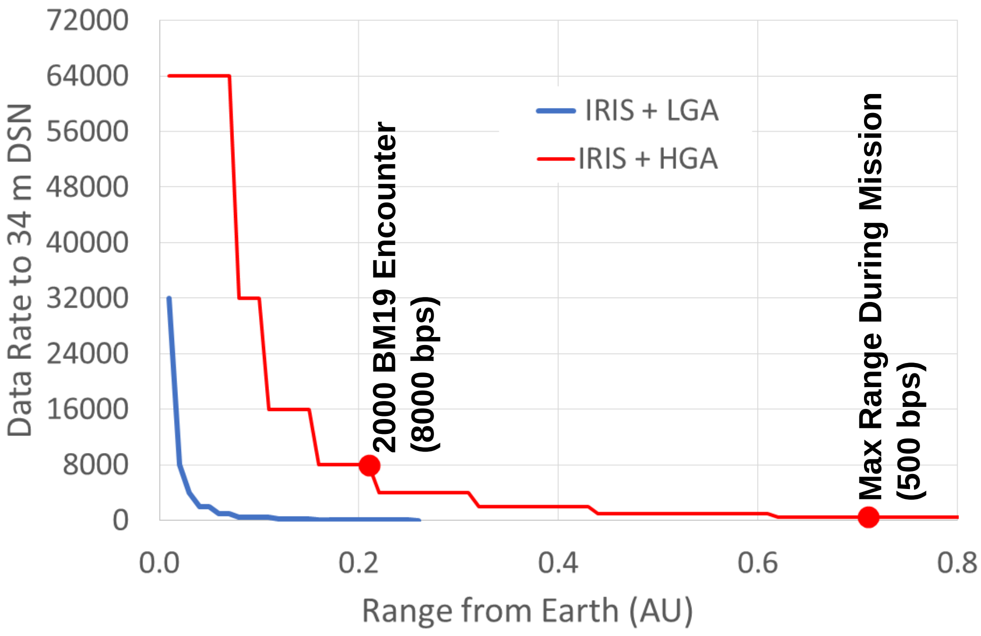

width: 297 pixels
height: 439 pixels
image i2439

Ross Provides Data to Advance Planetary Science

- Ross flyby data provide the needed resolutions and coverage to address fundamental science objectives for size, shape, bulk properties, and fundamental surface processes
  - Significant contribution to small-body science, and planetary formation
- Flybys naturally provide a range of phase angles, incidence angles, and emission angles
  - High-phase angle imaging (typically approach and departure) provides shape and surface geomorphology
  - Low-phase angle imaging (typically near closest approach) provides information on albedo and shape
- Other discoveries possible: satellites, and other environmental effects
  - Dactyl was detected as a satellite when just a few pixels across

Telecom

- **Returning data from a planetary CubeSat is slow but feasible**
  - **Earth range is important**



- **Data downlink strategy leverages low-overhead, initial return of "thumbnail" images to:**
  - **Select highest priority images for return**
  - **Of those images, the "windowed subset" of each image that contains the object**
  - **Enables fully-informed decision making to return highest-priority images, and preserves all data for complete download in the future if contacts available**

Propulsion

- Even trajectories with near-zero nominal ΔV need a non-trivial propulsion budget
  - Correction for launch vehicle dispersions
  - Trajectory modifications across the ~3 week launch period
  - Statistical trajectory correction maneuvers
  - Reaction wheel desaturation
- Options considered:
  - cold or warm gas systems, insufficient impulse
  - electric propulsion, needs larger solar arrays with gimbals, has more mission ops complexity
- We selected a ~2U VACCO green monopropellant integrated propulsion unit, which provides higher thrust and sufficient Isp

Technology Development

- Receiver noise floor improvements
  - Current CubeSat radios do not have sufficient performance to receive DSN commands through omni-directional antennas. Improved noise performance would support more robust contingency scenarios.
- Ka-band development
  - Ka-band communications would improve data rates from size-constrained small spacecraft. However, CubeSat-class radios that support Ka-band from deep space have not yet finished development.
- Low power / high efficiency telecom
  - current low-power telecom systems tend to be least efficient

Summary

- Ross explores a largely unknown class of planetary object and returns compelling new observations, complementary to larger-scale missions
- We examined a broad range of tradespace, and have found small-body encounters that fit within CubeSat capabilities
- Though small in scale, these are fully functional planetary spacecraft and missions and need systems engineering, design, and test strategies appropriate to deep space missions

Copyright 2018 Lockheed Martin Corporation, All Rights Reserved