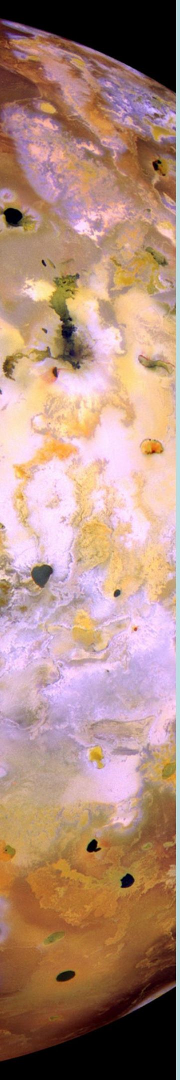
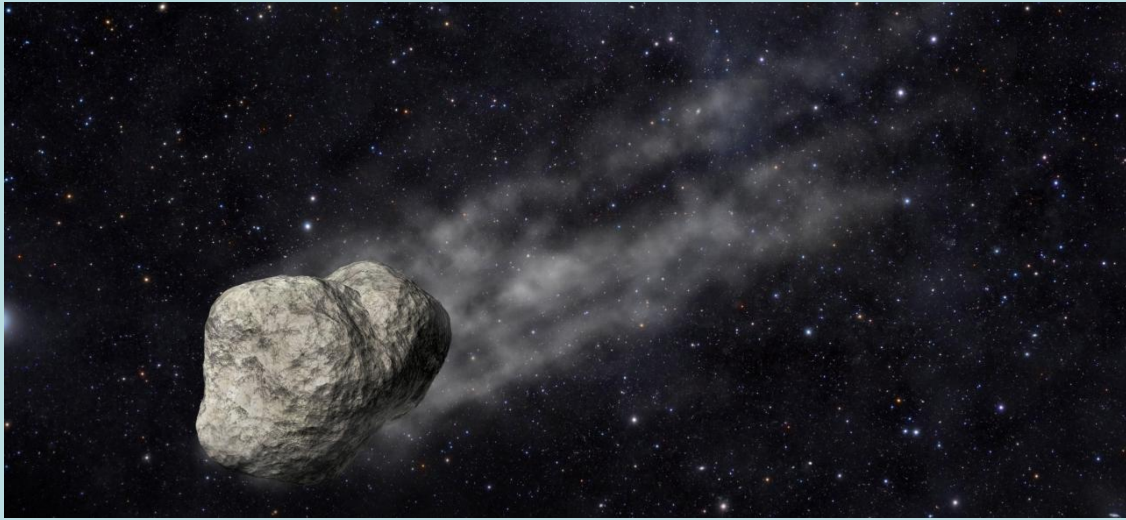
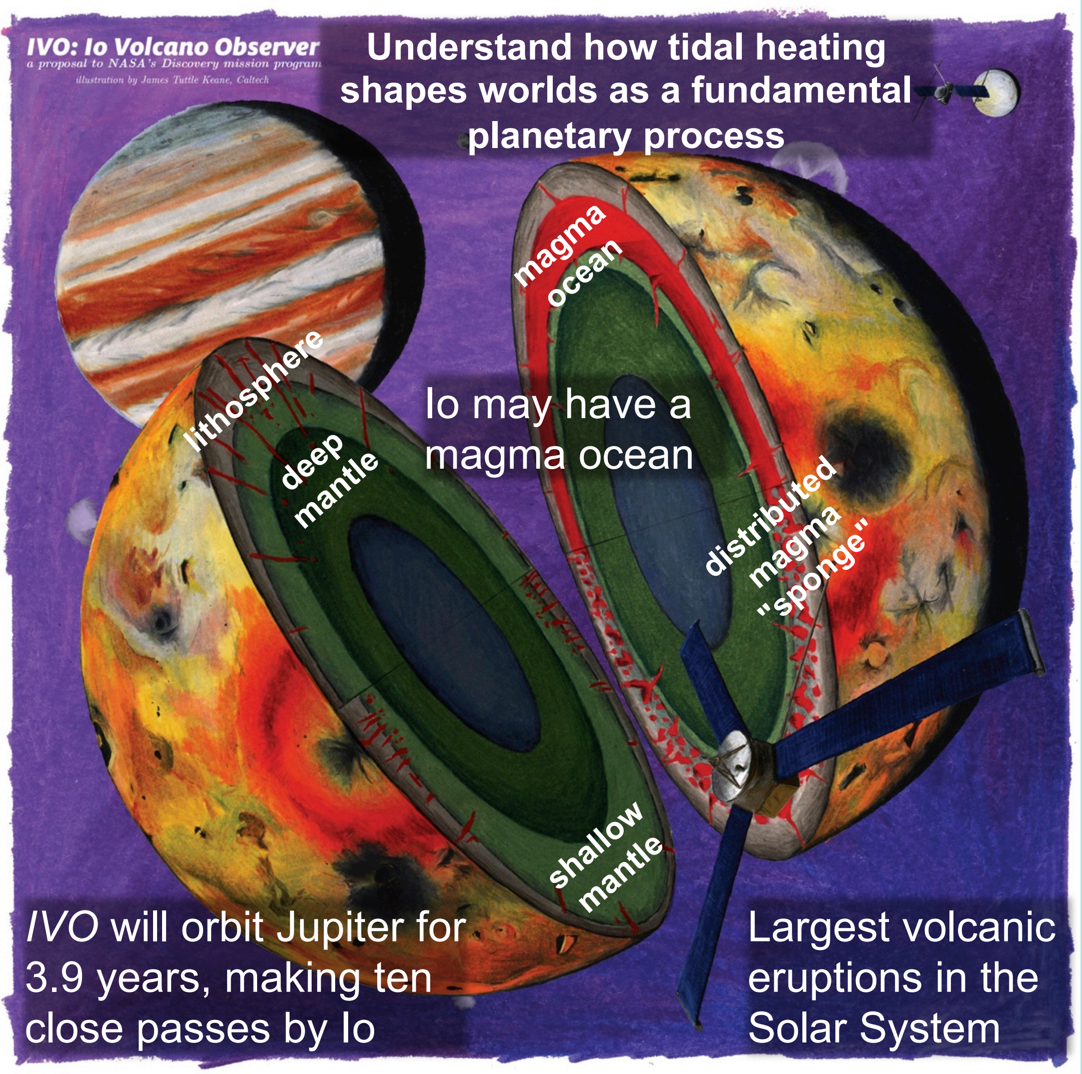


What could the Io Volcano Observer (in Discovery Phase A) do for the study of small bodies?

Alfred McEwen
UA/LPL
June 2, 2020 SBAG



Artistic representation of P/2012 F5 (Gibbs). / SINC



Io Volcano Observer (IVO): Follow the Heat!

IVO's primary goal is to "Follow the Heat" to understand how tidal heat (A) is generated, (B) is lost, and (C) drives the evolution of Io:

	SCIENCE OBJECTIVES:	KEY MEASUREMENTS:
A1	Determine the degree and distribution of melt within Io's interior	gravity, libration, magnetic induction, lava temperature + composition
B1	Determine Io's lithospheric structure	gravity, libration, magnetic induction, topography
B2	Determine where and how Io is losing heat	visible and thermal imaging
C1	Determine Io's orbit evolution	precision ranging from Earth
C2	Determine Io's volatile loss processes and rates	mass spectrometer, plasma measurements, imaging

University of Arizona: Principal Investigator Regents' Professor Alfred McEwen, science operations, student collaborations

Johns Hopkins Applied Physics Lab: Mission and spacecraft design, build, and management; Narrow-Angle Camera; Plasma Instrument for Magnetic Sounding

University of California Los Angeles: Dual Fluxgate Magnetometers

Jet Propulsion Lab: Radio science, navigation

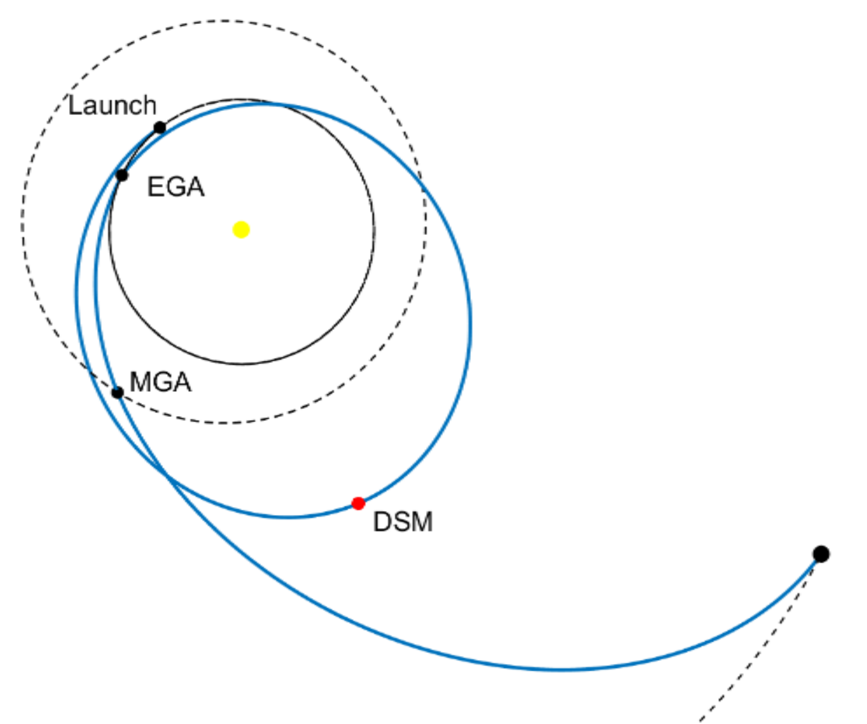
German Aerospace Center: Thermal Mapper

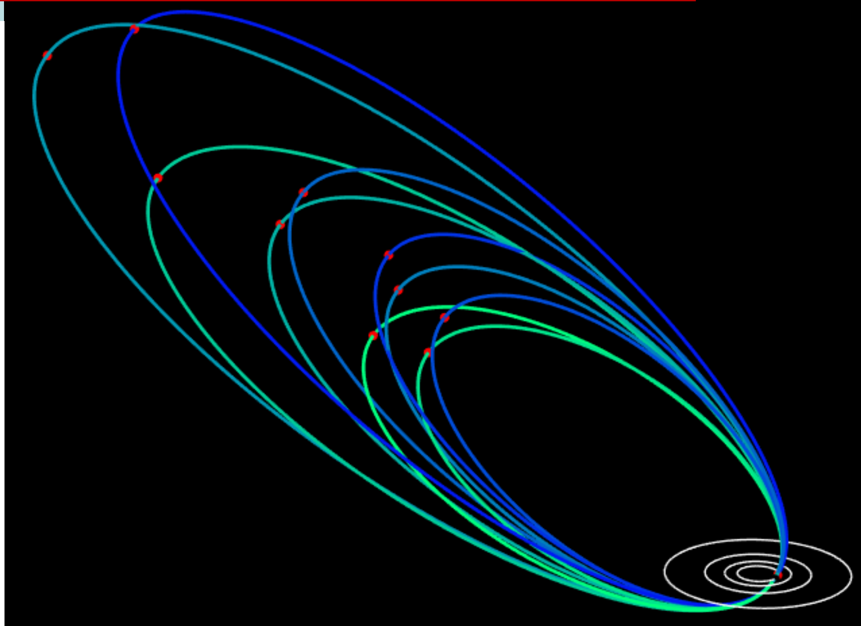
University of Bern: Ion and Neutral Mass Spectrometer

U.S. Geological Survey: Deputy PI, cartography

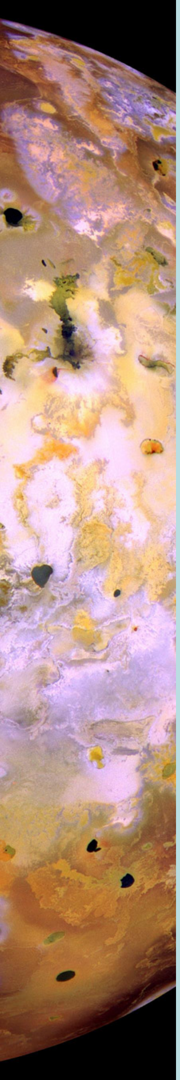
IVO Trajectory and Jupiter Orbit

- Launch Dec 2028 (2nd launch window for Discovery 2020)
- Mars and Earth Gravity Assists
  - Fly through asteroid belt twice
- Orbit inclined ~45º to Jupiter's orbital plane
- Jupiter Orbit Insertion Aug 2033



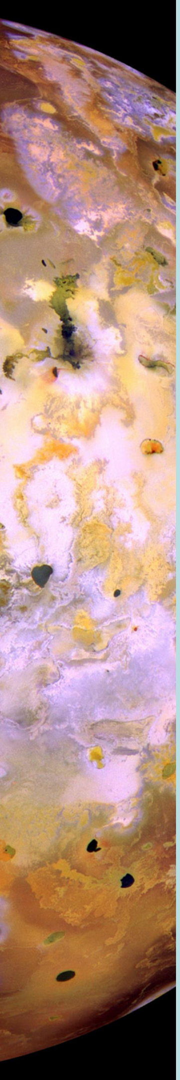


Ten Io encounters in nominal mission. Long orbital periods mean that IVO crosses orbits of outer irregular moons.



IVO Science Enhancement Options (SEOs) or other opportunities of interest to SBAG

- Potential observations of Phobos and Deimos
- Close encounter with a main-belt asteroid
- Distant observations of the many small moons of Jupiter
- Possible close encounter with an outer moon of Jupiter

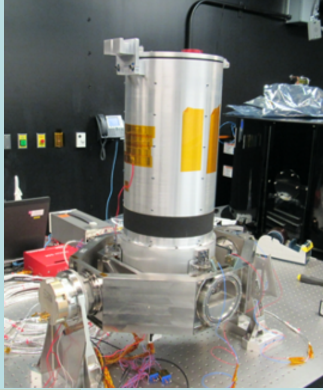


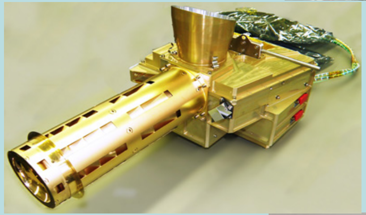
IVO Science Experiments

- **Narrow--Angle Camera (NAC)**
  - 10 µrad/pixel, 12 color bandpasses
  - APL, Europa Clipper
- **Dual fluxgate magnetometers (FMAG)**
  - UCLA, multi-mission heritage
- **Plasma Instrument for Magnetic Sounding (PIMS)**
  - APL, Europa Clipper
- **Thermal Mapper (TMAP)**
  - 125 µrad/pixel, 10 bandpasses from 3-14 microns plus radiometer (7-40 microns)
  - DLR, MERTIS
- **Ion and Neutral Mass Spectrometer (INMS)**
  - University of Bern, JUICE/PEP
- **Gravity Science**
  - Tidal k_2
  - Io's orbital migration

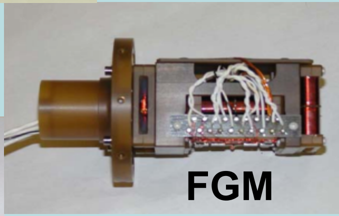
NAC and TMAP mounted on ±90° pivot: Can target anywhere with solar arrays to sun and/or high-gain antenna to Earth.

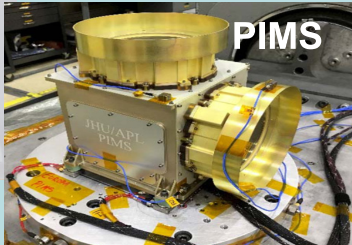
EIS NAC

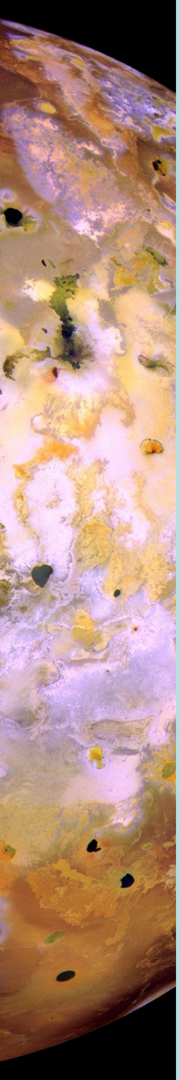




MERTIS

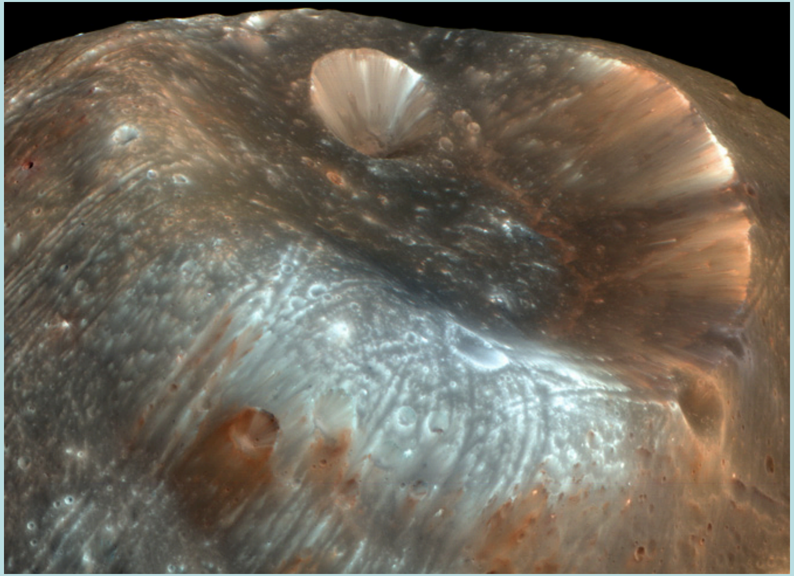




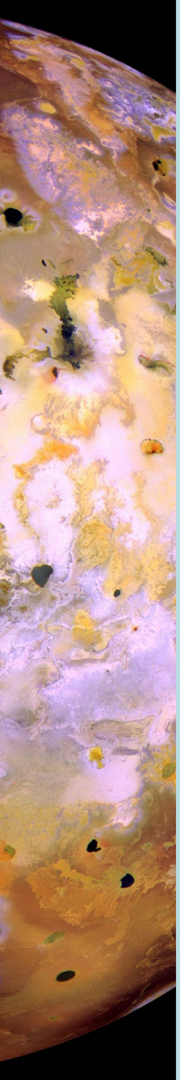


Phobos/Deimos

- ~500 km flyby of Mars for gravity assist needed to get to Jupiter
- No SEO planned, but the the moons are good calibration targets for NAC and TMAP

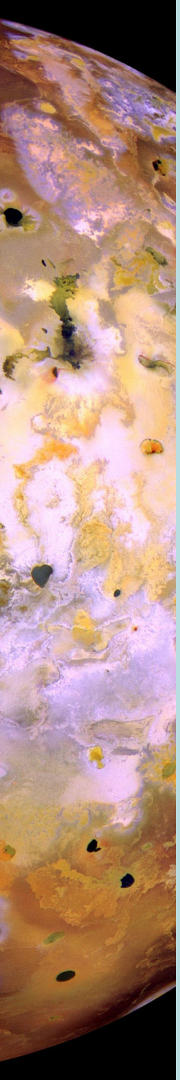


HiRISE images of Phobos and Deimos



Asteroid Encounter

- There is a set of asteroids that the IVO trajectory approaches, so a close encounter is feasible with a small cost in fuel (delta-v).
- We need an Io encounter “dress rehearsal” during cruise, and it is much better to do this with an actual target to observe.
- Outer asteroid belt is best because we pass through it later in the cruise period.
- A larger asteroid of scientific interest is preferred.

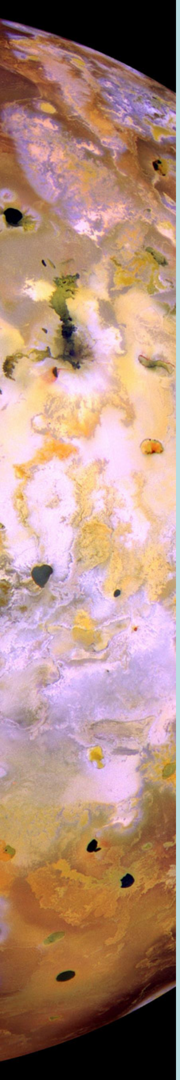


11377 Nye is the best candidate

- Discovered by Lowell Observatory and named after Ralph Nye, Lowell instrument designer
- 9.8 km diameter, albedo 0.096 (from NEOWISE); H=13.3
- Member of Themis family, C-Type

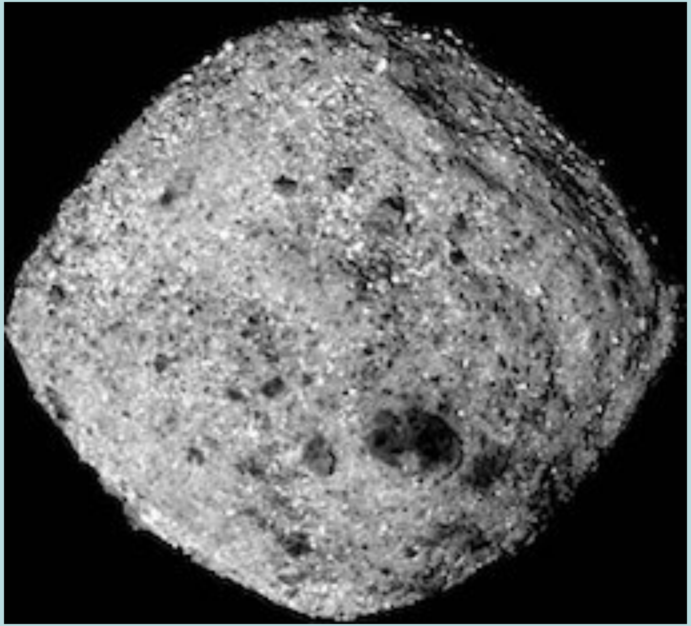
Themis Family is of great interest:

- “Main belt comets”
- Water ice plus organics may have been detected on 24 Themis (198 km): (Campins et al. 2010; Rivkin and Emery 2010) and 90 Antiope might have some surface water ice (Hargrove et al. 2015).
- Many members of the Themis family show evidence for hydration (Florczak et al. 1999; Takir and Emery 2012).
- Based on the ‘Nice model’, trans-Neptunian objects might have been implanted in the main asteroid belt (Levison et al. 2009).
- Themis was not found to be active (Jewitt and Guilbert-Lepoutre 2012) when observed far from perihelion. Other Themis family asteroids “present comet-like activity” (Hsieh & Jewitt 2006; Licandro et al. 2011).



11377 Nye Encounter by IVO

- March 2032, 14 months before JOI.
- Fast flyby (9.4 km/s) makes it a good Io dress rehearsal.
- Ephemeris uncertainty for the asteroid will drive closest approach distance.
  - ➢ Ground-based observations will be needed to improve ephemeris. Nye is at opposition this July.
  - ➢ *If* IVO can come within 250 km range *and* we know where to point, then we can image the entire disk in up to 12 colors at 2.5 m/pixel, plus 10 thermal IR channels at 31 m/pixel.
- Could INMS detect a water exosphere and measure D/H, relevant to the origin of Earth’s water?
  - ➢ This was not possible for the Lutetia flyby of Rosetta due to spacecraft outgassing (Altwegg et al., 2012).

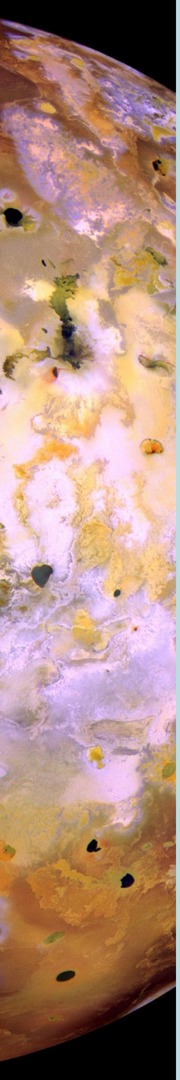


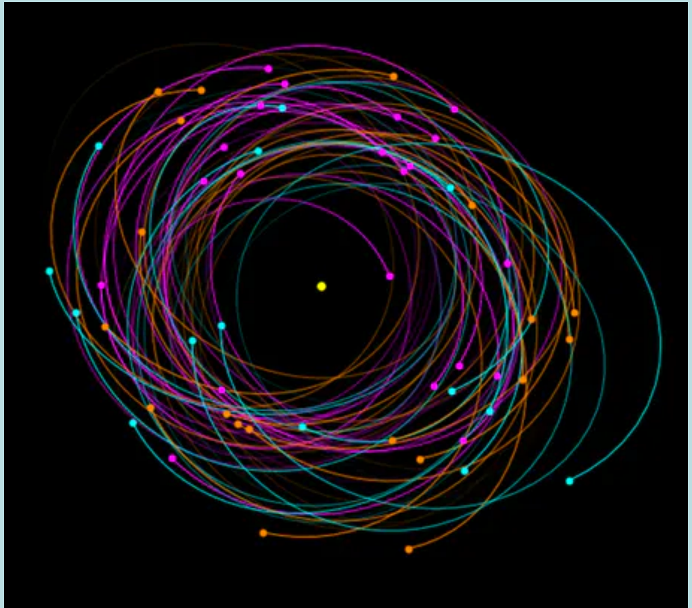
Bennu image from OSIRIS-REx reduced to 2.5 m/pixel

Jupiter’s Outer Irregular Moons

Distant observations of outer moons can be acquired to determine rotation periods, phase curves, pole directions, and constrain shapes and sizes, as did Cassini (Denk and Mottola 2019):

- Disk-integrated time-resolved observations performed for 25 irregular moons of Saturn.
- Rotation periods range from ~5.5 h to ~76 h.
- The lightcurves show very different structures from a large variety of shapes.





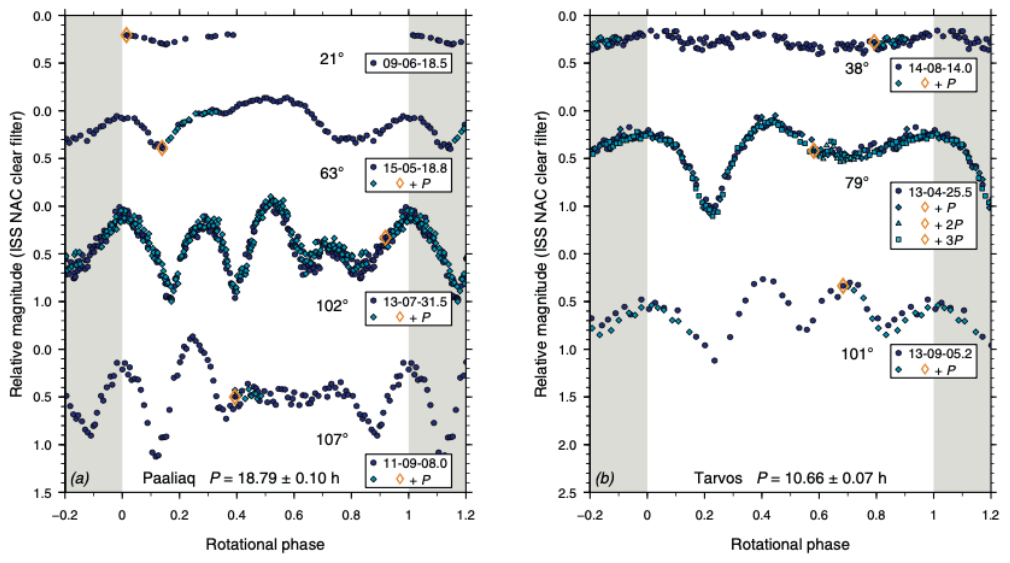
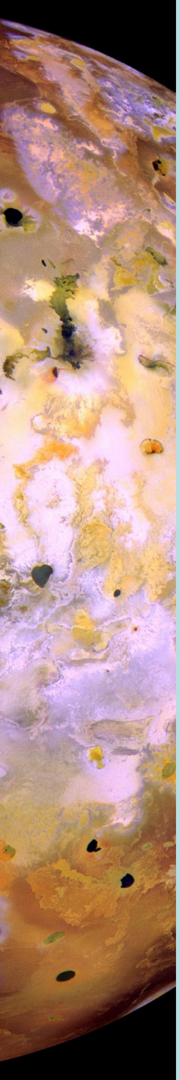


Fig. 4. Lightcurves of (a) Paaliaq (S20) and (b) Tarvos (S21). The Paaliaq 107° and the Tarvos 101° data are 3× binned.

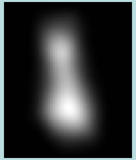


IVO orbit will get close to Sinope

- 690,000 km range, 6.9 km/pixel with NAC.
- 36 km diameter with assumed albedo of 0.04.
- Spectra similar to D-type asteroids, likely primitive organic-rich body.
- Size and color similar to KBO Arrokoth.
- High-eccentricity and high-inclination retrograde orbit, likely product of early capture (Sheppard and Jewitt, 2003)
- IVO can also get 13.8 km/pixel images of Lysithea (38 km diameter) and 25.8 km/pixel of Himalia (150 x 120 km)

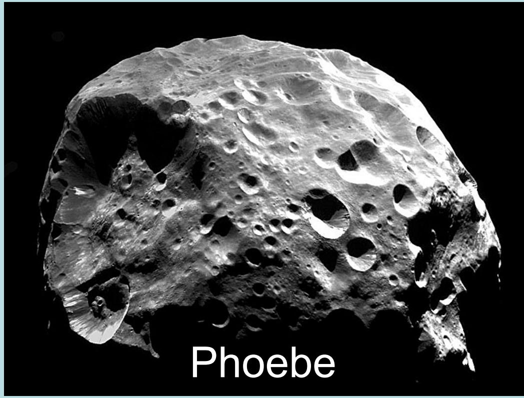
Arrokoth

Arrokoth at 5 km/pixel



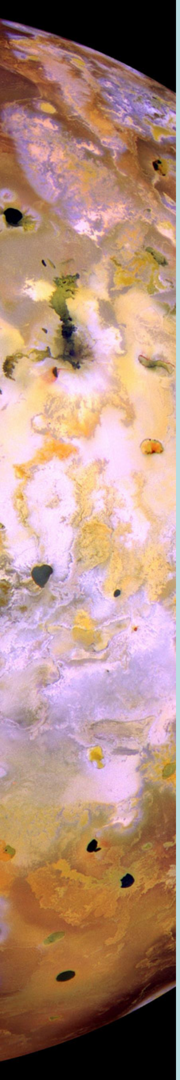
We are not, at this time, proposing to tweak the orbit for close encounters to outer moons

- Too much time and effort to plan encounters in Phase A.
- If IVO goes forward, we could, if NASA agrees, re-evaluate the possibility of doing very close, leisurely flybys, getting resolution better than the best images of Arrokoth and Phoebe.



Phoebe

Water ice and CO_2 detected on Phoebe from Cassini's close flyby.



Jupiter’s inner moons and rings

- IVO can image these down to ~3 km/pixel, with different viewing angles than those from Galileo.
- The orbital dynamics of the small inner satellites can be used to estimate the Jovian dissipation for different frequencies and possibly over a longer period of time (Lainey and Van Hoolst, 2009).