

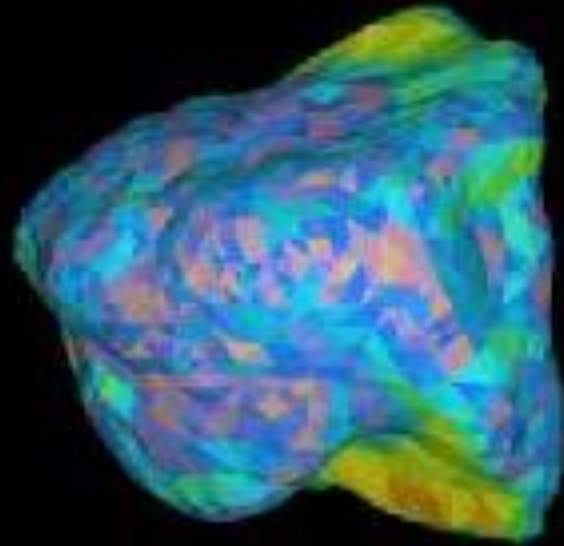
Asteroids



Ida and Dactyl (NASA)



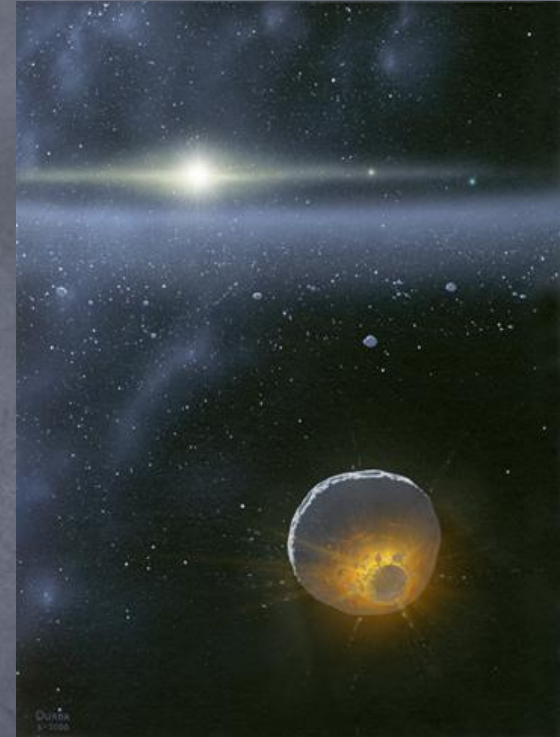
Itokawa (JAXA)



Golevka (Ostro)

“Science Before Missions”

- Origin of solar systems
- Provenance of planets
- Geophysics in microgravity
- Resources for in situ utilization
- Hazards and human interest
- Meteorites and sample return
- Dynamics and impact studies
- Astronomy of ours and other solar systems
- Exploration, robotic and human

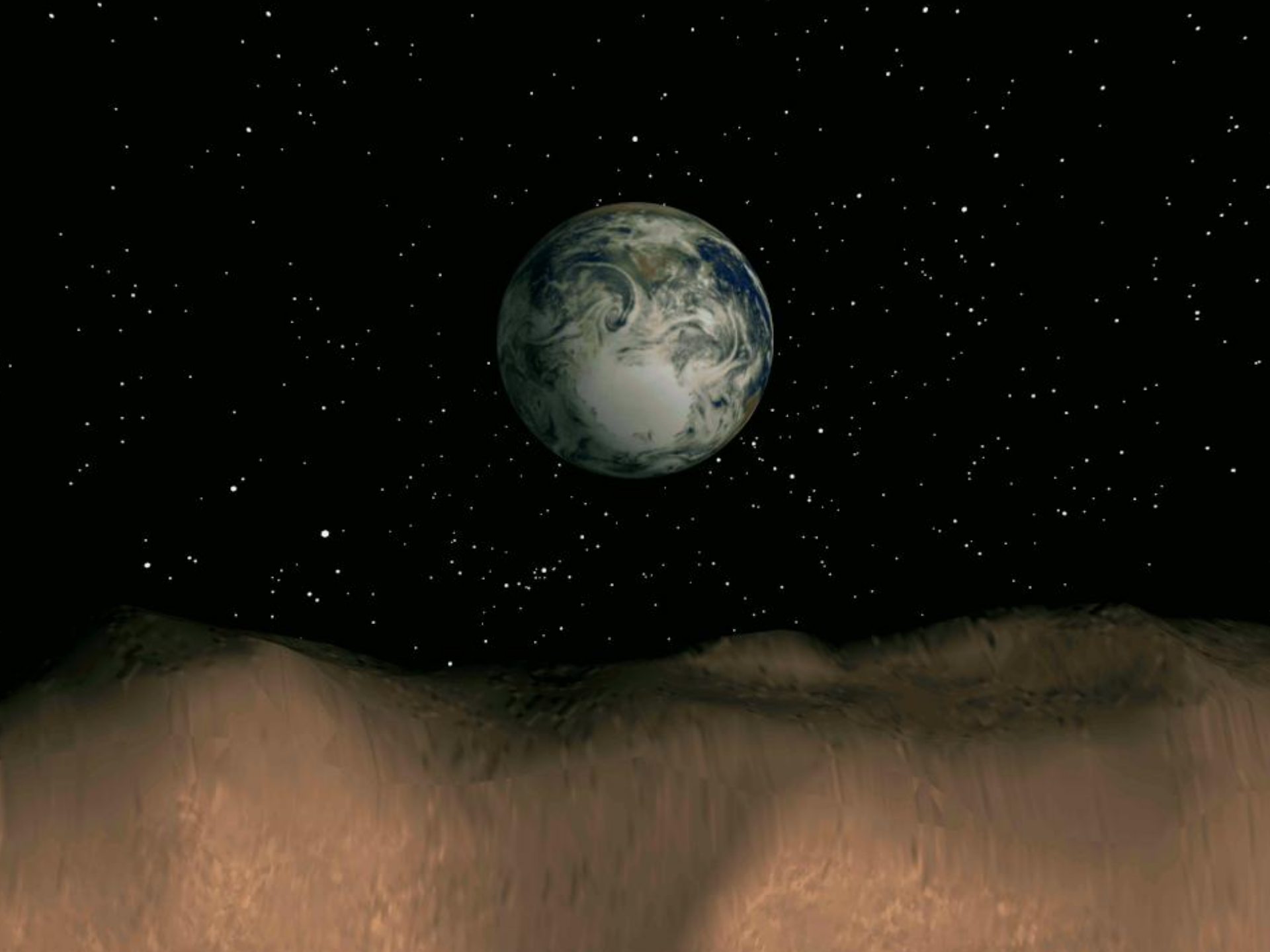


Dan Durda

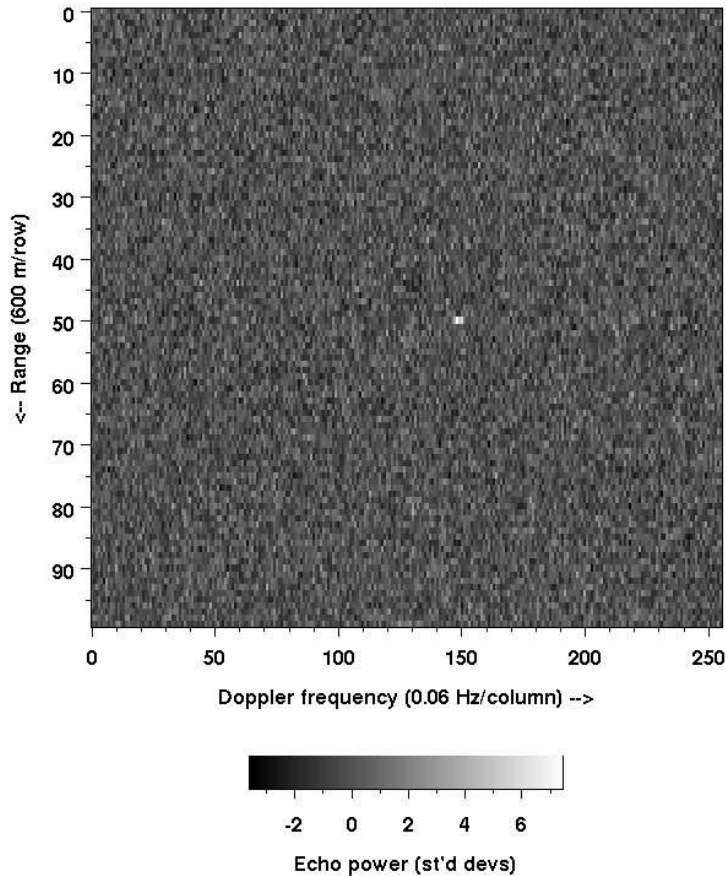
OK that's about a
3 hour talk...

Earth passing through the Geminid meteor shower
average flux of meteoroids is 40,000 tons per day

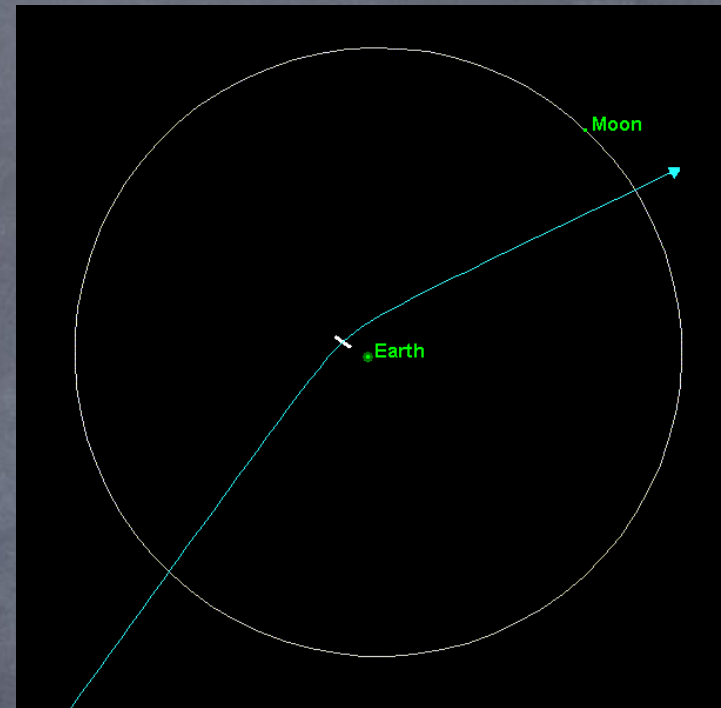
Let's start
close to home



RADAR DETECTION OF APOPHIS: 2005 JAN 28-29, 23:21:29-00:22:29 UTC



Dynamical Nuances



What are the links between our national **science goals** and our national **hazard mitigation goals** and the **public face of planetary science**?

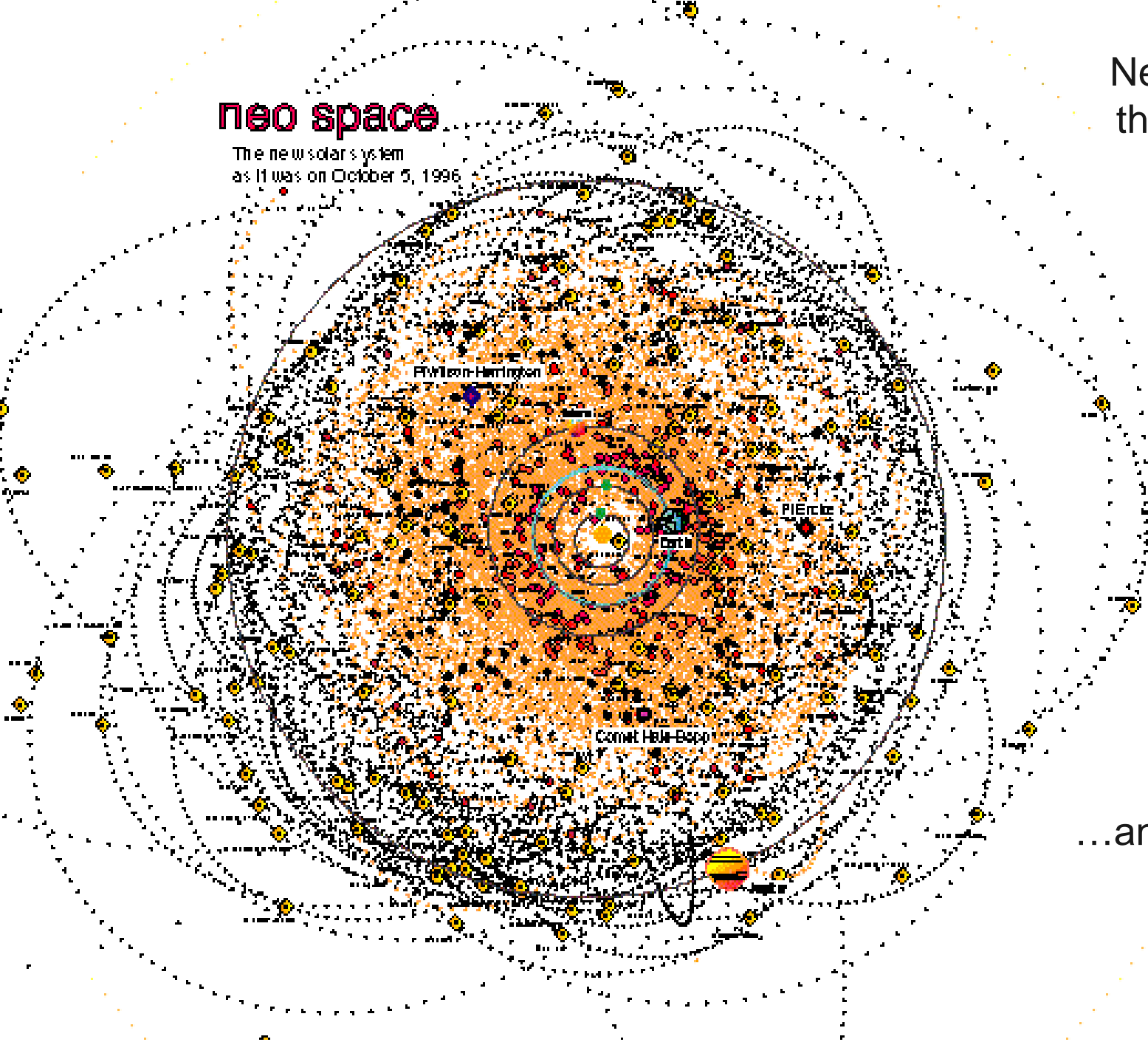
Is there a science mission rationale for Apophis?



...or, "been there, done that"

neo space

The new solar system
as it was on October 5, 1996

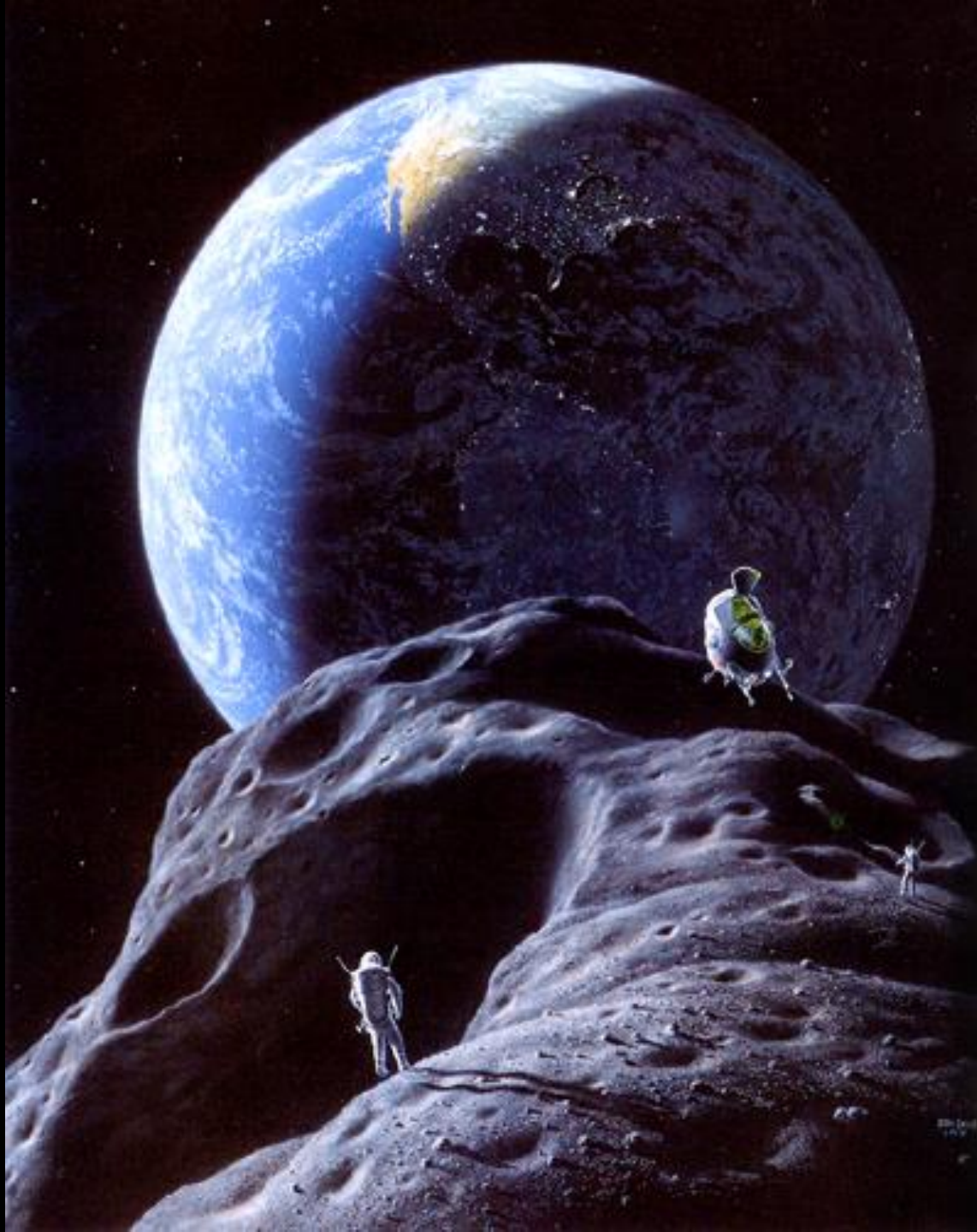


Newton: God as
the divine clock
maker,

...and the problem
of chaos

Hazard or Treasure?

- Water-rich?
- Metal-rich
- Shelter from cosmic rays
- Training for a Mars-Phobos mission
- Someplace relatively easy “to boldly go”





To Get Humans to Mars...



Captured
asteroid,
future Mars-
base?

Upcoming
missions from
Russia, China...

...It May Help to Understand Asteroids!

Robert Hooke, preface to *Micrographia* (1665):

"The truth is, the Science of Nature has been already too long made only a work of the Brain and the Fancy: It is now high time that it should return to the plainness and soundness of Observations on material and obvious things."

Remote Sensing

- Groundbased...
- From flyby:
 - Visible imaging
 - NIR mapping
 - IR, UV spectrometry
 - Thermal imaging
 - Magnetic fields
- From orbit:
 - Above, but better
 - XGRS etc.
 - Gravity modeling
 - Radar studies
 - Laser blast spectroscopy
 - Poor man's seismology
 - Telemicroscopy

On the Surface

- Compositional studies
- Penetrated packages
- Seismology experiments
 - Simple (time, attenuation)
 - Detailed (imaging)
- Magnetotelluric sensors
- Thermometers (buried)
- Electric field sensors
 - Langmuir probe
- Dust detectors
- Microscopes and spectroscopic microscopes
- E/PO cameras

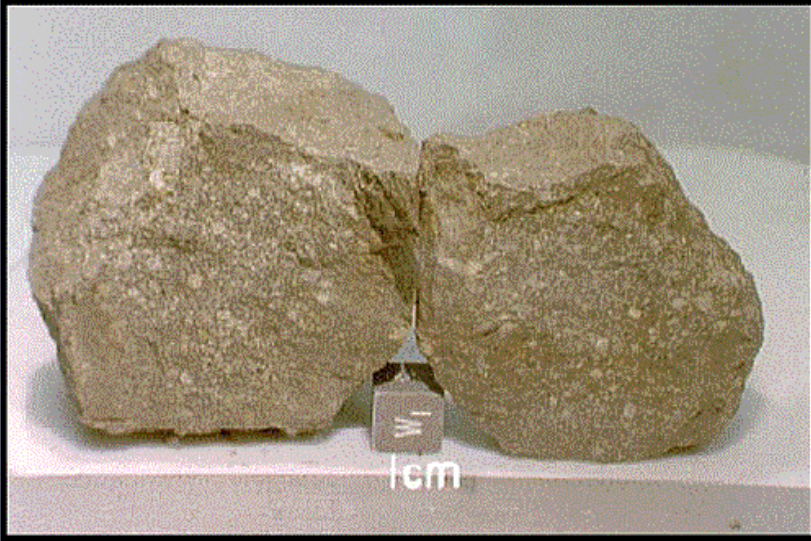
Sample Return

- Small surface sample (Hayabusa)
- Larger sample (~1 kg) is much more difficult, but \$ per gram is much cheaper...
- Vital to sample the materials that don't make it to Earth as meteorites



Increasing cost

But we get samples of asteroids for free



ordinary chondrite meteorite



saddle of Himeros on Eros

Meteorites are highly selected!



Importance of sample return

Impact trajectory
of 2008 TC3

1:00 UT

2:00 UT

Earth

to Sun



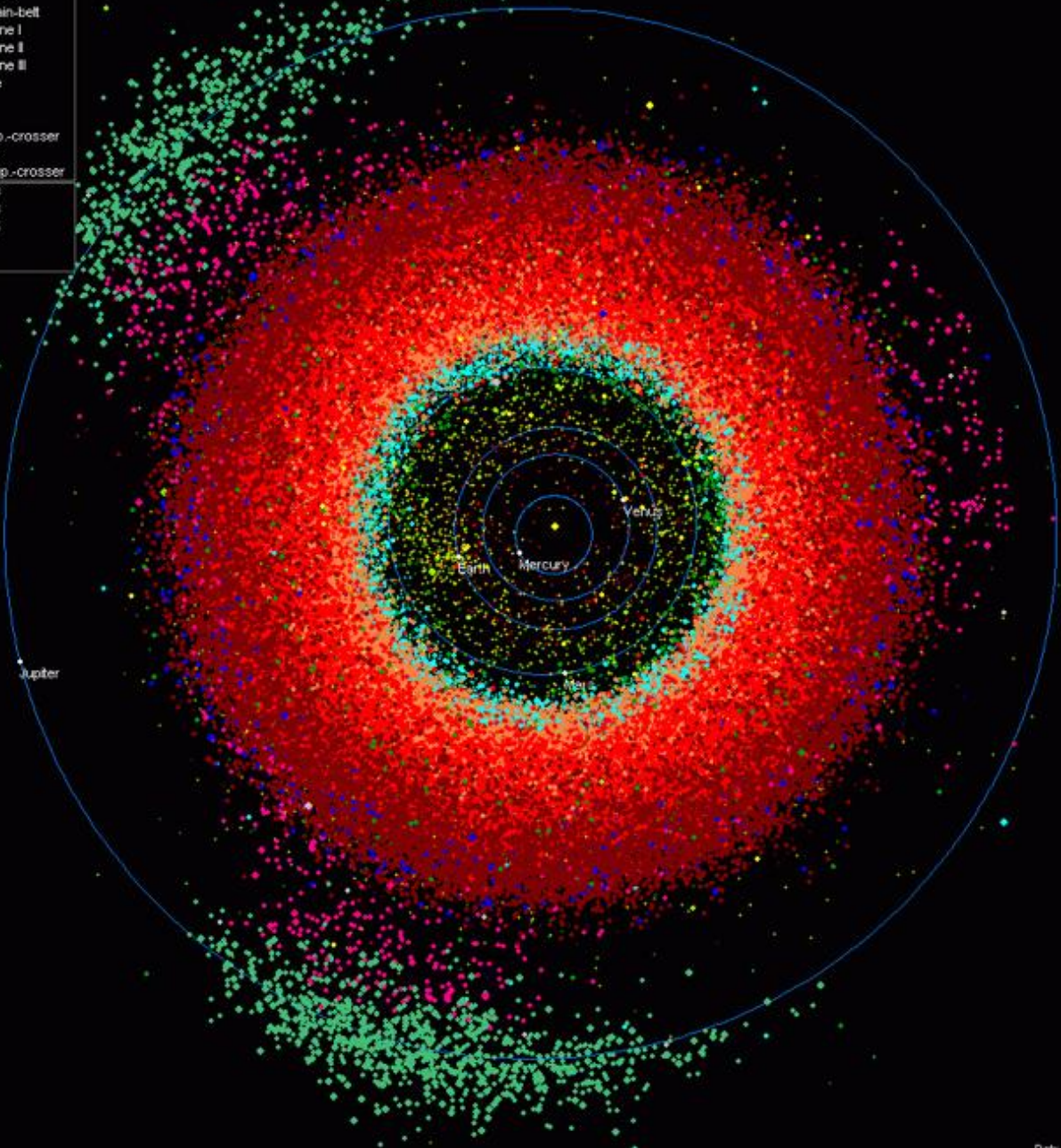
Sample return from
asteroid 2008 TC3...

Students and staff from the
University of Khartoum
lined up to comb the
desert, yielding 280
meteorites (P.
Jenniskens/SETI/NASA)

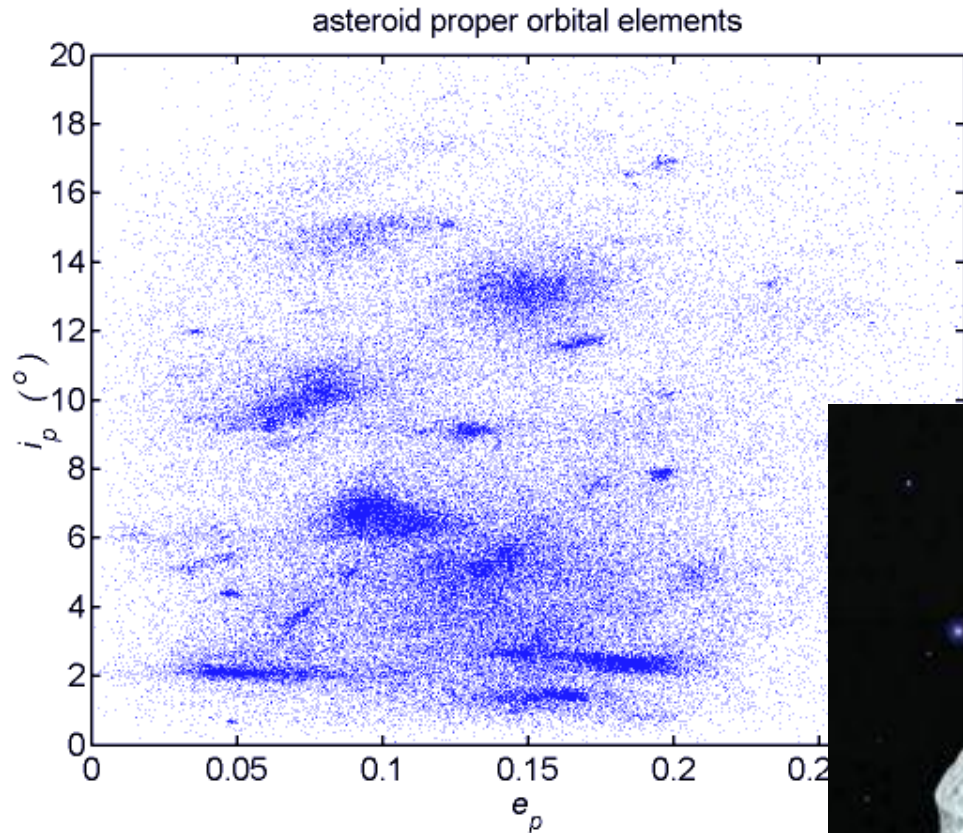


- IEA
- Aten
- Apollo
- Amor
- Mars-Crosser
- Hungaria
- Pre-Main-belt
- MB Zone I
- MB Zone II
- MB Zone III
- Cybele
- Hilda
- Thule
- Int. Jup.-crosser
- Trojan
- Ext. Jup.-crosser
- H= 20.0
- H= 15.8
- H= 11.5
- H= 7.3
- H= 3.0

Major Populations of Asteroids



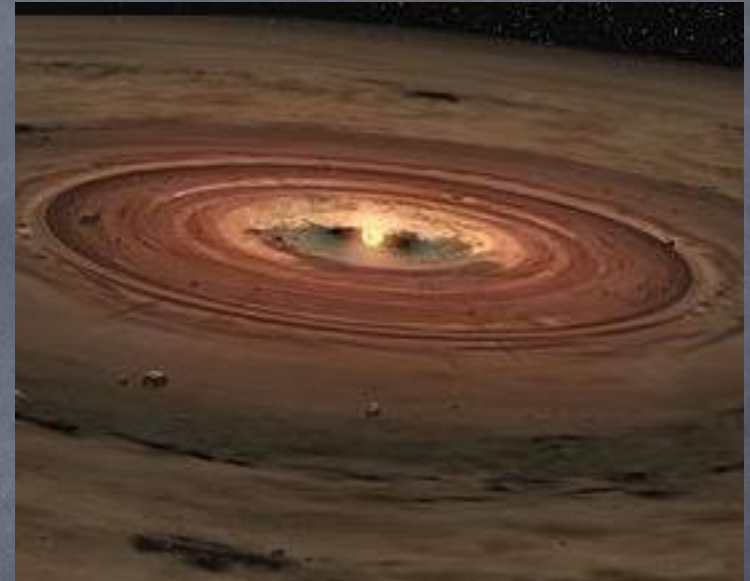
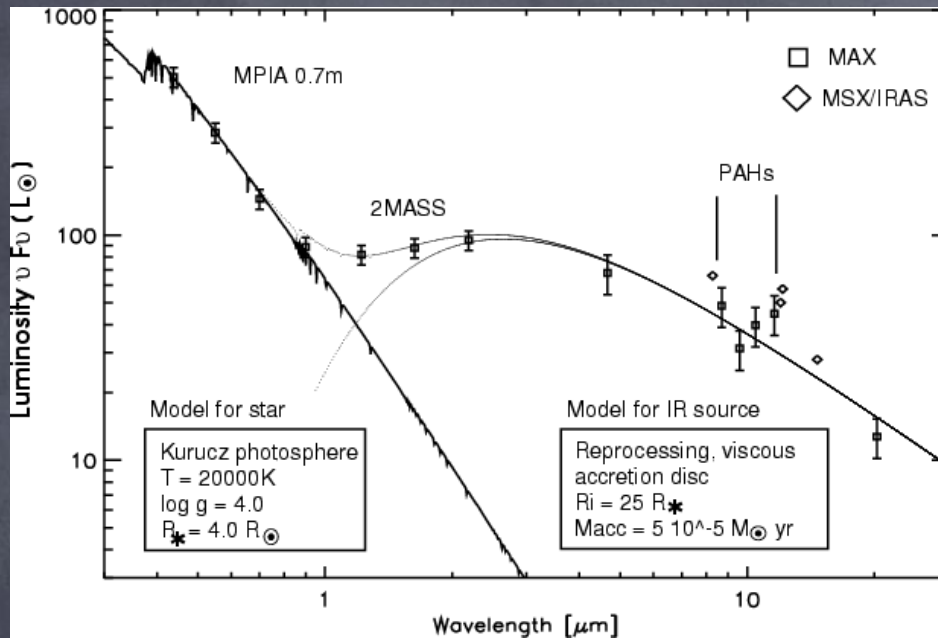
Asteroid Family Formation



Smaller asteroids undergo catastrophic disruption

In principle, can tour several members of a family





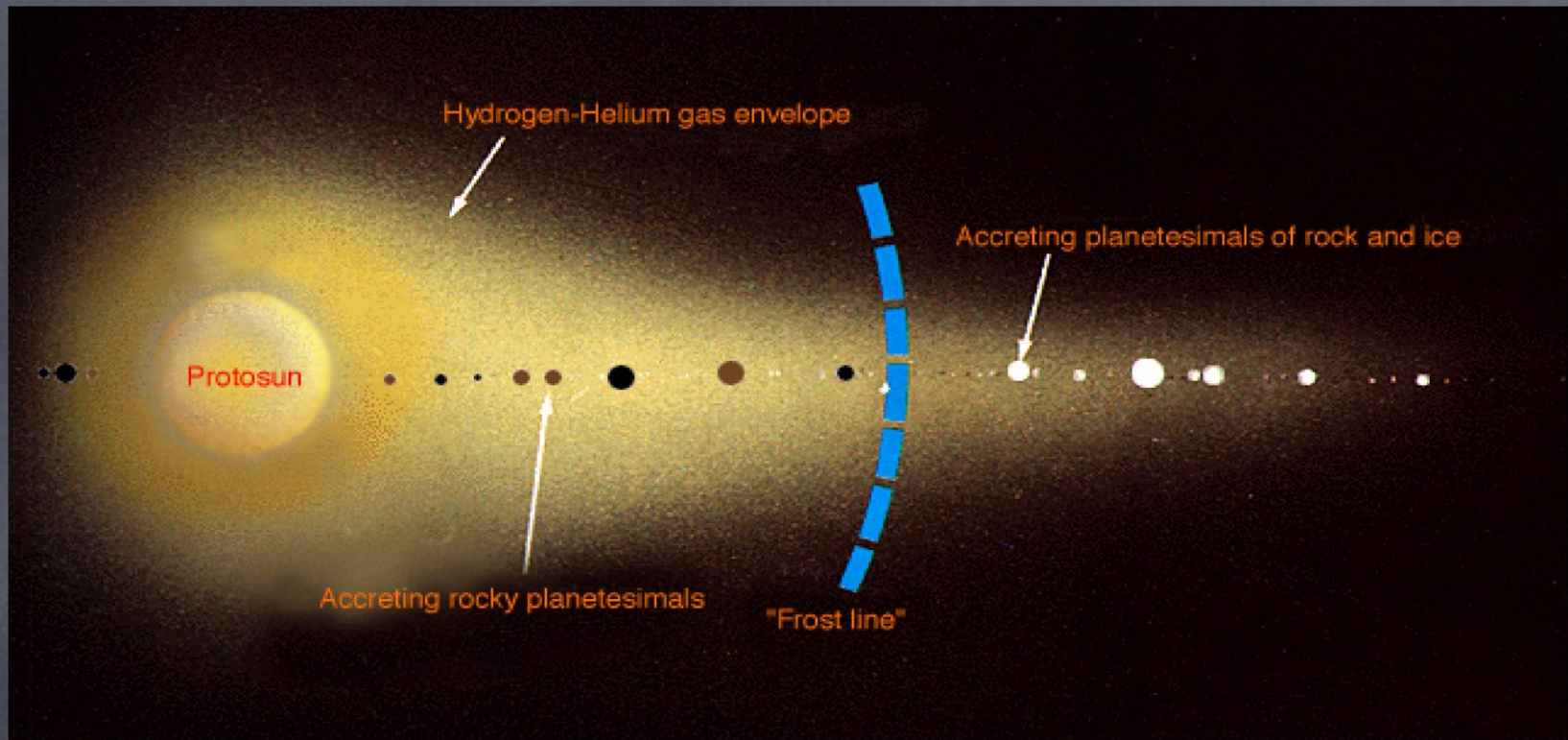
Infrared excesses (Spitzer; Meyer et al. 2008):

18% of young (3 to 30 Ma) Sun-type stars have them

12% of ~30-300 Ma Sun-type stars have them

2% of ~300 Ma and older Sun-type stars have them

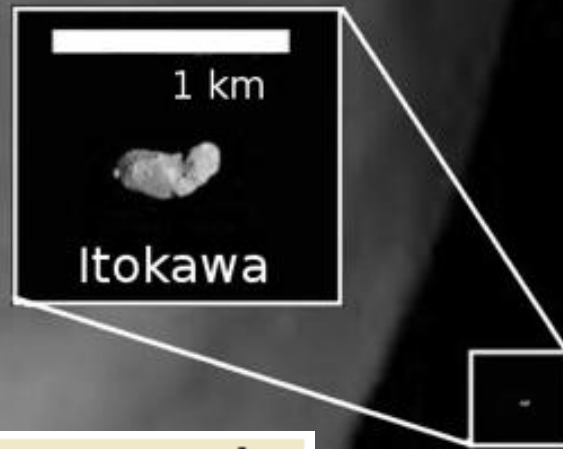
Surface area reflectance diminishes as particles grow into planets



- The Main Belt samples most planet-forming materials.
- NEOs sample most Main Belt materials.
- Ergo, sample collection from low-delta-V NEOs is obvious IF it is supported by the ground-based studies that find us opportune targets for investigation.

We have meteorites from many hundreds of NEOs, but not many of the hydrous and friable ones. The argument appears sound, for an NF-level mission focused on sample collection from a very primitive or hydrous NEO.

DIVERSITY

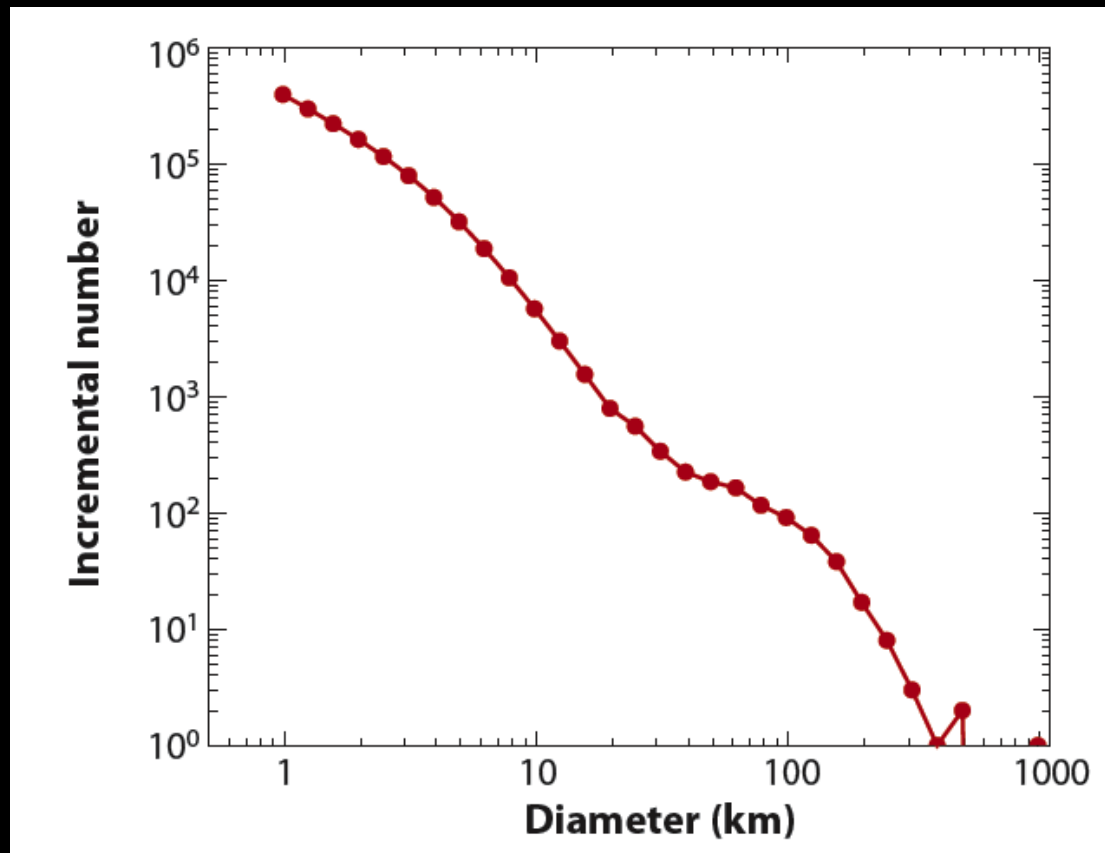


Asteroid or planetoid	Diameter (km)	Gravity (cm/s ²)
Itokawa	0.33	~0.01
Eros	20	~0.4
Vesta	530	~22
Moon	3474	162



100 km

Mathilde



Almost half the mass of the Main Belt is in the four largest asteroids... new science themes will emerge after Dawn, and these big beasts are not, perhaps, “primitive bodies”...

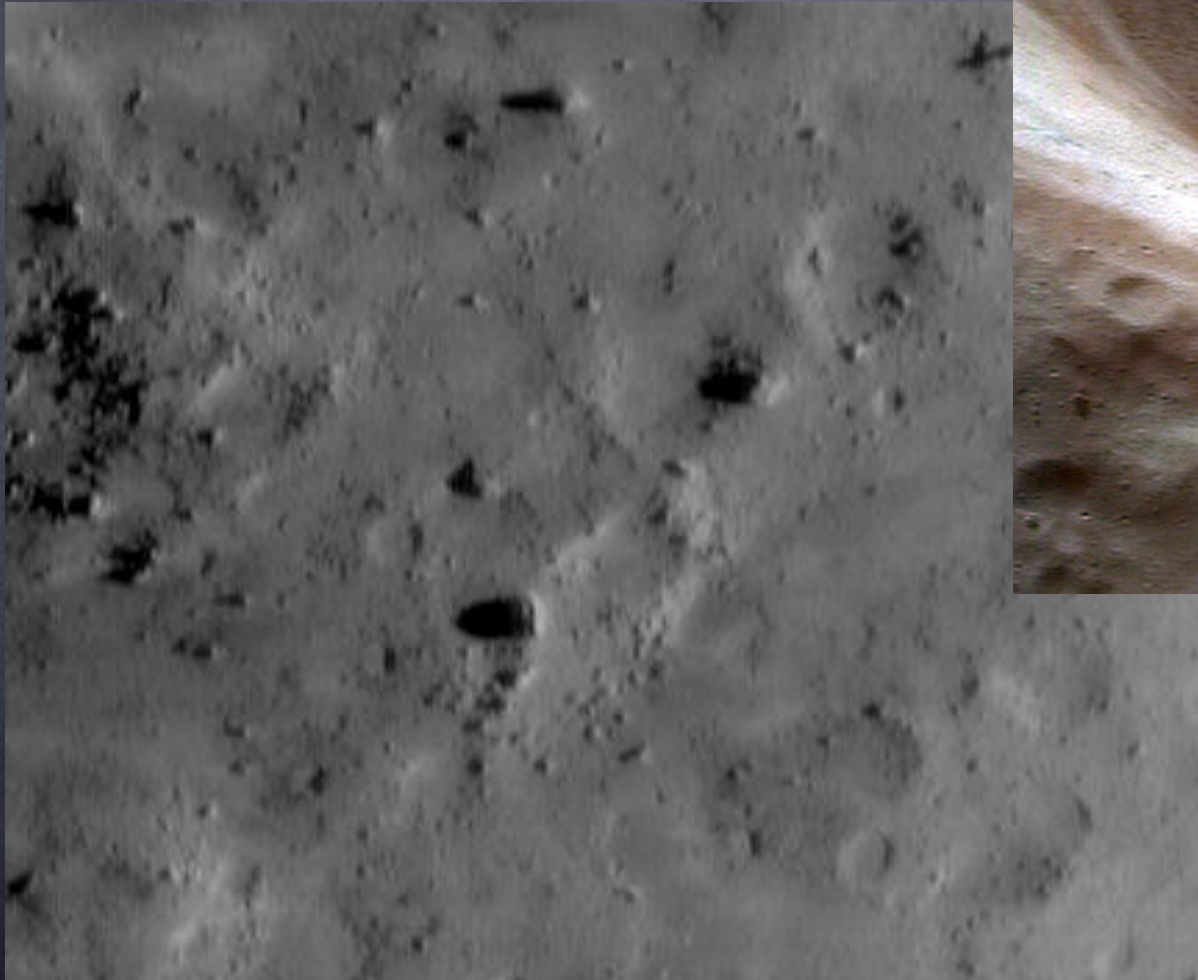


NEAR - 433 Eros

March 07 2000 08:10:00 -27 -158

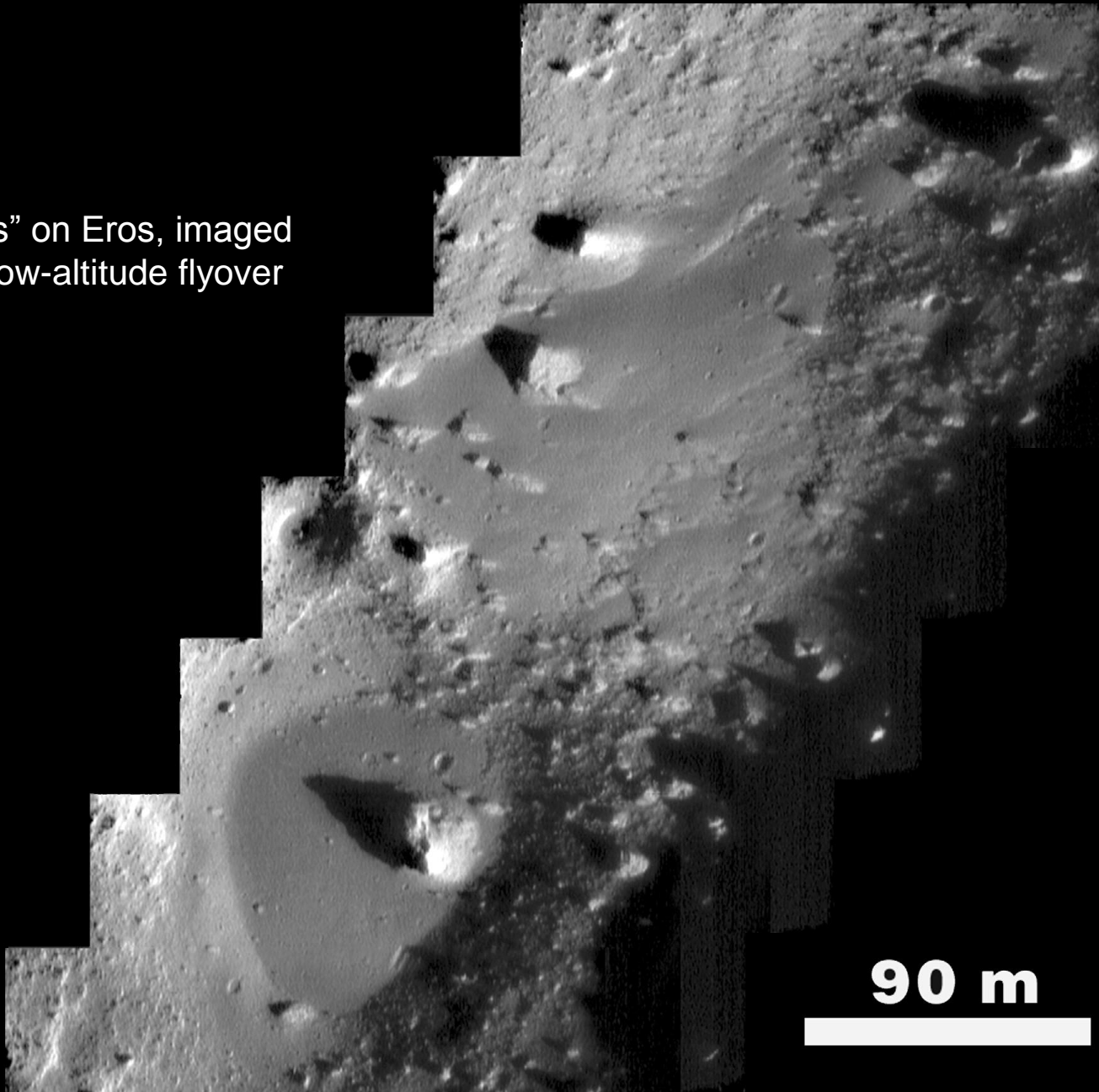
Eros:

Sediment-filled landscape, like
the bottom of the ocean!



See Robinson et al.,
Meteoritics & Planetary
Science, 2002

“Ponds” on Eros, imaged
from low-altitude flyover

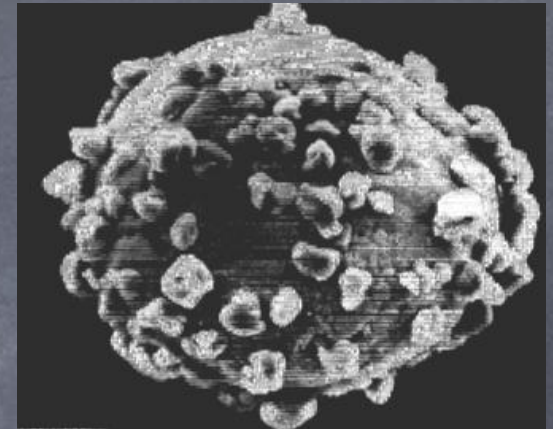


90 m

Veverka
01-0185-7



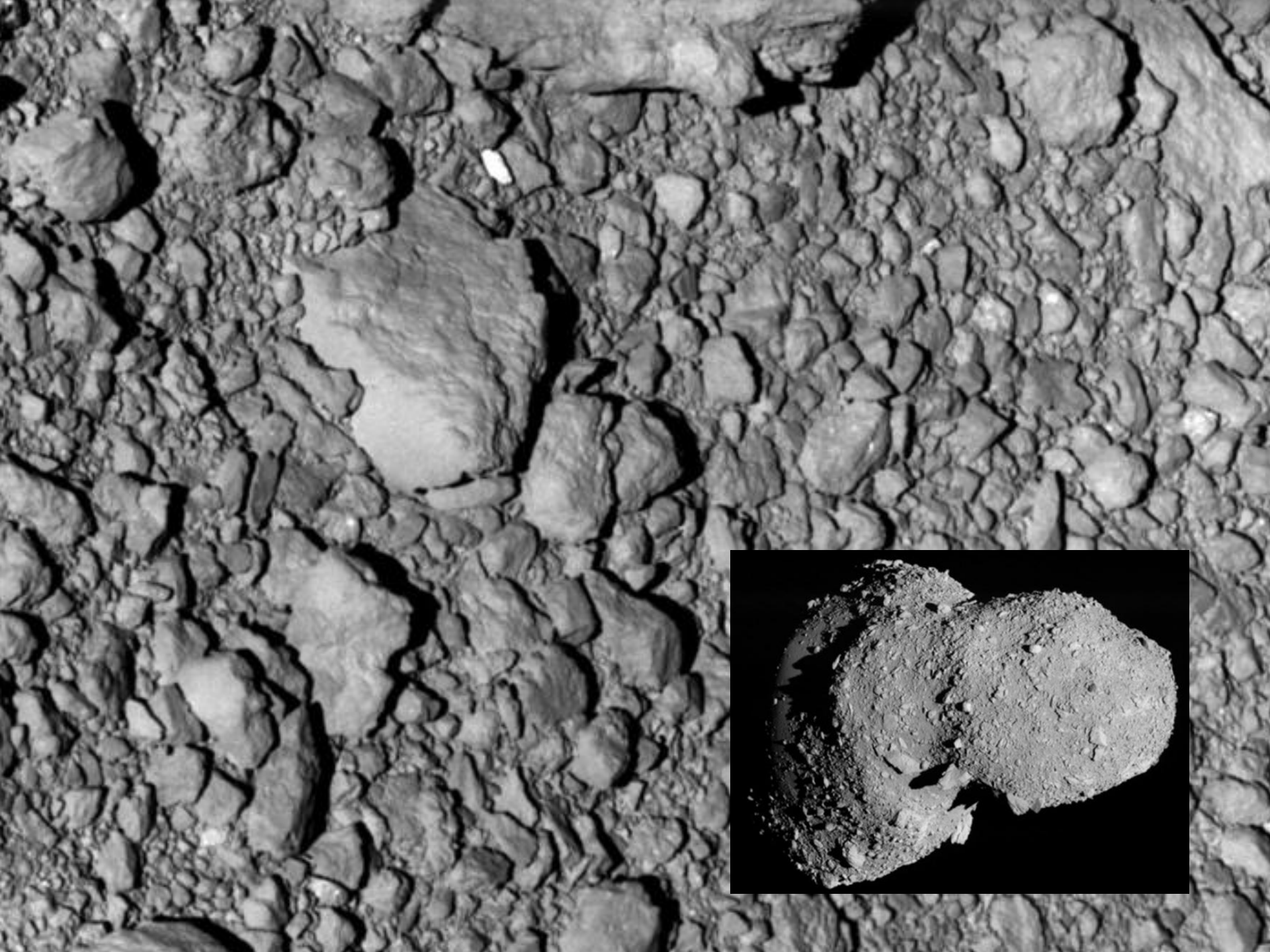
2-3 meter boulders on Eros

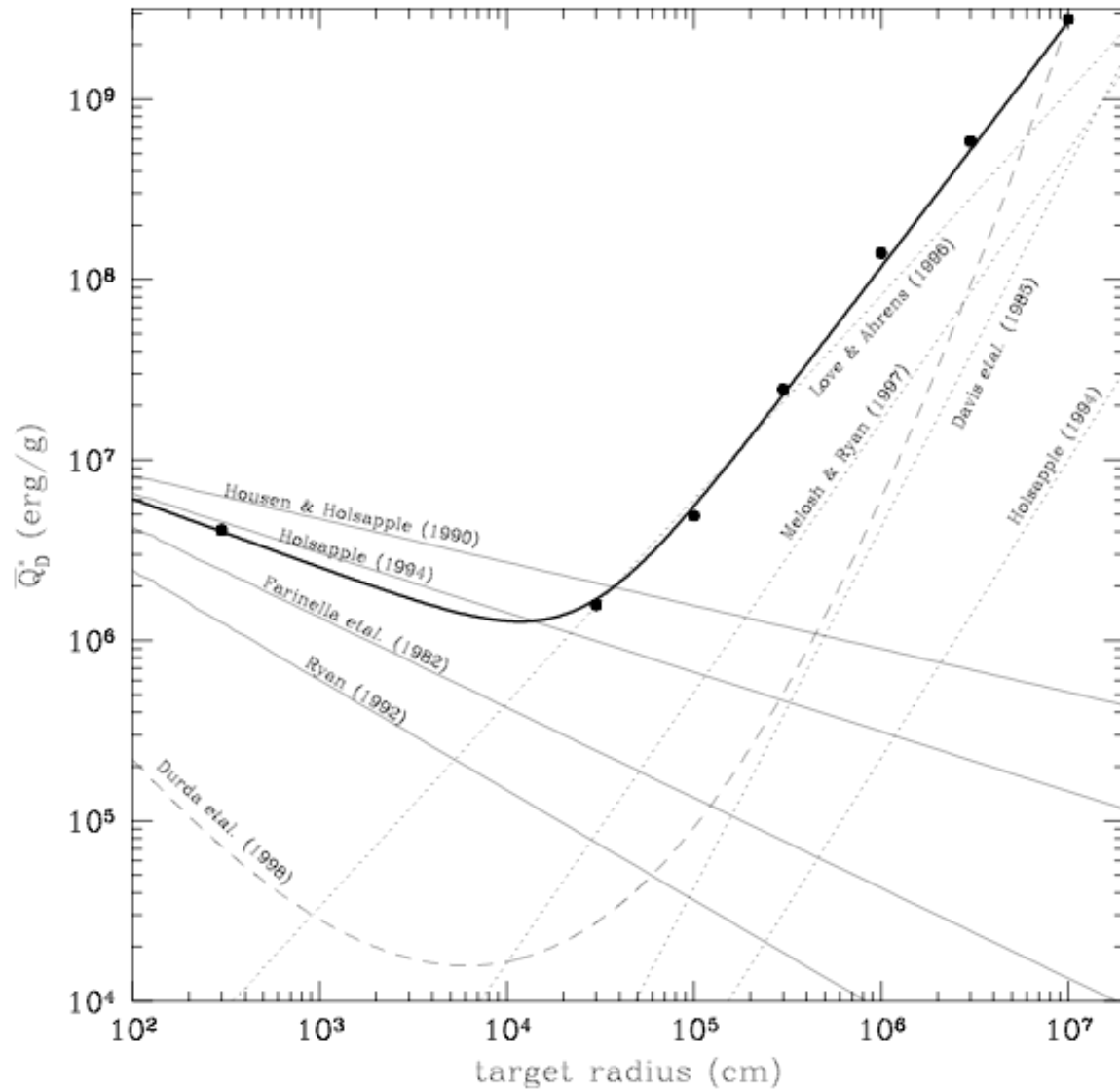


Xerox toner particles (~20 μm)
stuck to a bead

Granular Cohesion

If cohesion goes like $1/\text{grain-size}$, then ~1 m boulders on Eros should have the same cohesion:gravity ratio as micron-sized powders on Earth...



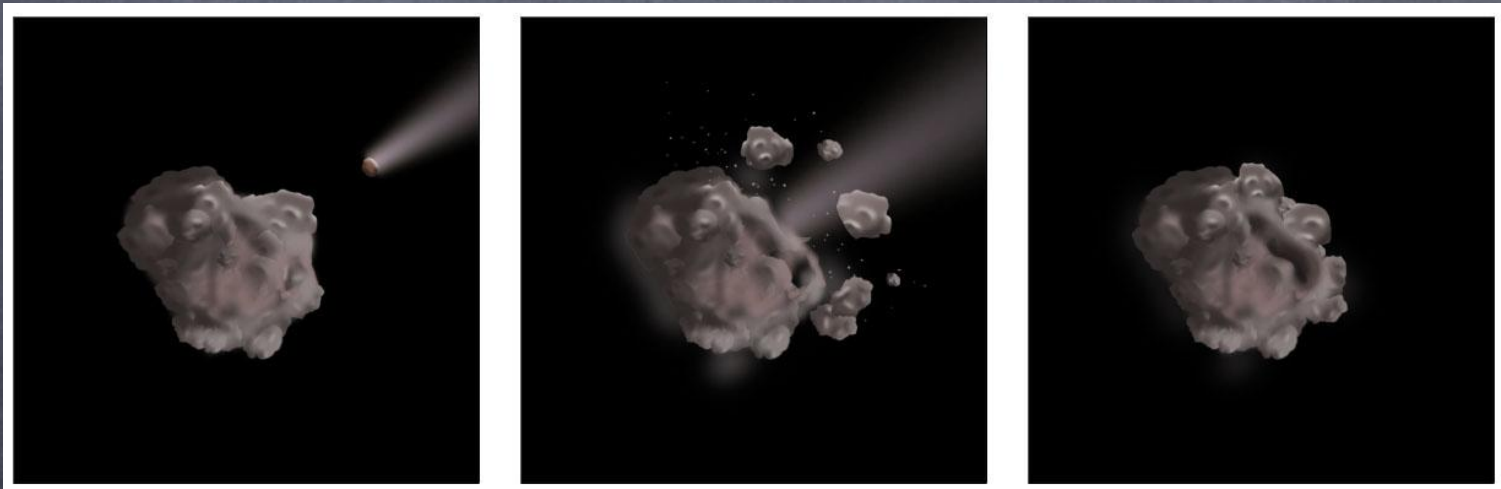


Impact physics in a nutshell and the case for rubble piles

Ⓜ Survival of the Weakest?

1) Minor collisions make any solid small body into a rubble pile

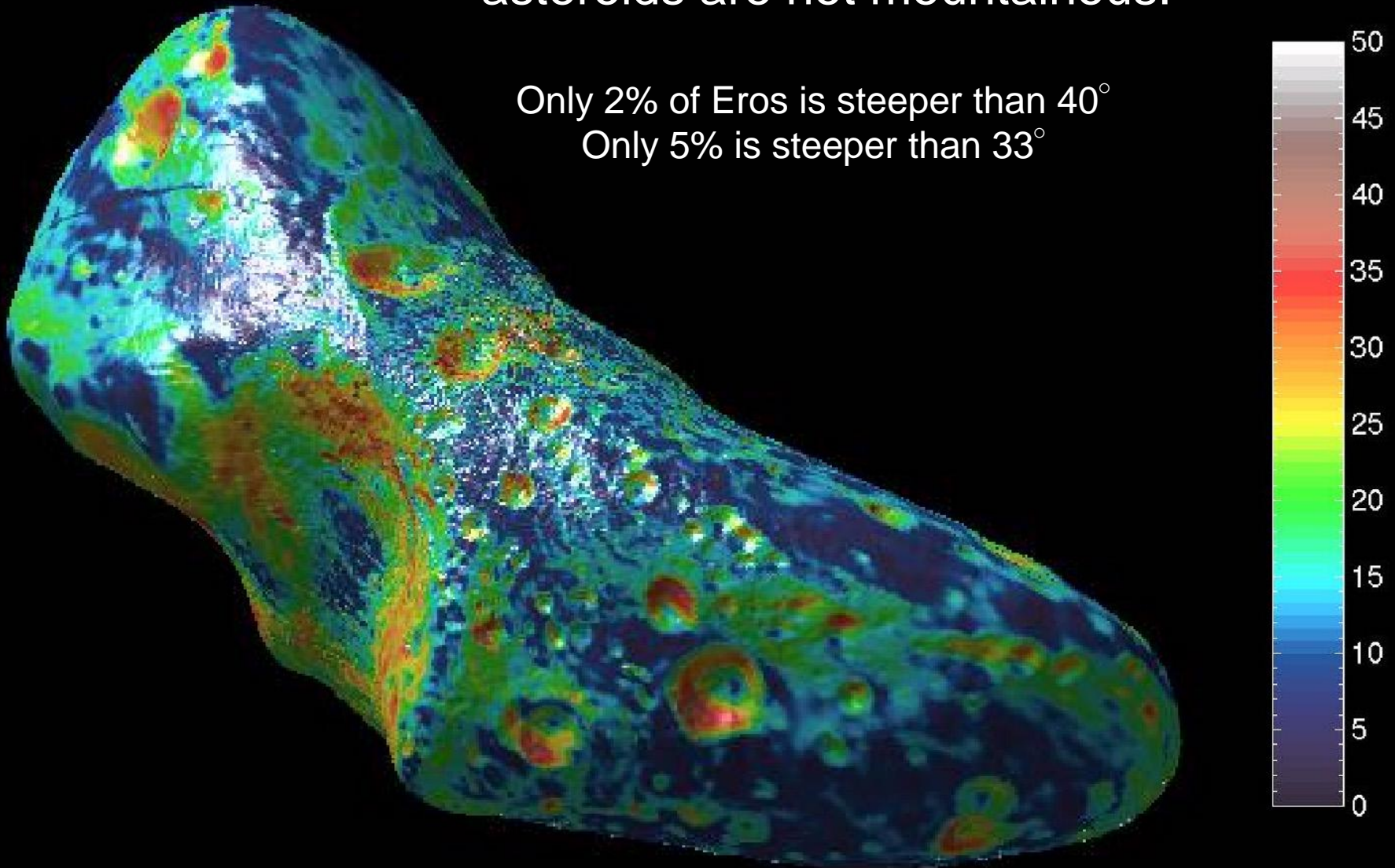
2) A rubble pile is thereafter resistant to catastrophic disruption: it dissipates the energy of impact



Are rubble piles the natural end state of comets and asteroids?

Despite appearances, most
asteroids are not mountainous:

Only 2% of Eros is steeper than 40°
Only 5% is steeper than 33°



Mathilde: example of bizarre geophysics

- a 60 km asteroid that shouldn't exist!

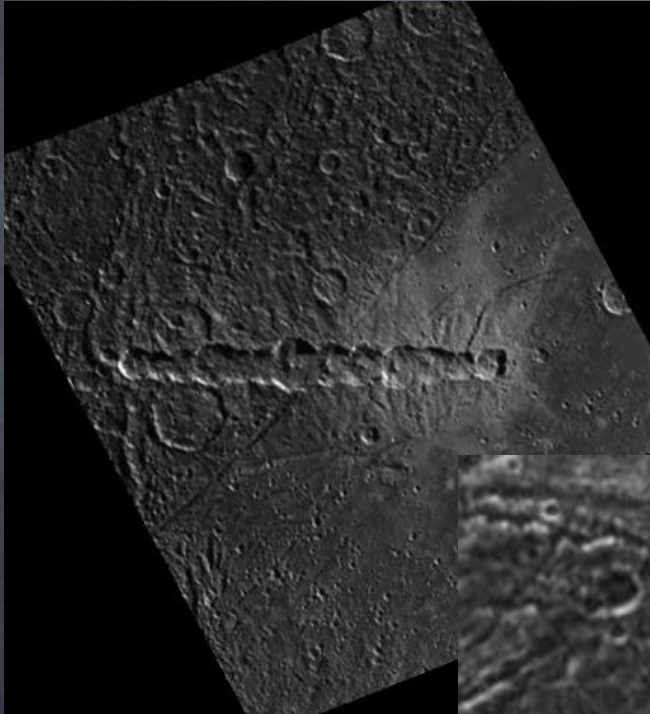
- Mathilde is more than 30% crater volume - “bites” taken out of the asteroid by impacts
- The rest is 2/3 pore space! Bulk density is about 1.3 g/cm^3
- There is no evidence for global impact damage (!)
- Very, very slow rotation (17.4 days) makes no sense at all

BIG GEOPHYSICS PUZZLES

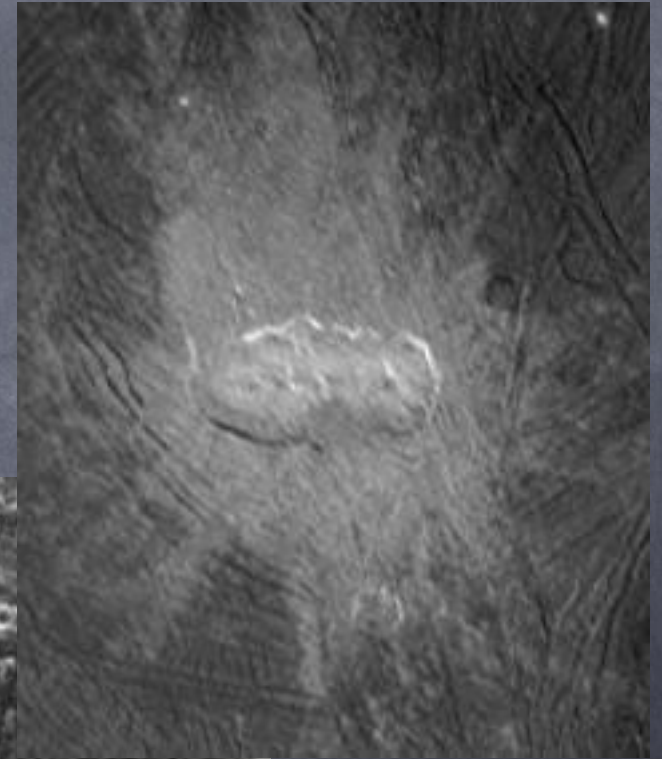


Second image mosaic of Mathilde, at NEAR's closest approach: Perfect targeting, but of what?

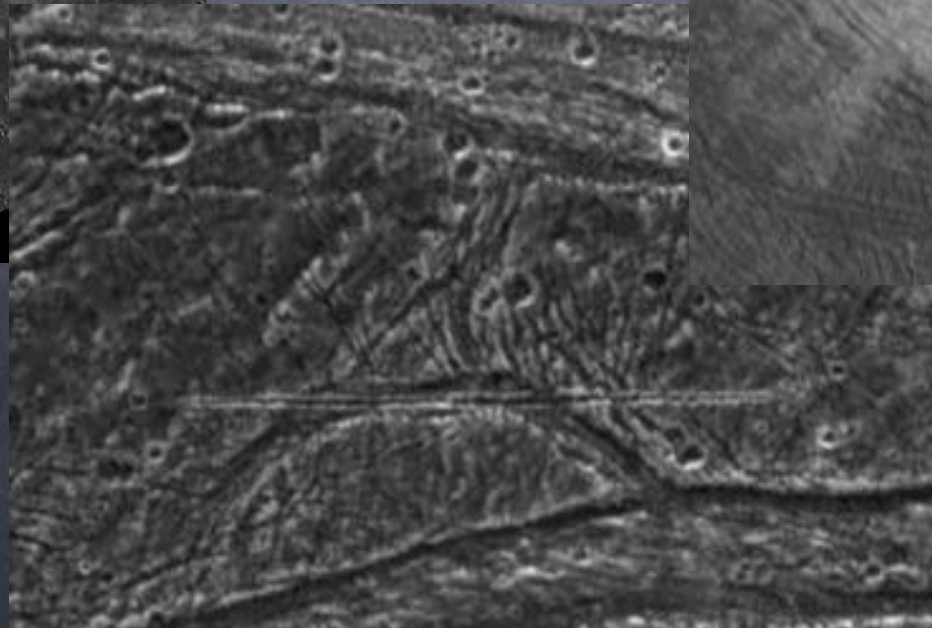
Cometary Rubble...



Imprinted
on the
moons of
Jupiter



Do Galilean satellite
missions tell us what a
comet mission cannot?



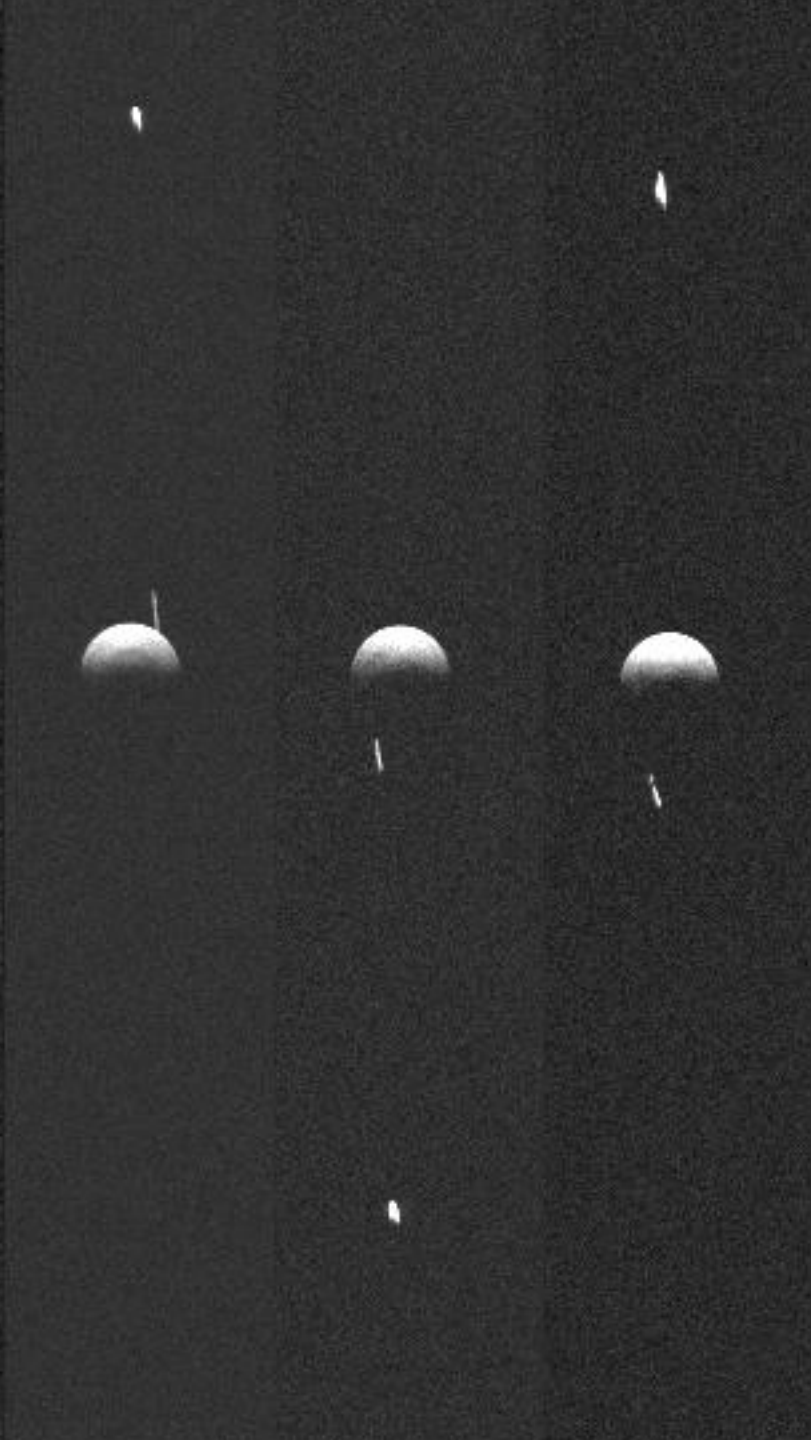
Multiple Asteroids

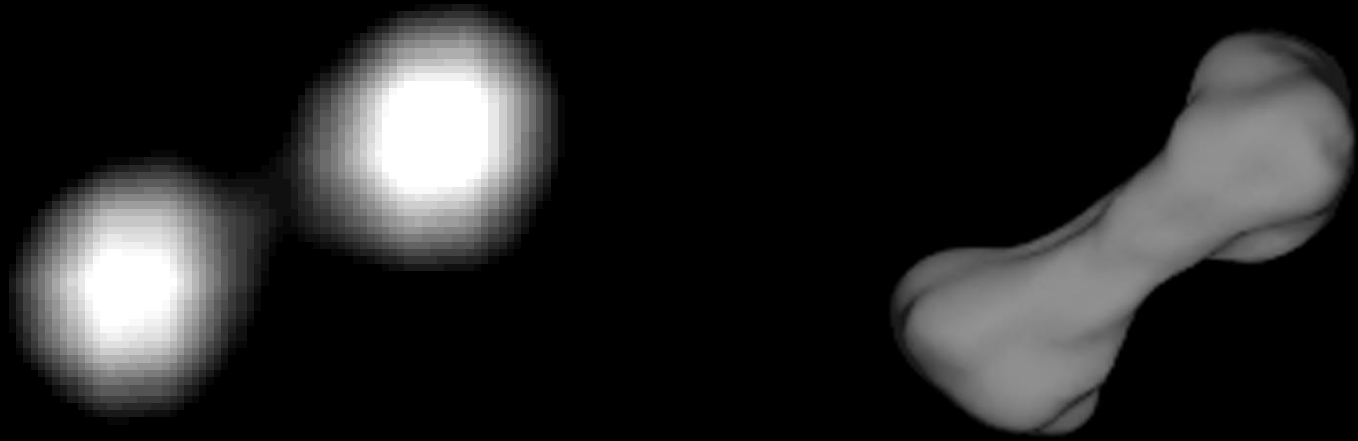


1999 KW4 (Margot et al. 2001 radar)

1/6 of near-Earth asteroids larger than 200 m have satellites!

New paradigm: the “NEO life cycle”

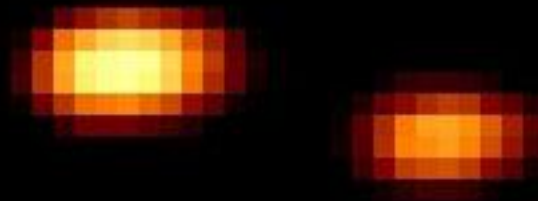




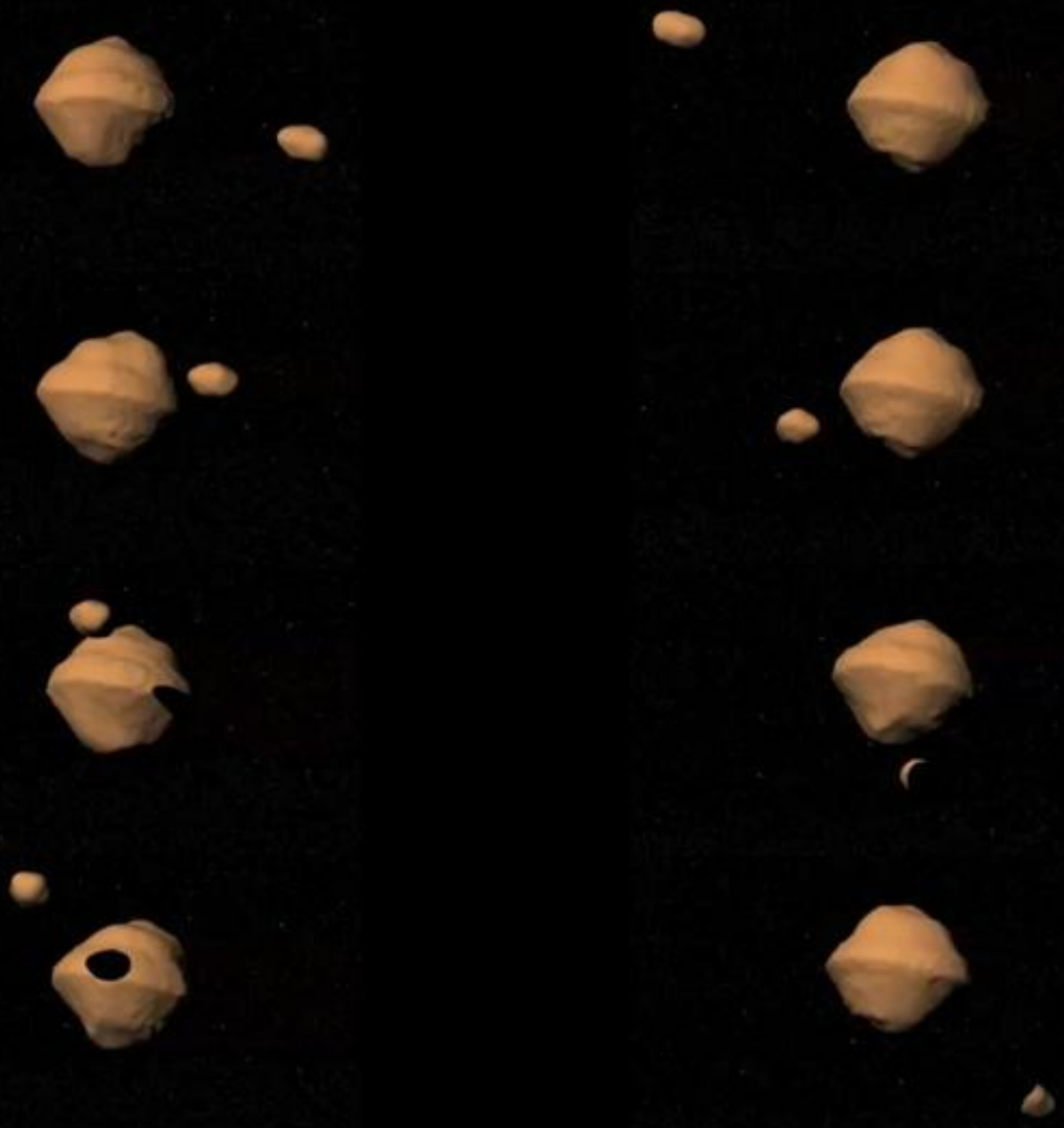
Antiope (Merline et al., Keck AO) and Kleopatra (Ostro et al., Arecibo radar) approx. to scale. One is a C-type binary (two ~80 km asteroids), the other is a double-lobed flying metallic dog-bone ~200 km long

Patroclus and Menoetius

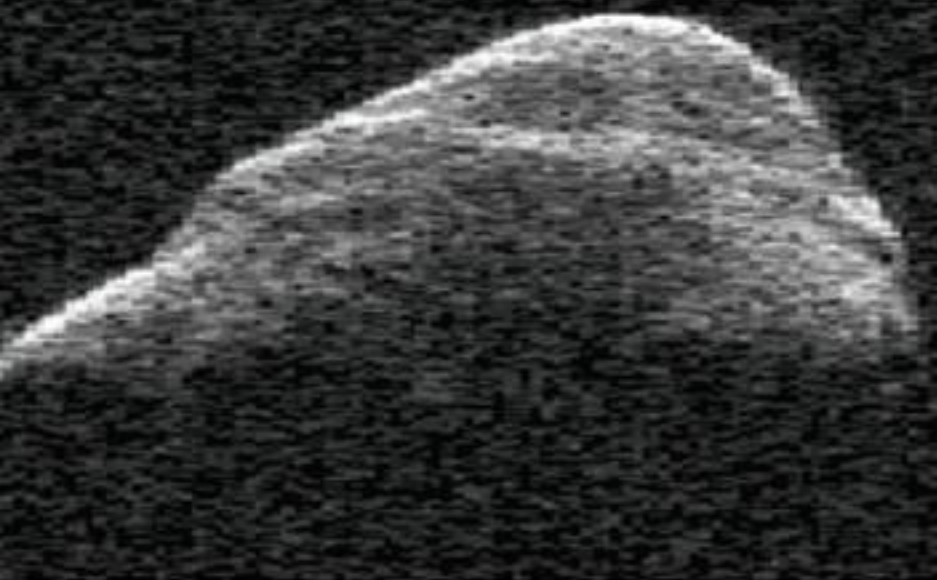
(Marchis, Keck AO), these are Trojan
“asteroids” with density of $\sim 0.8 \text{ g/cm}^3$



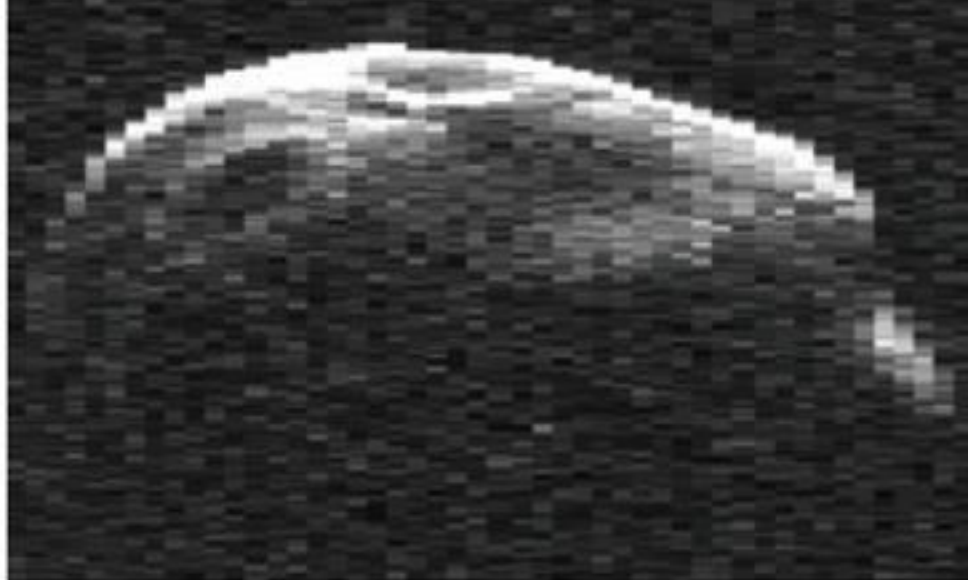
Trojan asteroids: did they form alongside TNOs, then captured into their current orbits early in solar system history? Did they form in place alongside Jupiter, e.g. precursors to the Galilean satellites? Did they scatter late into their present orbits as per the Nice model? Trojan asteroids are compelling mission targets.



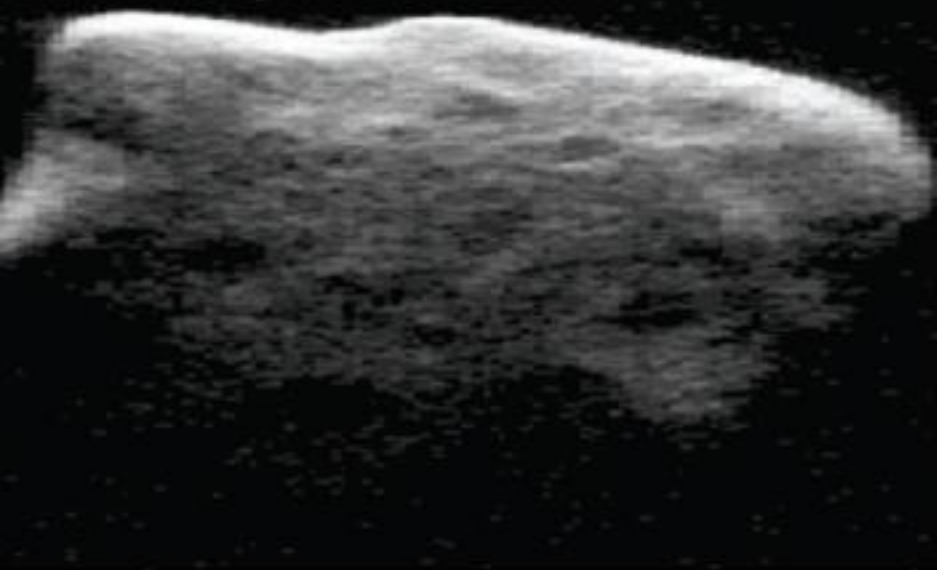
August 4, 1999



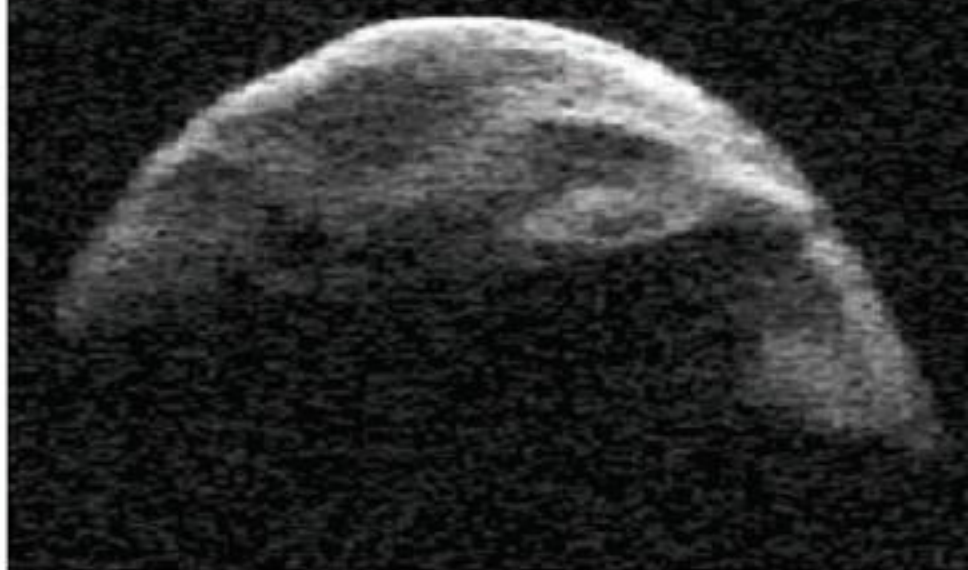
August 8, 1999



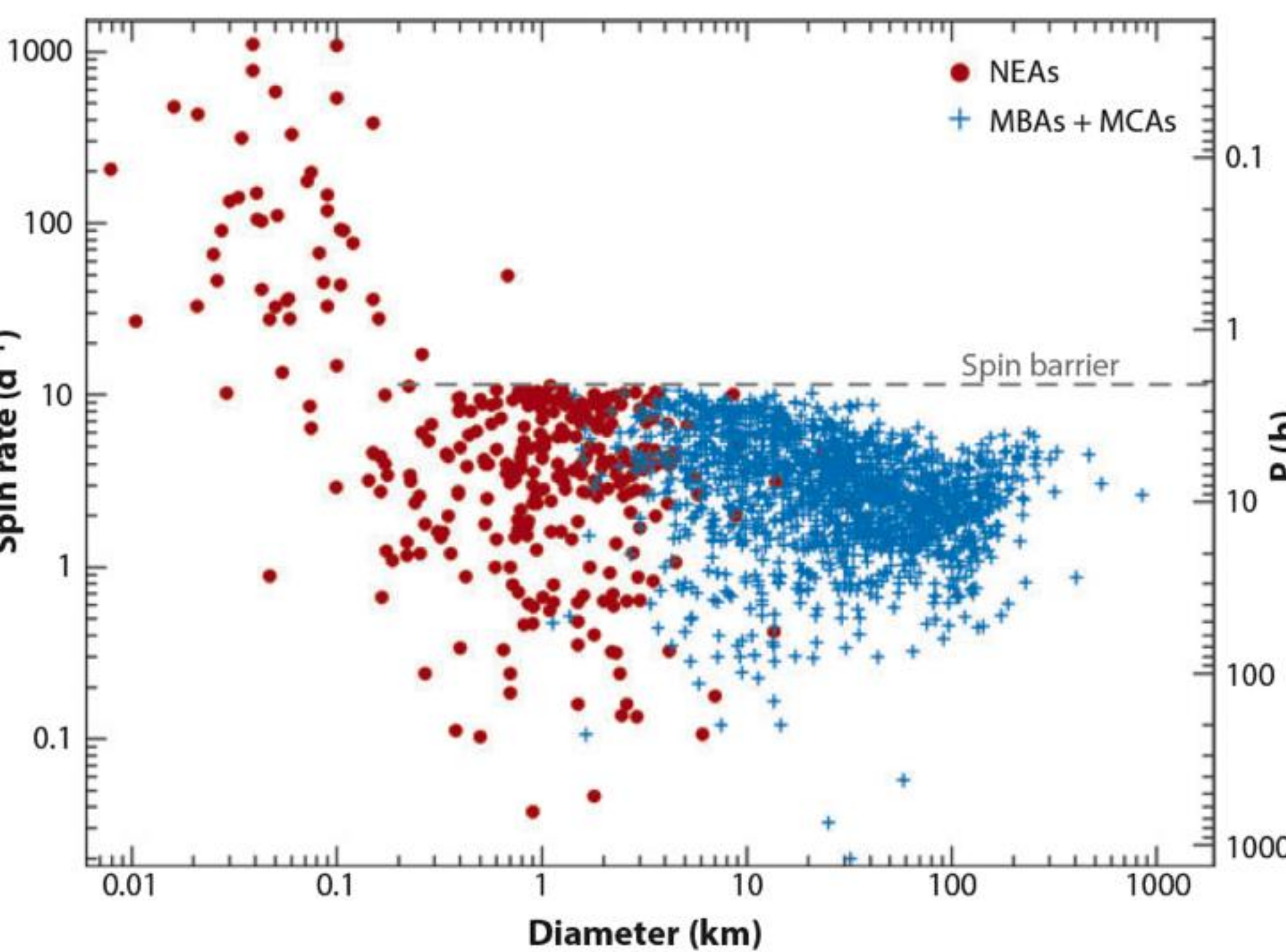
August 5, 1999



August 9, 1999



1999 JM8 (Arecibo and Goldstone)



“..return to the plainness and soundness of Observations on material and obvious things.”

Primitive bodies are incredibly diverse and have a most alien geophysics and geology. “How do they work?”

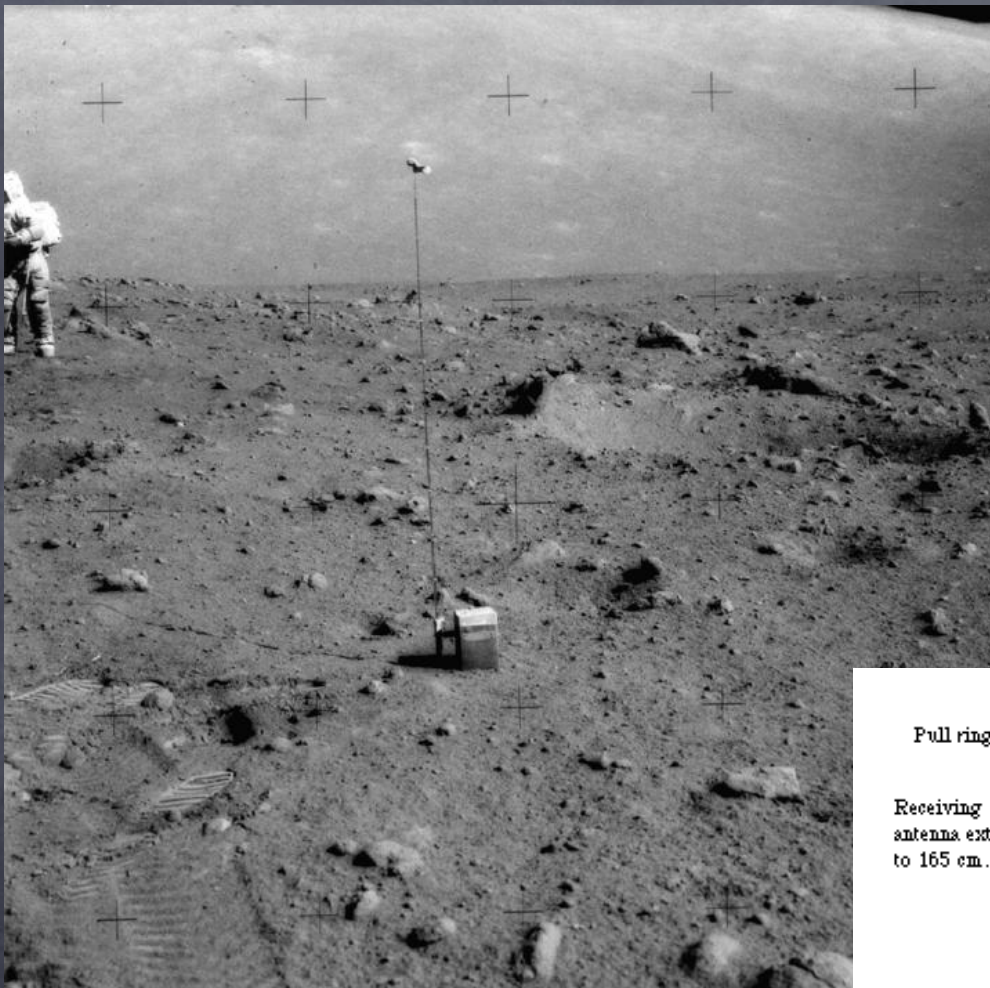
There is a strong requirement for doing active experiments rather than only passive observations.

Also, this can facilitate a cost-effective sample return.

On the flip side, active experiments are facilitated on small bodies by their low gravity.

- easy to bring a payload close to the body
- landing = dropping
- easy to globally activate the body

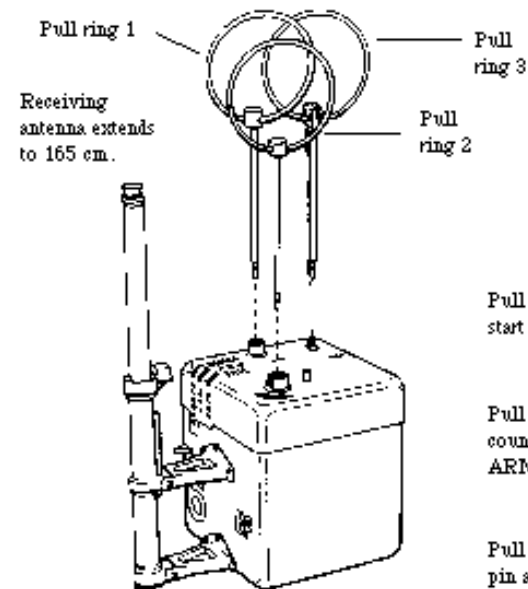
Two examples...



Explosive charge left on the surface of the Moon (Apollo 17)

On A-17, eight explosive charges (containing from 57 to 2722 g of high explosive) were deployed at distances between 100 m and 3.5 km from an array of 4 identical geophones.

These astronauts took
acceptable risks for
science



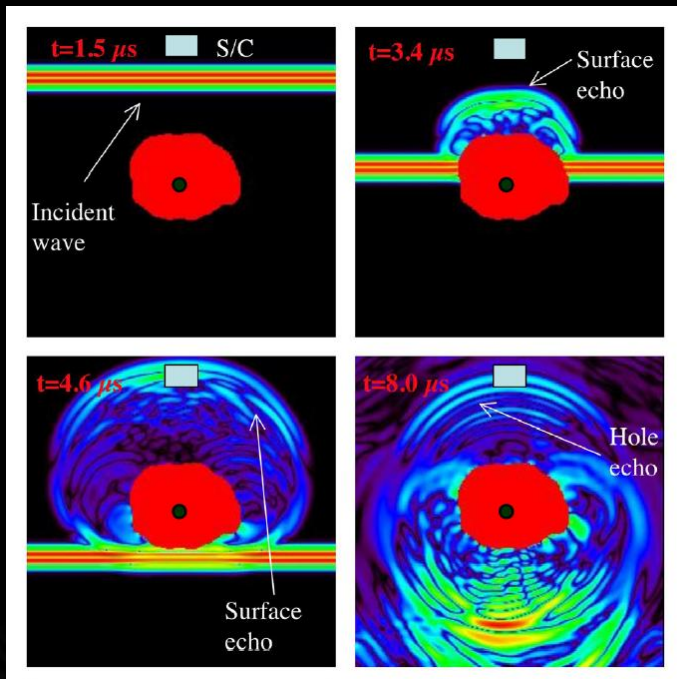
Concept study by Ali Safaeinili et al.

Active radar studies

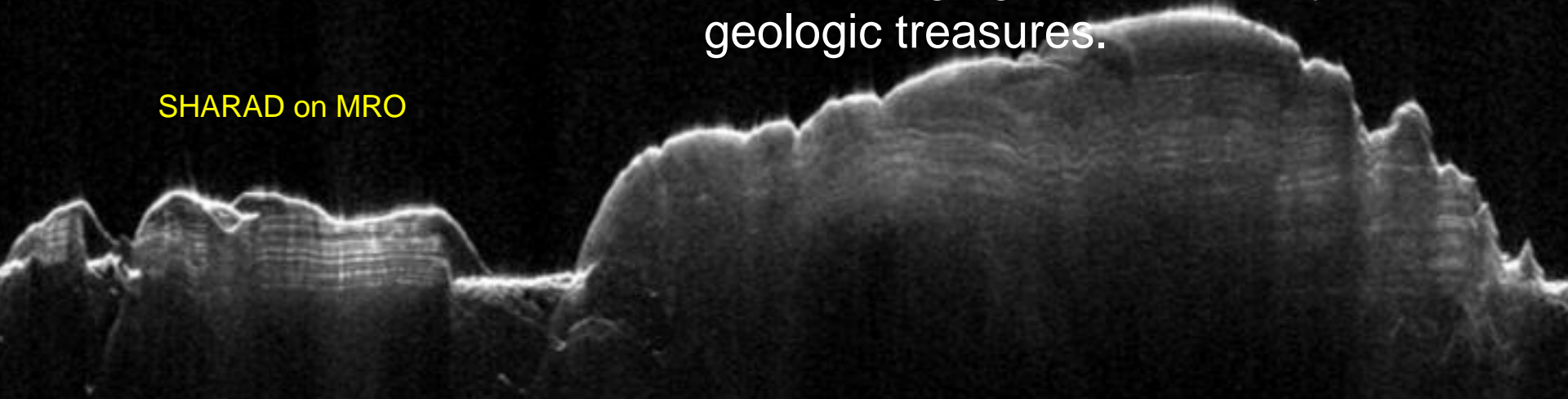
A great idea for comets, maybe even MBCs, but for silicate materials this needs a lot of laboratory work and simulated demonstrations.

For instance, radar imaging of landslides yields very poor information.

Radar imaging of ice sheets yields geologic treasures.



SHARAD on MRO



Lander Technology Development

- Low gravity design studies are essential (e.g. Hayabusa benchmarks in drop towers).
- Will they land right side up in 10^{-5} G? Leave the wheels at home...
- Dust! You thought the Moon was bad...
- Will denser probes sink into the loose surface, never to be seen again? Will ballistic penetrators scatter off the asteroid?
- Thermal concerns! Perhaps especially at NEOs
- Power: batteries get fried; solar panels may deploy upside down or get coated; etc.



OK, here is what's gleaned so far from community input

Why study NEOs

- First, as samples of Main Belt asteroids and comets, replenished on 10 Ma timescales
- Second, because of their biological and societal importance
- Third, to learn of their resources (“...the resources and hazards that are present as humans explore space...”)
- Fourth, because they are easy... the natural first place to go in space

NEO Mission Priorities

Striking the balance between geophysics, astronomy & chemistry..

- Flagship: None (at least until one is headed right for us...)
- New Frontiers: two are recommended for study
 - Sample return from A, P, D, W, B, C, G... that are unrepresented and/or hydrous
 - Multi-rendezvous with higher cost/mass instruments and microlanders
- Discovery: there are existing studies for most of these
 - Rendezvous with novel remote sensing and microlanders
 - Demonstration of sample return strategies (touch & go; kicking rocks around...)
 - Space-based astronomical telescopes
- Research requirement: stable support for ground observations!
 - Identify lowest delta V targets = save hundreds of \$M
 - Scientific context relating to the broad tableau

Asteroid Mission Priorities

- Flagship: none identified so far
- New Frontiers:
 - Trojan asteroid rendezvous
 - Multiple flybys or rendezvous of Main Belt asteroids
 - Asteroid family multi-body tour
- Discovery:
 - D/P/M/K type asteroid rendezvous
 - Multiple asteroid system (binary) rendezvous
 - Trojan and/or MB multiple flybys

Required Technologies

- Remote sensors on Earth and in space
 - Spacecraft systems: guidance, navigation, propulsion
 - Proximity operations at small bodies
 - Flight qualification of instruments
 - Surface mobility and sample collection in microgravity environments
 - Surface science instruments
- Where do we find the greatest potential for cost realism?

Conclusions

- HUGE new developments in asteroid science since the previous decadal review
 - Yark/YORP, Trojans, Itokawa, MBCs, rubble, multiple systems
 - Look at where these developments came from...
- Astronomical capability is flexing plenty of muscle, aligning characterization with detection
- NEO's human interest enhances their potential for international missions and perhaps human spaceflight
- For low cost missions, there is a clear path for technological development and astronomical support.