Resources from Asteroids: What We Can Expect From What We Know Now

Faith Vilas

MMT Observatory

Asteroids: What Do We Know?

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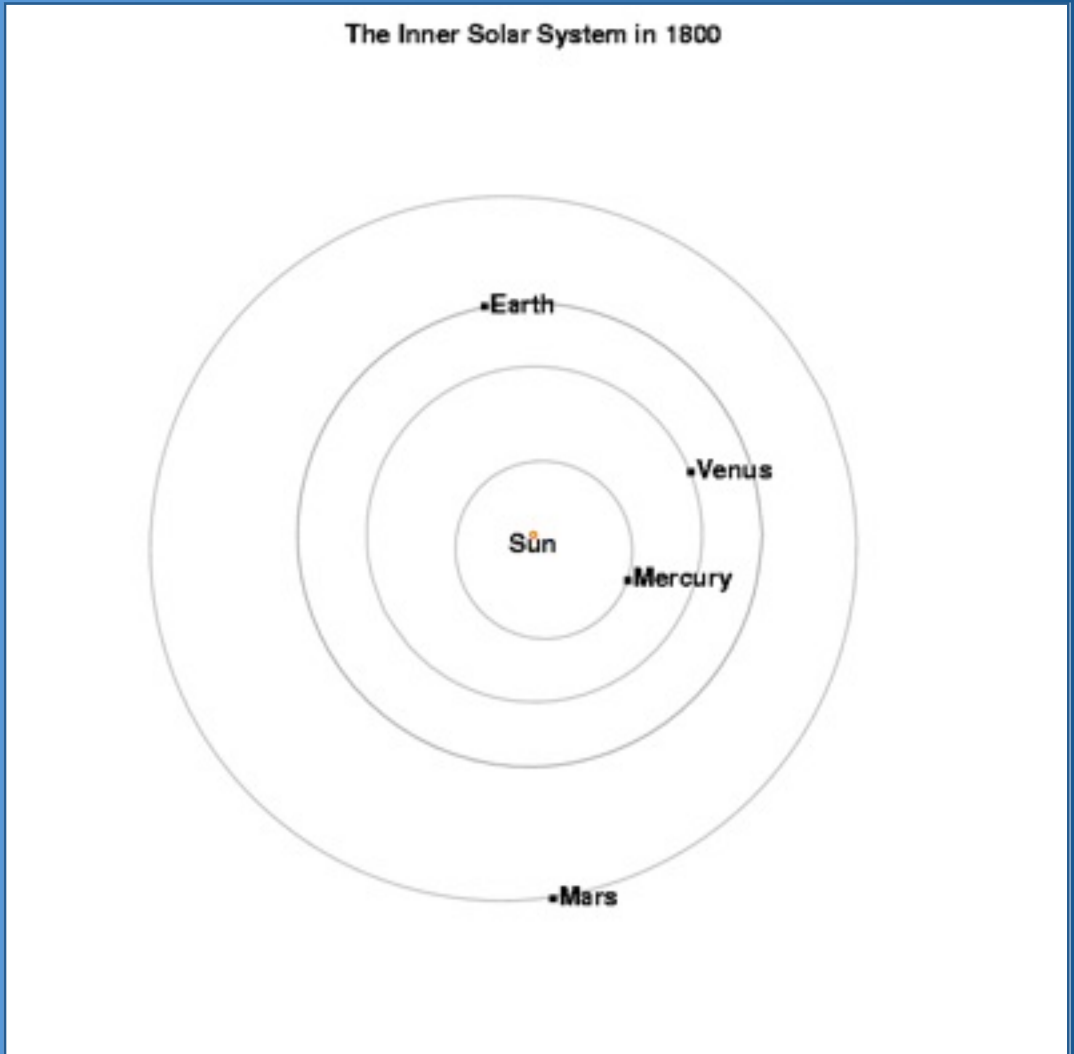
How many asteroids are available to mine?

History of Known Asteroid Population

1800

Earth Crossing

Outside Earth's Orbit



Armagh Observatory

11/20/10

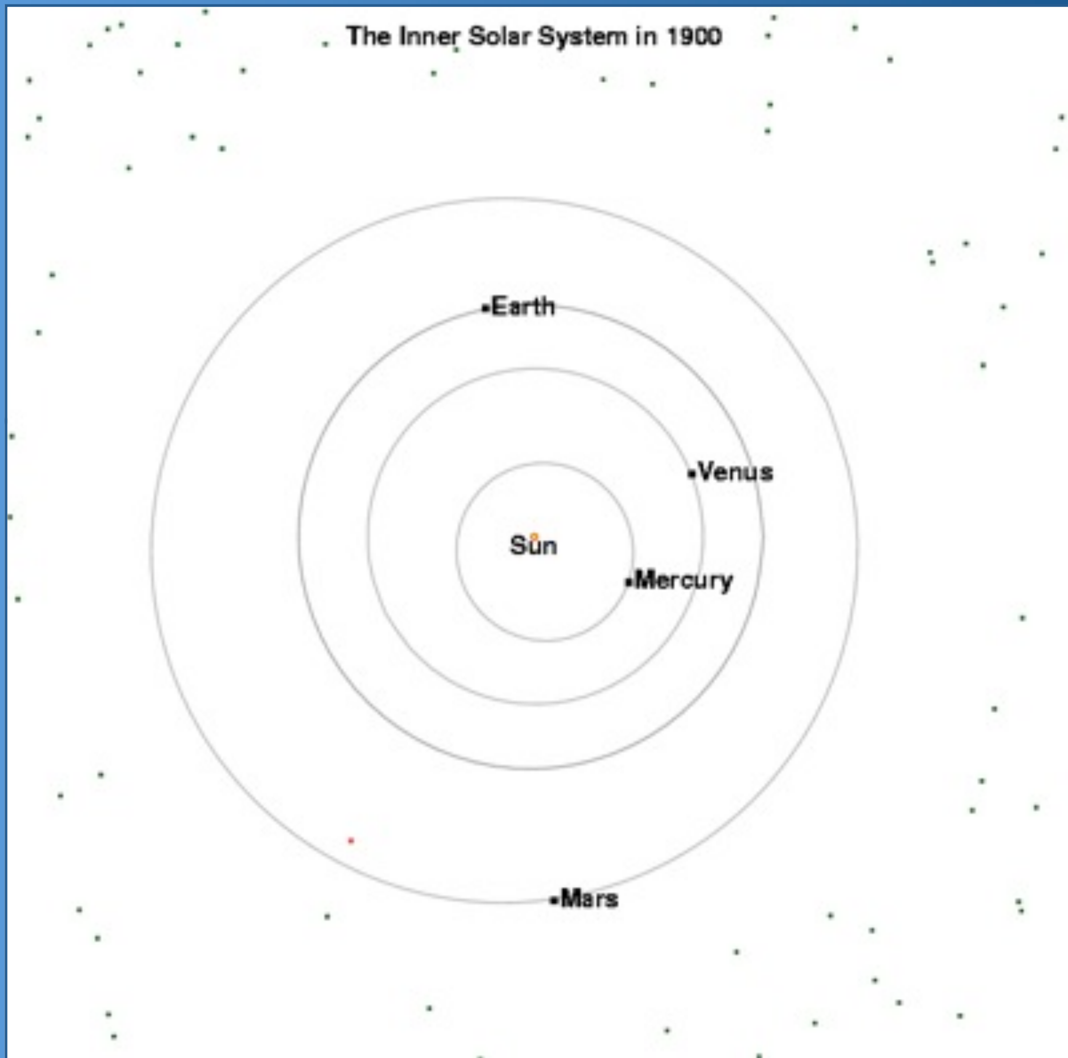
Courtesy L. Johnson

History of Known Asteroid Population

1900

Earth Crossing

Outside Earth's Orbit



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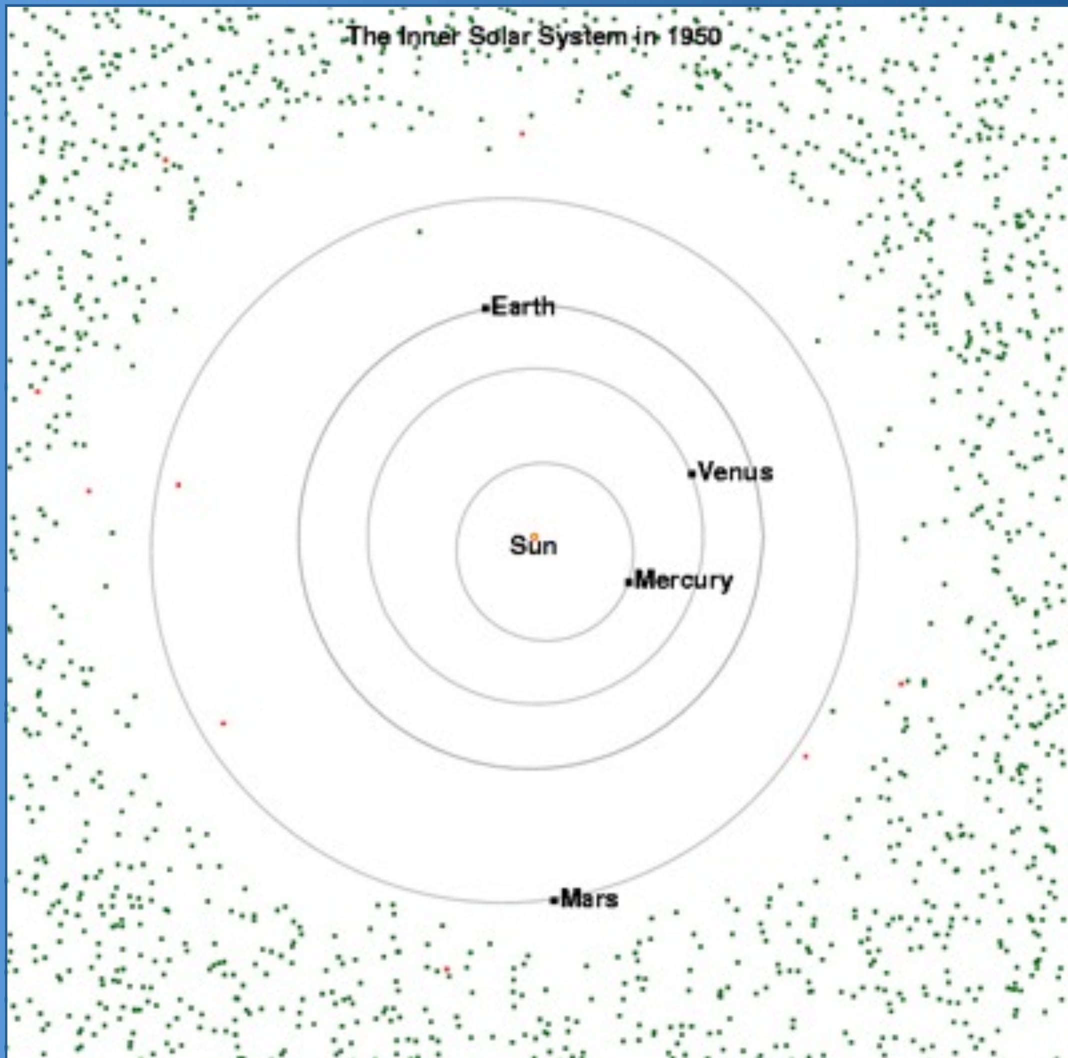
History of Known Asteroid Population

1950

Earth Crossing

Outside Earth's Orbit



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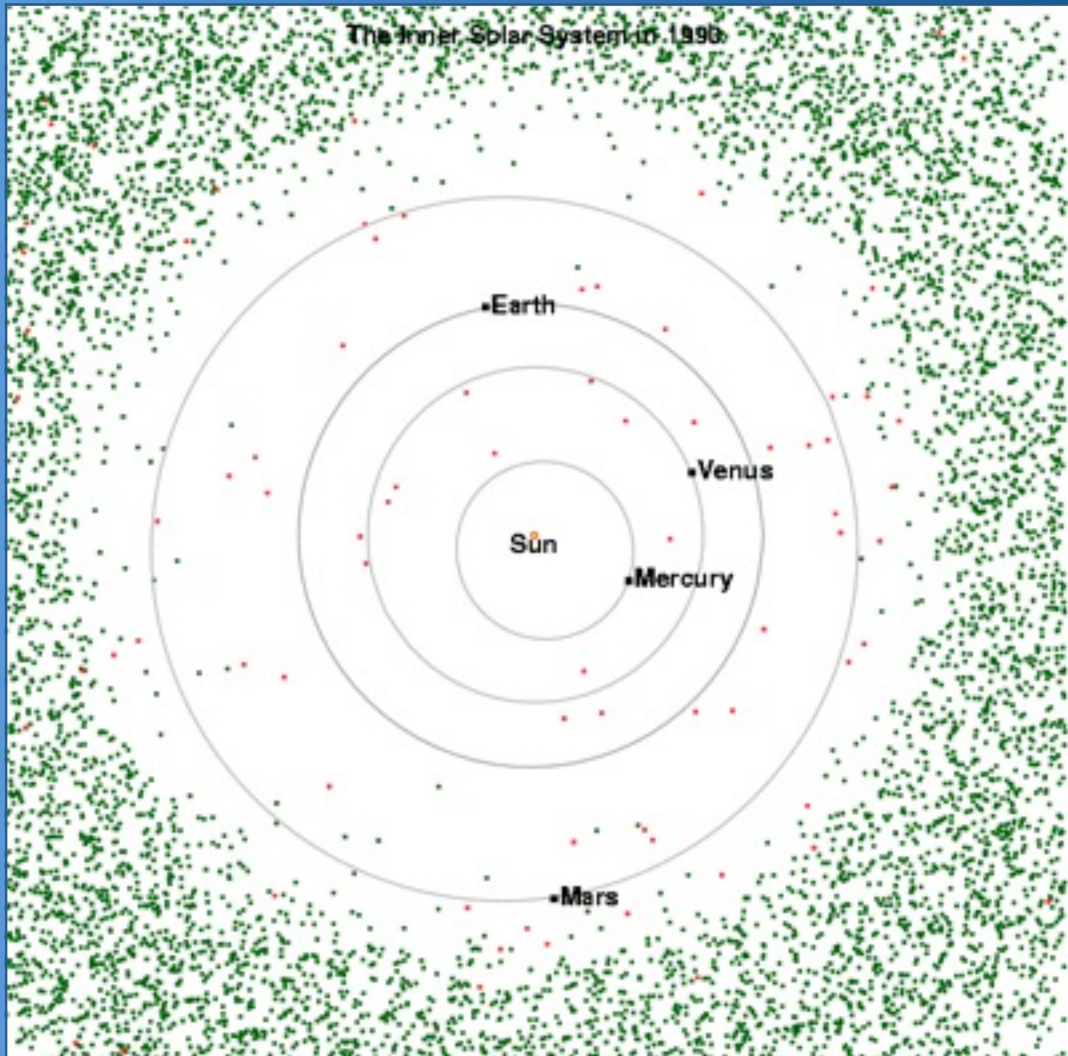
Courtesy L. Johnson

History of Known Asteroid Population

1990

Earth Crossing

Outside Earth's Orbit



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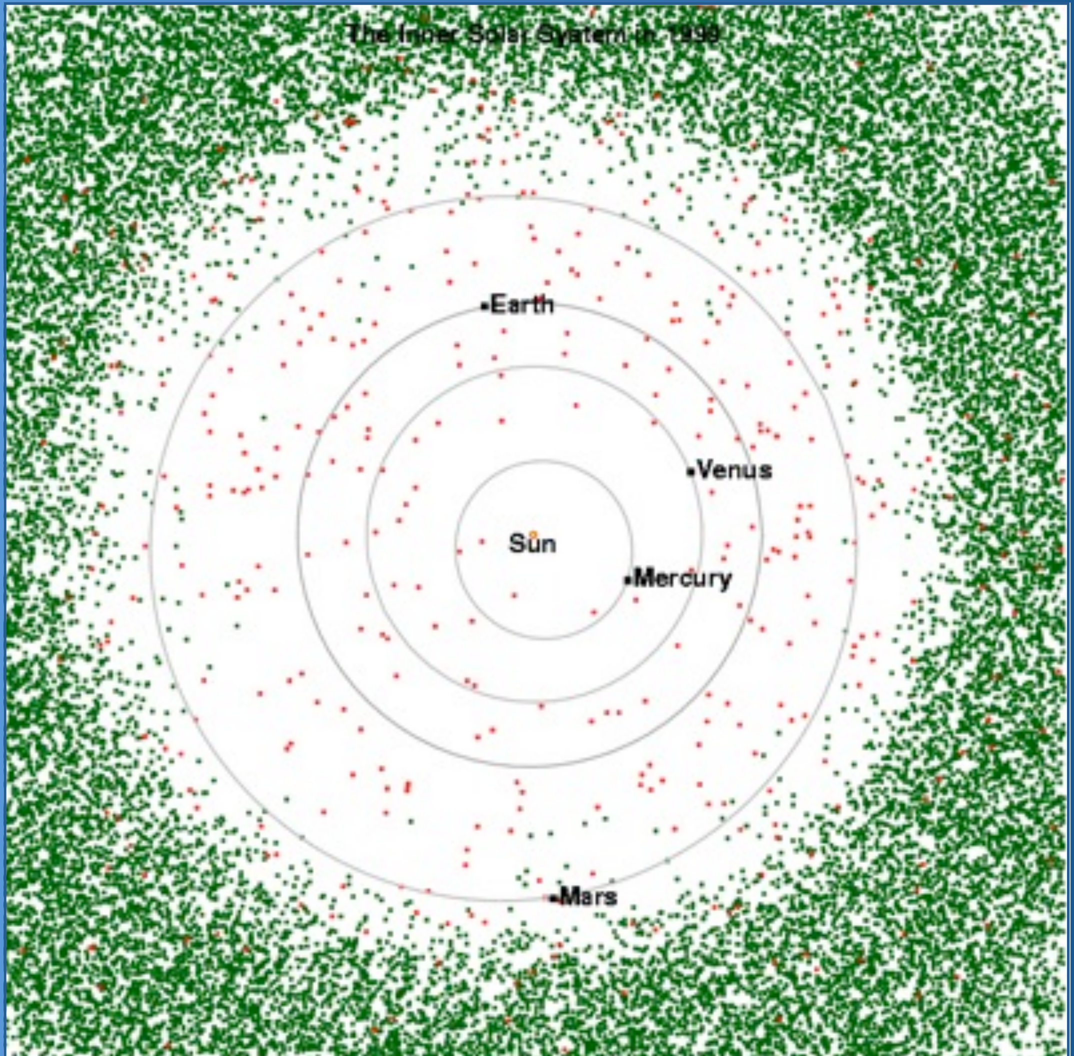
History of Known Asteroid Population

1999



Earth Crossing

Outside Earth's Orbit

Armagh Observatory

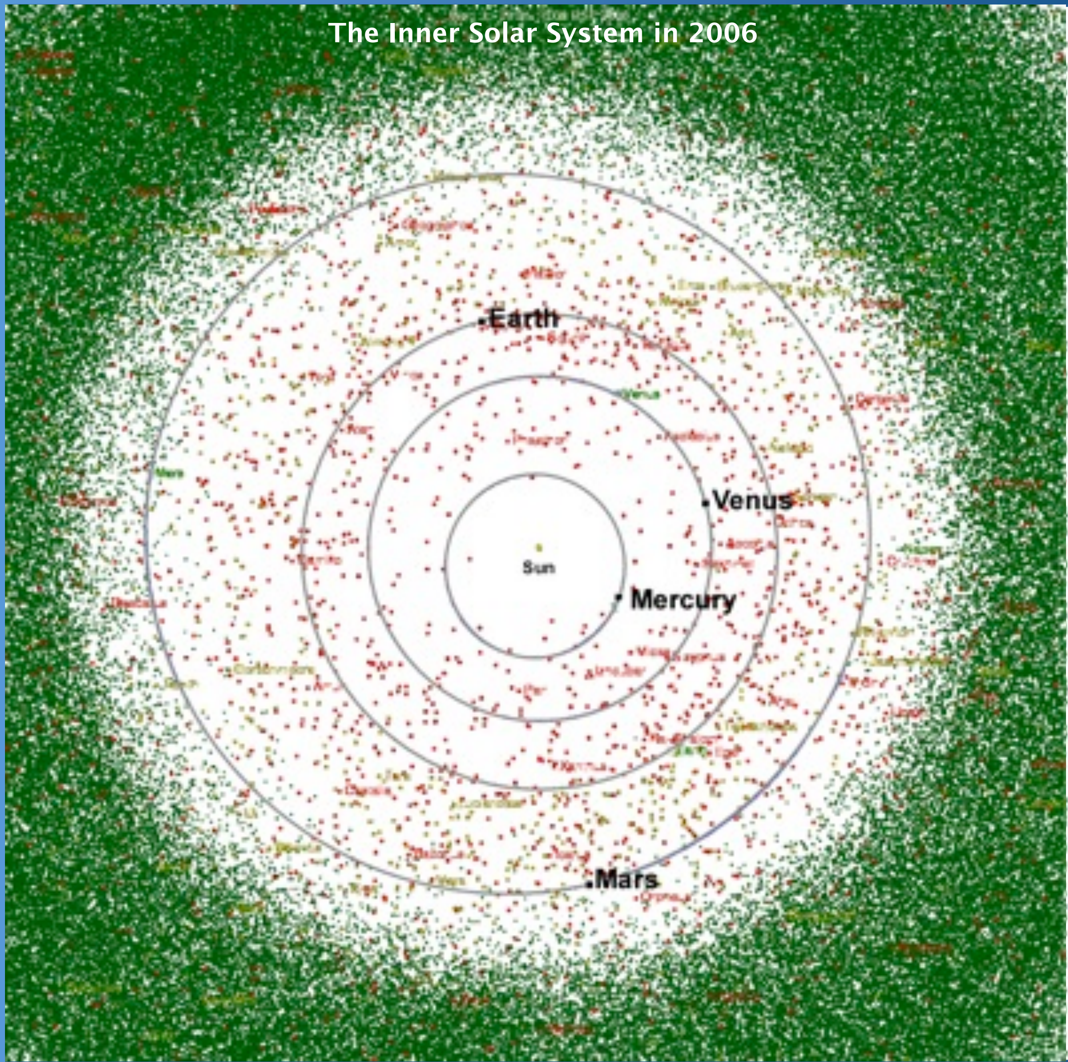
Courtesy L. Johnson

History of Known Asteroid Population

2006

Earth Crossing

Outside Earth's Orbit



Known (10/29/10)

- 538261 asteroids
- 7317 NEAs
- 1150 PHAs

- 66,000+ NEOs
- 18,000+ PHOs

Scott Manley

11/20/10

Courtesy L. Johnson

Asteroids: What Do We Know?

How many asteroids are available to mine?

What's their composition?

Asteroids: Composition and Mineralogy

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We can approach our knowledge of this through different mean

Remote sensing of mineralogy from telescopic or spacecraf
observations of spectral reflectance

"Ground truth" (usually somewhat contaminated) samples
present in meteorite samples (!!)

Spacecraft elemental compositional experiments (γ–ray, x–ray
neutron spectrometers)

Spectral reflectance gives us spectra and photometry by which we class
asteroids, including the NEAs

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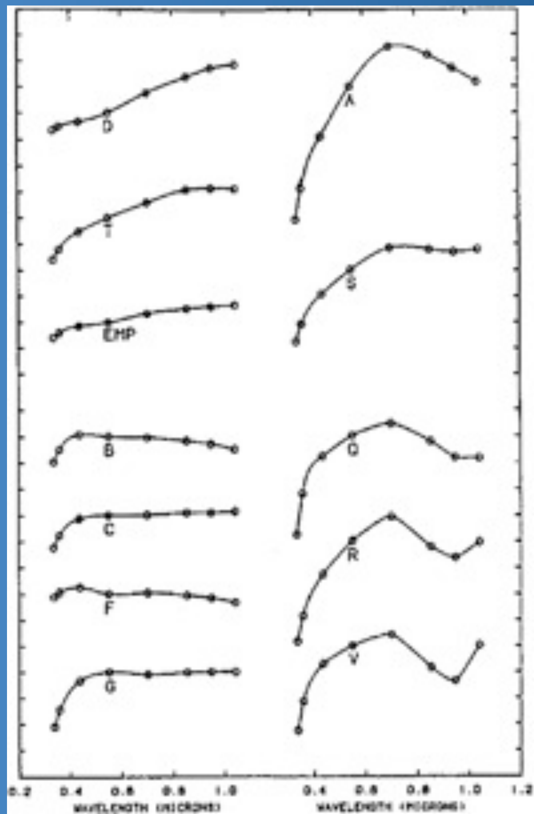
BUT: spacecraft have visited < a dozen asteroids, landed on 2 asteroids, and possibly returned a small sample of one NEA

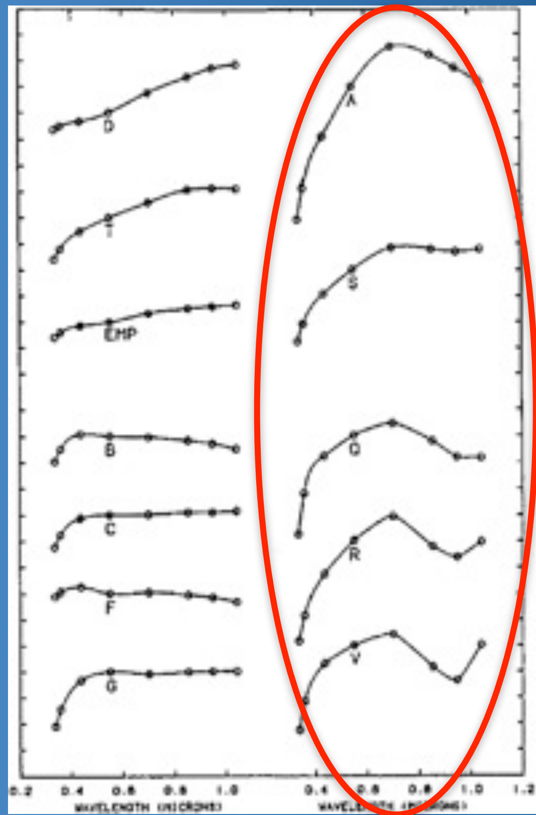
This won’t increase hugely in the near future

So…Earth–based remote sensing is our present best means of studying a large sample of asteroids

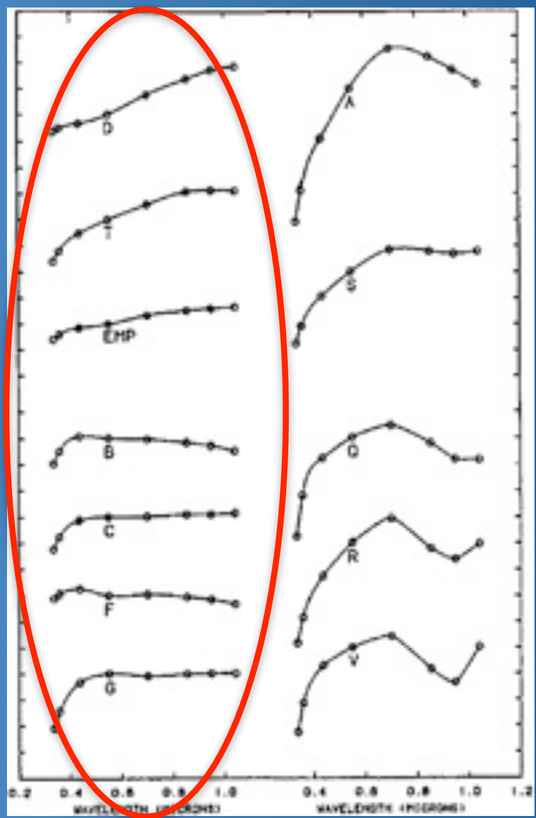
Tholen Asteroid Classes



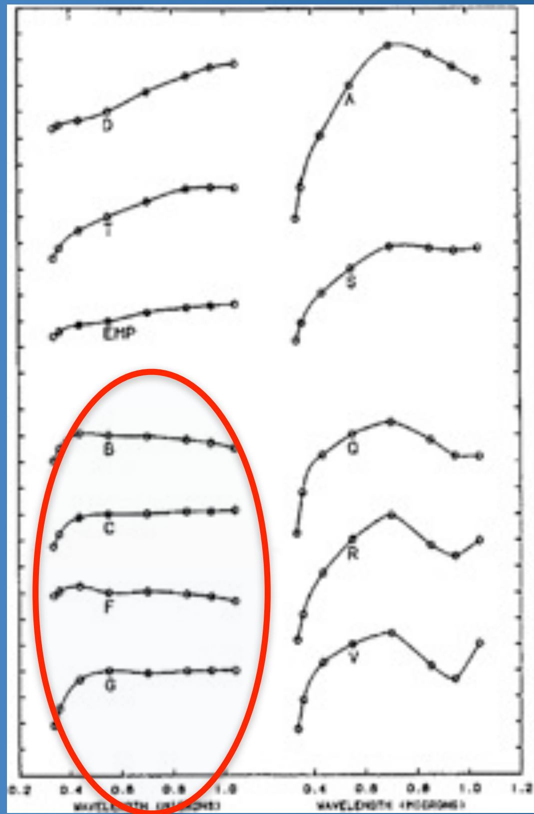
Tholen Asteroid Classes



Tholen Asteroid Classes



Tholen Asteroid Classes



Water-Bearing!

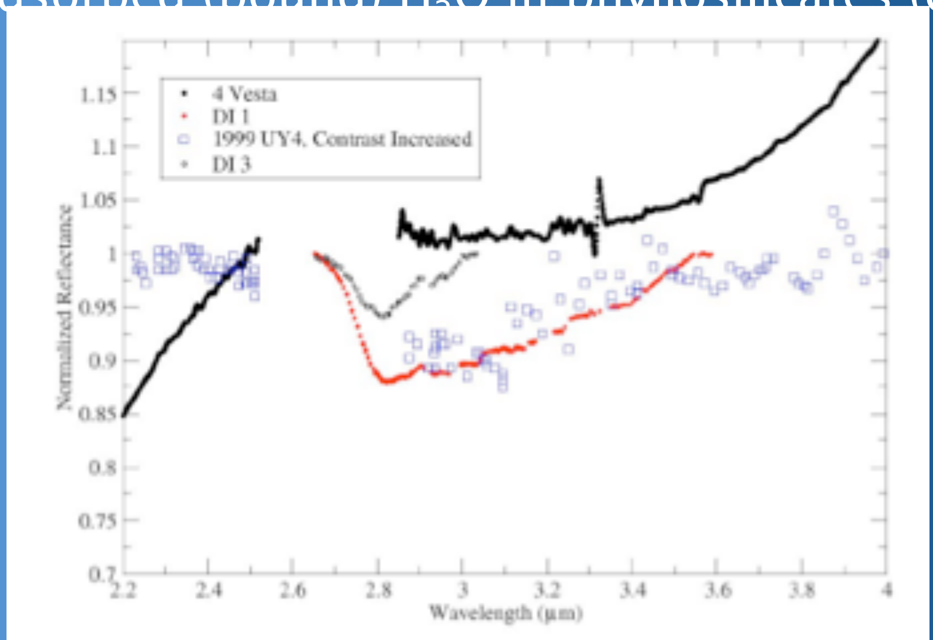
Evidence of water I: Aqueous Alteration

Aqueous alteration: the alteration of material by the interaction of that material with liquid formed by melting of incorporated ice

Asteroids?

Low albedo asteroids : absorption feature near 3.0 μm attributed to structural hydroxyl (OH) and interlayer and adsorbed (bound) H_2O in phyllosilicates (clays)

Rivkin et al. 2010



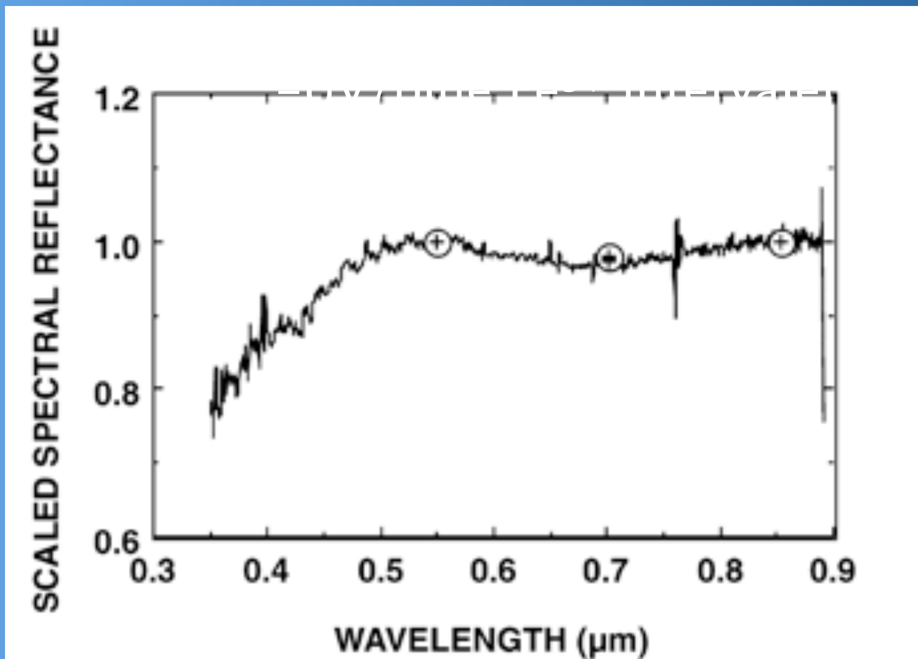
Aqueous Alteration … more

– 0.7-μm $Fe^{2+} \rightarrow Fe^{3+}$ charge-transfer transition in phyllosilicate,
CM2 carbonaceous chondrite, C-class asteroid spectra

–0.43-μm $^6A_1 \rightarrow {}^4A_1$, $^4E(G)$ spin-forbidden Fe^{3+} crystal field
transition similar to that seen in iron sulfate jarosite

charge transfer transition

Vilas et al. 2005



19 Fortuna

Aqueous Alteration … yet more

Aqueously-altered C-complex asteroids dominate asteroid population between 2.6 – 3.2 AU (“Aqueous Alteration Zone” – Vilas 1994)

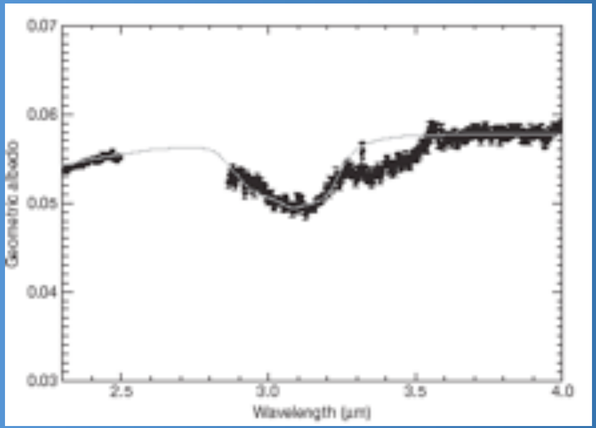
Largely absent in NEA population: 1 asteroid with 0.7-μm feature

1 asteroid with 3.0-μm feature

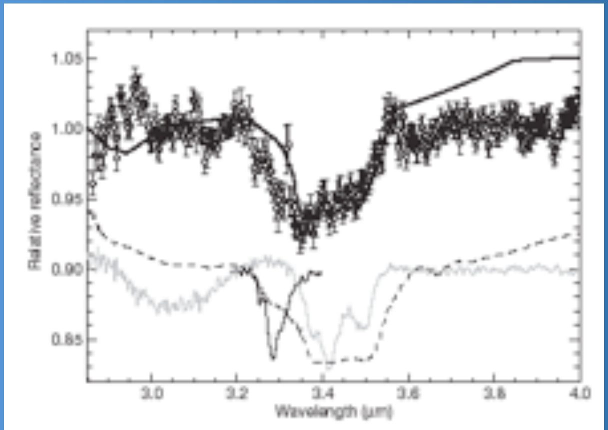
Hard to observe as thermal IR interferes with spectral detection for NEAs

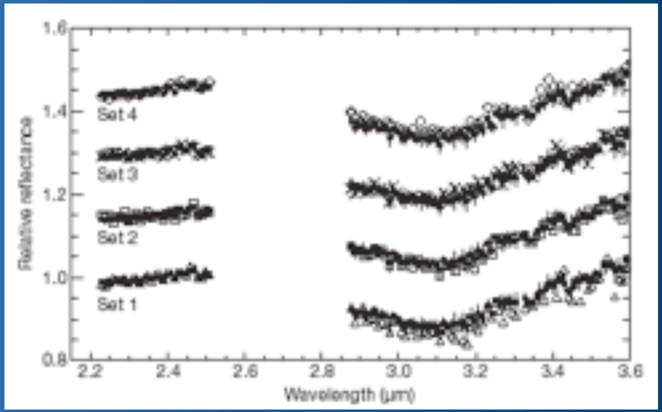
Not replenished in this population in last 10 Myr?

Evidence of water – II: Water Ice on 24 Themis



Rivkin & Emery, 2010





Campins et al., 2010

Evidence of water - II: 1 Ceres (special!)

Varying polar ice caps? IUE spectra of area around Ceres searched for OH generated by photodissociation of atmopsheric water vapor. Detected off northern limb of Ceres after perihelion. (A'Hearn and Feldman, 1992)

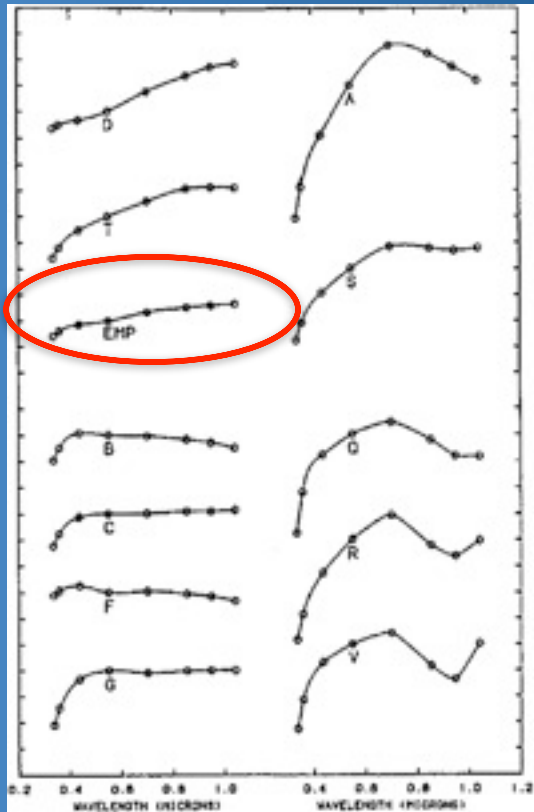
3.0-μm water of hydration absorption feature discovered by Lebofsky (1978, 1980)

Revised interpretation of 3.0-μm feature by King et al. (1989) to be ammoniated saponite
 (different volatile)?

No 0.7-μm feature, but other absorption features in VNIR (Vilas and McFadden 1992,
Vilas et al. 1993, Sawyer 1991)

Radar, mid-IR studies inconclusive

Tholen Asteroid Classes



Heavy Metals!

e.g., concentrated iron,
nickel

Metallics: M-Complex Asteroids

16 Psyche: spectrally "flat", radar reflectivity of a metal

Other M types: cores with remaining bits of mantle on them?

Radar evidence for 4 objects suggesting iron meteorite composition, silicate (pyroxene) absorption features (Bell et al. 2010)

10 different geologic or meteoritic interpretations, including iron meteorites with or without low-Fe pyroxene mantle material, partial melts, serpentinite, CV, R, enstatite chondrites (Harderson et al. 2010)

NEAs? Few M types

NEA Surface Roughness Determined by Radar Observations
Correlated with Taxonomic Class (Benner et al., 2008)

Mineralogy affects the centimeter - to - decimeter structural complexity of NEA surfaces (M class smoothness due to metal component; roughness suggests more structural integrity of minerals in E, V classes)

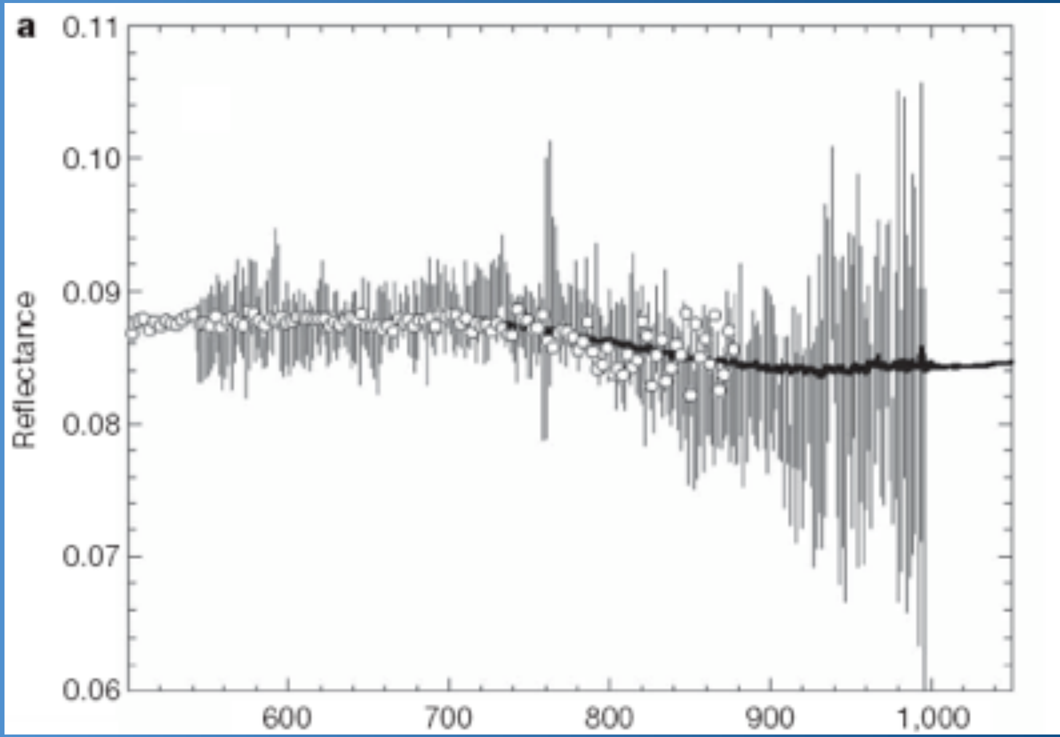
Forrnation ages and collisional histories affect the state of regolith
(if any) on the surface - thicker regolith suggests lower circular
polarization ratio. (E class very young?)

NEAs have higher polarization ratios tha MBAs. This suggests two
types of objects have very different surfaces.

Only M-class NEAs have circular polarization ratios comparable to
MBAs - strength of metal resisting regolith generation.

CAUTION!

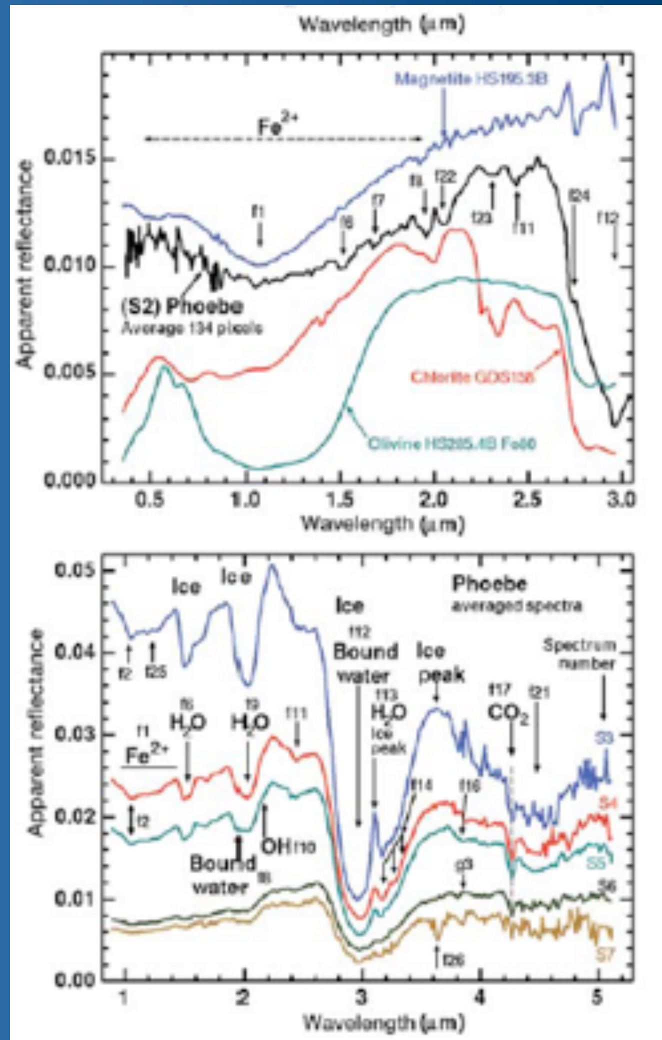
2008 TC3

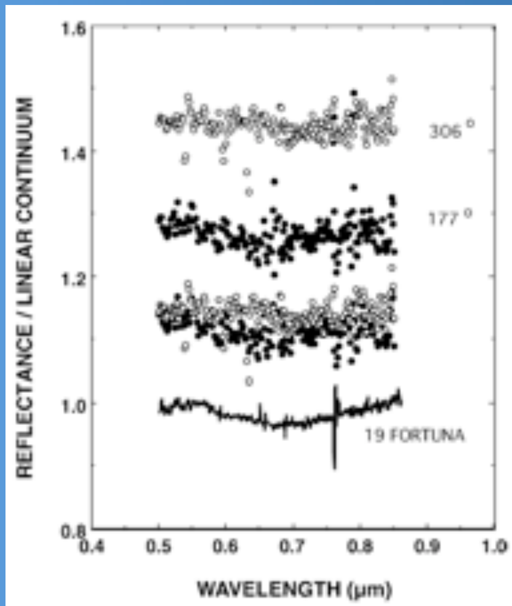


From Jenniskens et al., 2009: TC3 spectrum acquired with 4.2-m Herschell telescope for 6 min; solar analogue 16 Cyg B. Each line represents std dev of 10 spectral points

S6 Phoebe From Ground and Space

Cassini data





Vilas et al. 2005

Clark et al. 2005

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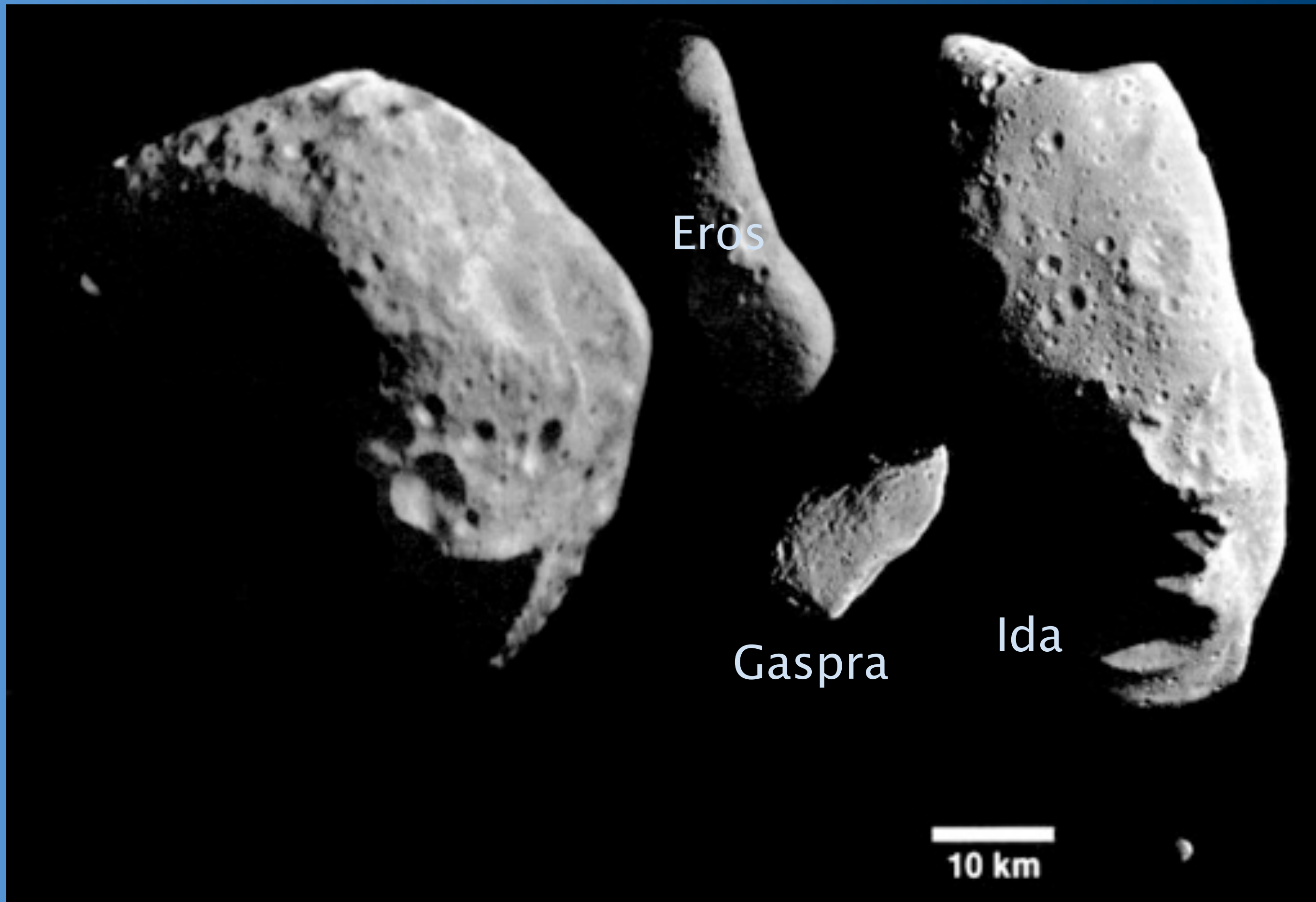
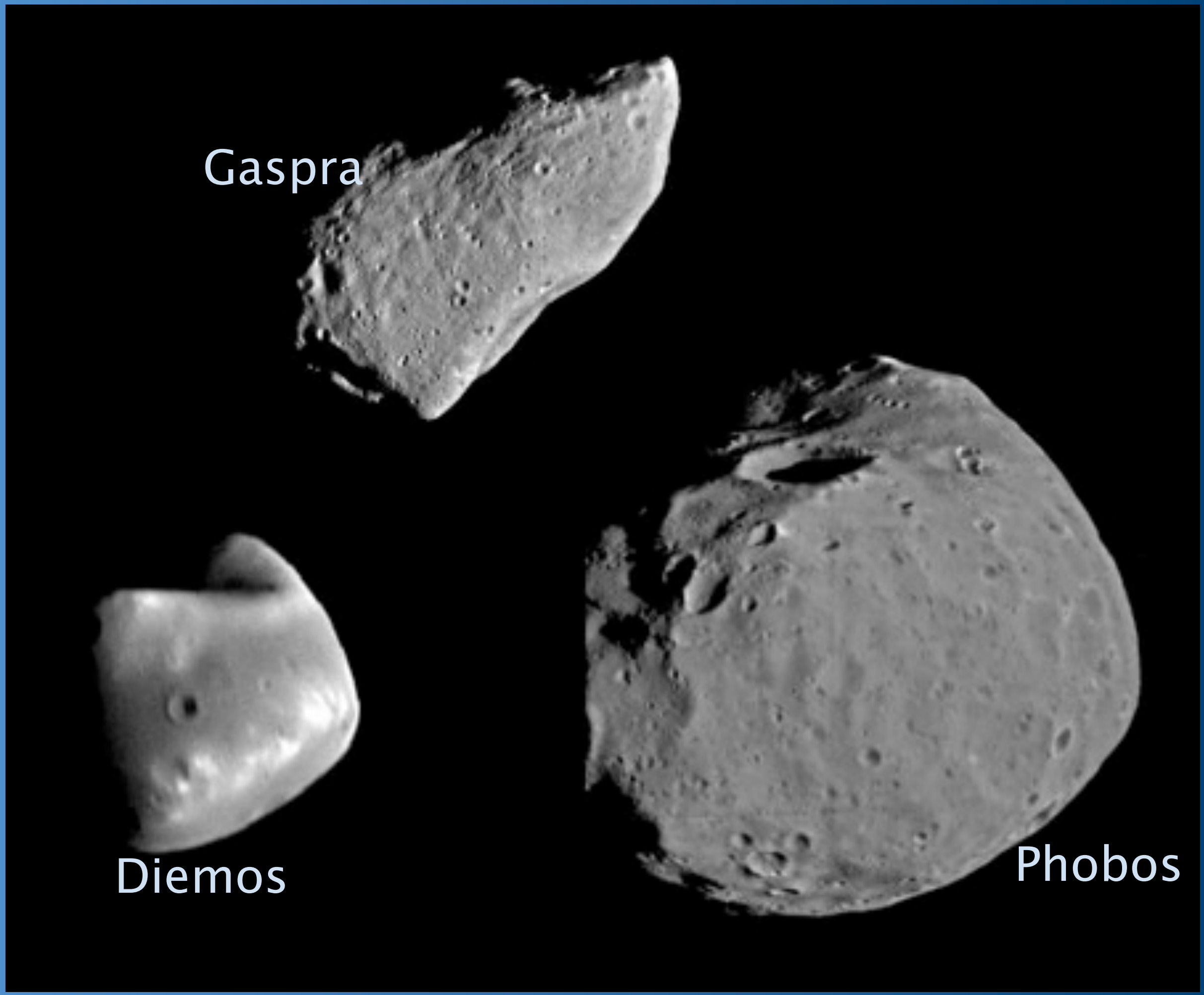
What's their composition?

What's their structure?


Eros
Gaspra
Ida
10 km


Gaspra
Diemos
Phobos

Itokawa Surface Features @ +270 deg. Longitude

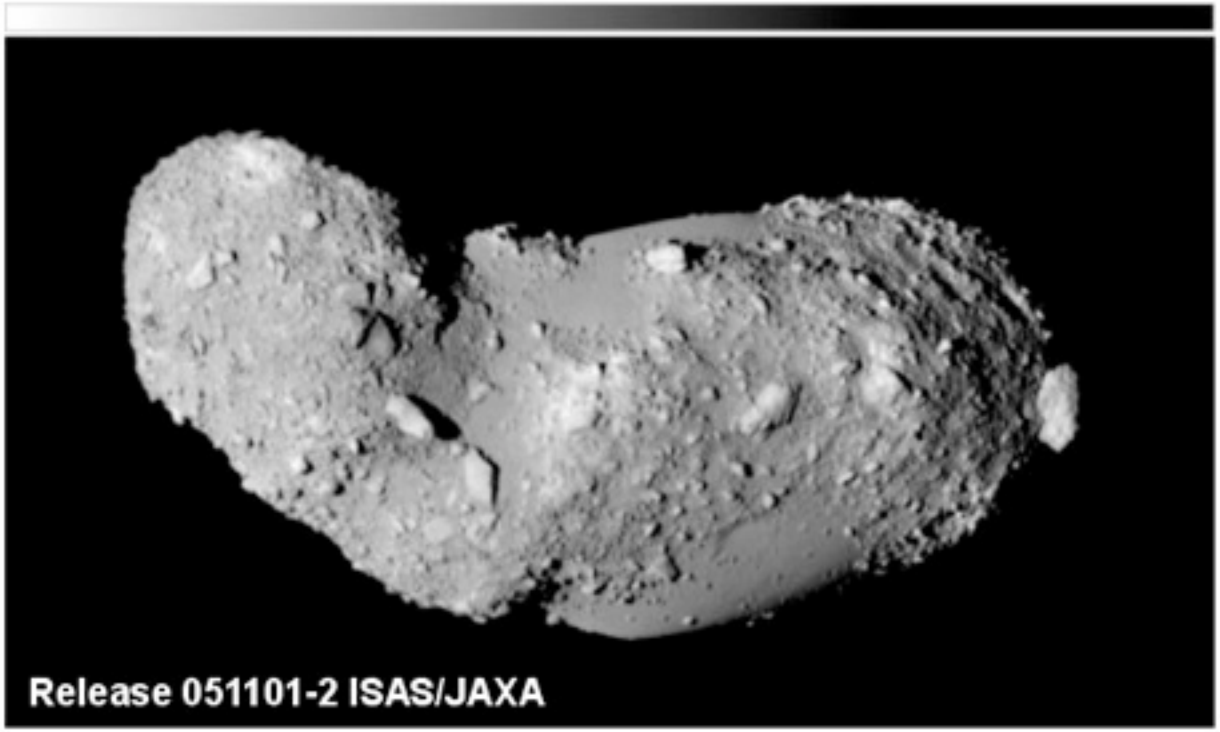


図4 イトカワの +270 度面

Itokawa Surface Features @ +90 deg. Longitude

図3 イトカワの +90 度面

25143 Itokawa

Mass 3.58 ± 0.18 x 10 kg

Density 1.95 ± 0.14 g/cm2

Porosity 39% (assuming bulk density of LL chondrite meteorite)

Rotational Period 12.1324 hr (>> 2 hr period below which rubble pile cannot withstand centrifugal forces)

Surface structure characteristics suggest gravitational re-accumulation of material

“There is more diversity in the Solar System than there is in the brains

"There is more diversity in the Solar System than there is in the brains of bright theorists!"

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Andre Brahic

Where do NEAs reside in near-Earth space?

Apollos: perihelia $<$ 1.017 AU; a $>$ 1 AU; most PHAs are Apollos

Amors: 1.017 AU $<$ perihelia $<$ 1.3 AU; cross Mars' orbit

Atens: a $\leq$ 1.0 AU, aphelia $>$ 0.983 AU, orbits that cross Earth orbit $\leq$ 500 known, ~20% PHAs

Apohele's/Arjuna/A-something: both perihelia and aphelia $<$ 1.0 AU, very difficult to observe, 5 are known, 4 are also suspected (D. Tholen, private comm)