Martian Satellites and Asteroids

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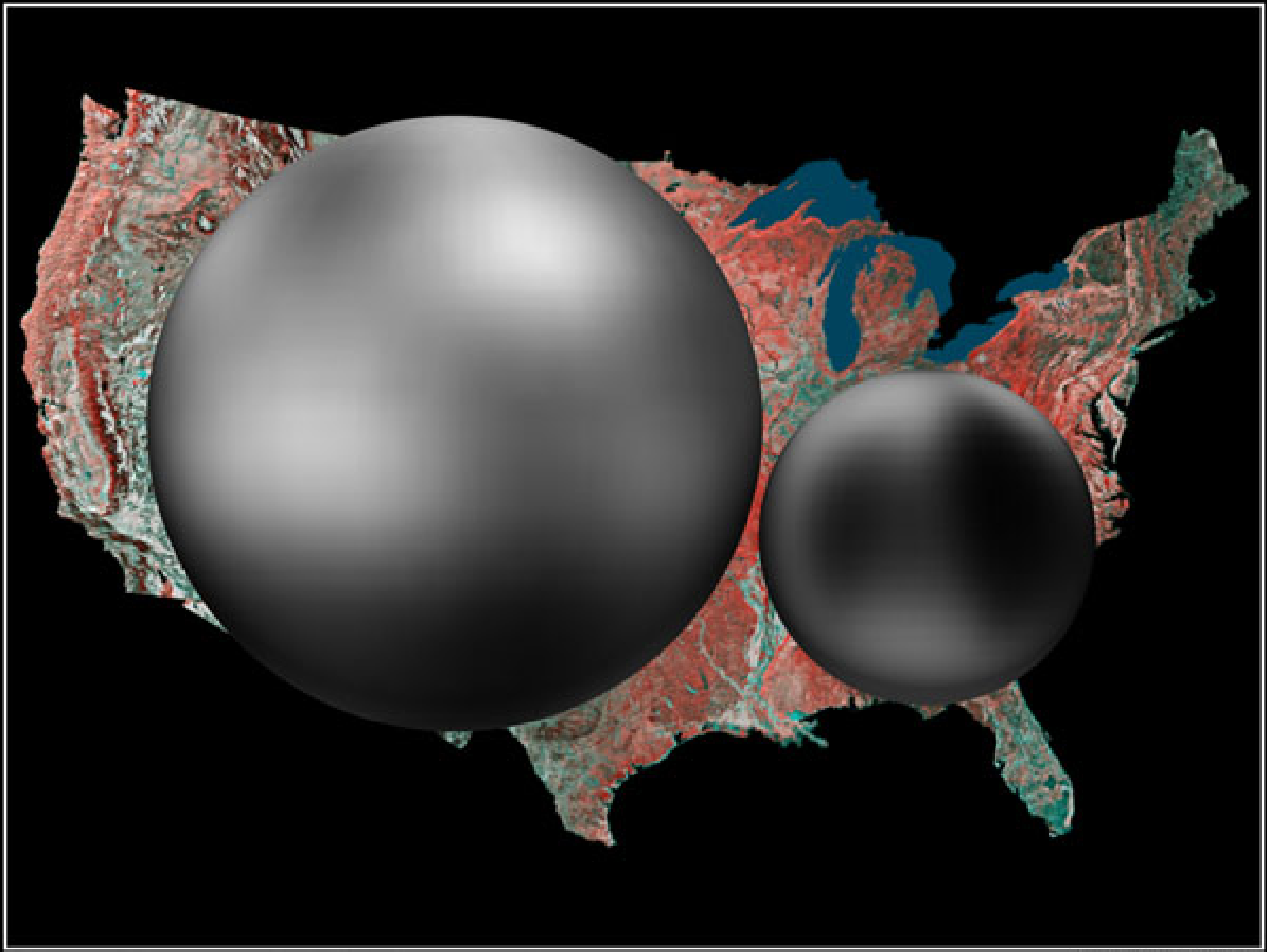
International School of Planetary Sciences, Awaji, 13-17 September 2004

Quiz-1

- There is a satellite larger than planet Pluto.

- **YES or NO**



Pluto, Charon, & USA Comparison

Equatorial radius: Pluto (1137km), Charon (586 km)

YES! There are 7 satellites larger than Pluto (1137 km)

The Moon (Earth) 1738

Io (Jupiter I) 1821

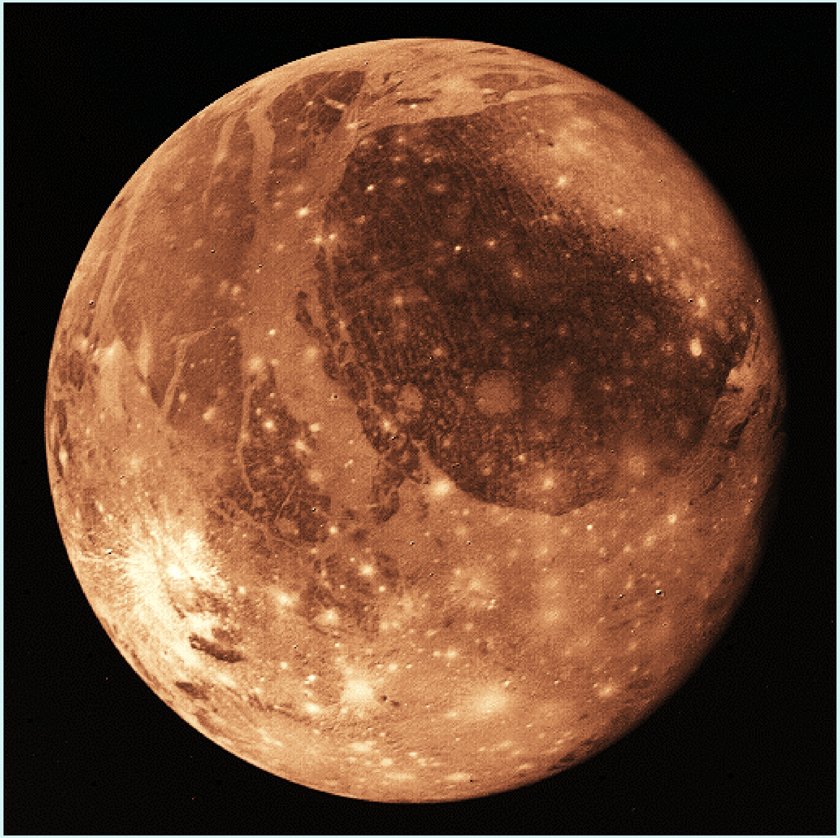
Europa (JupiterII) 1565

Ganymede (JupiterIII) 2634→

Callisto (Jupiter IV) 2403

Titan (Saturn IV) 2575

Triton (Neptune I) 1353



Quiz-2

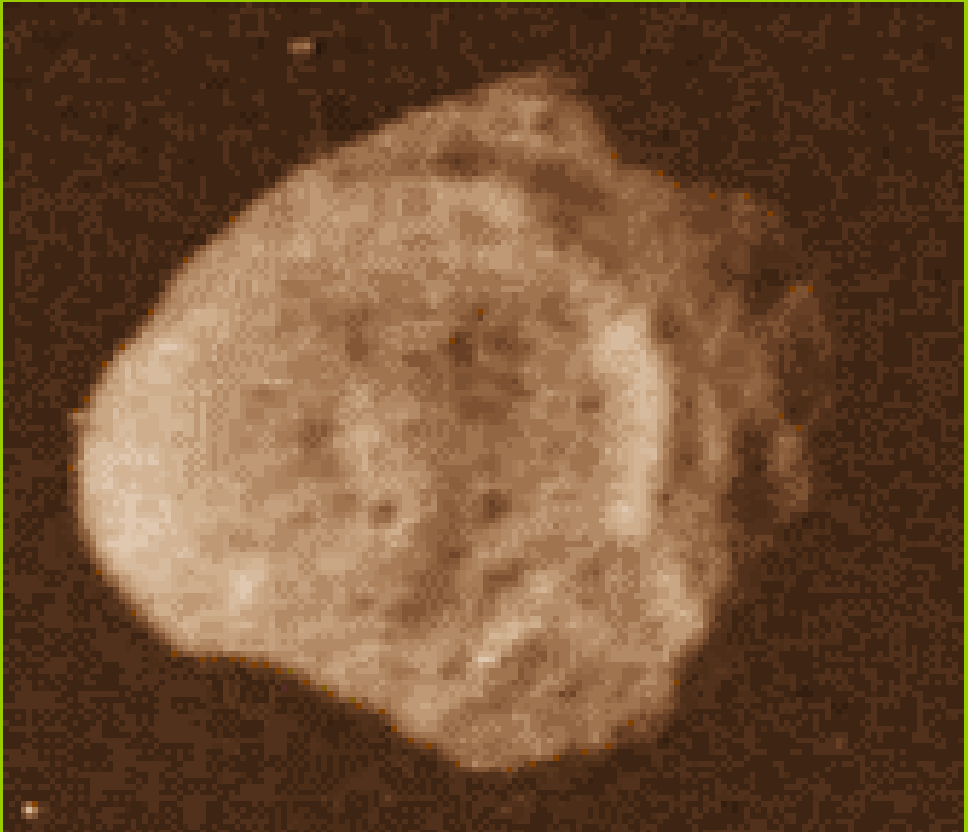
- There is a satellite with irregularly shape, not a sphere.

- YES or NO

YES!   Many irregularly satellites exist.

The largest one is Hyperion

(Saturn VII, 180 x 140 x 113 km)



the Voyager 2 spacecraft on August 25, 1981.

Martian satellites are also irregularly shape.

Quiz-3

- There is a satellite, which orbital period T (length of year) is shorter than rotation period P_M (length of day) of mother planet.

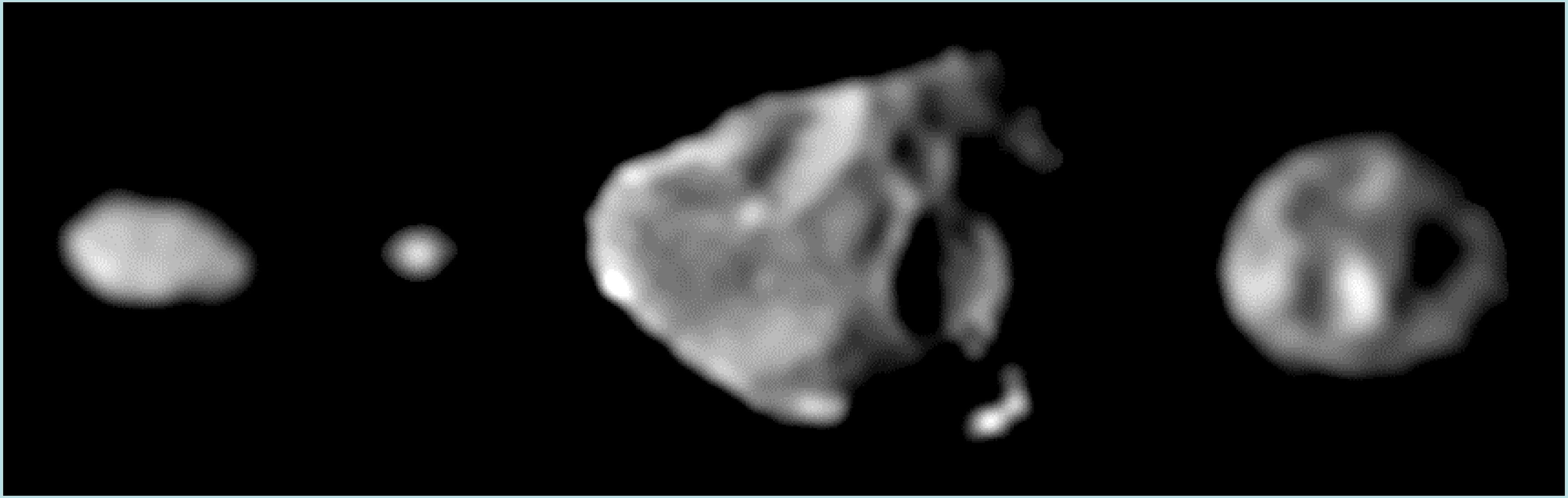
- YES or NO

- **In the case of The Moon T = 27.3 Earth days**
- **Earth P_{earth} = 1 Earth day**
- **→ → → $T > P_M$**

YES! There are 3 satellites, up to now.

- **Adrastea (Jupiter XV) T=0.2983 < $P_{jupiter}$=0.414 E-days**
- **Metis (Jupiter XVI) T=0.2949 < $P_{jupiter}$=0.414**

- **Metis(60km), Adrastea(20km), Amalthea(247km), Thebe(116km)**



- **Galileo Produced by: NASA/Cornell University Copyright: Public Domain**

The third one is one of Martian satellites

Phobos (Mars I)

$T=0.3189 < P_M=1.026$ Earth days

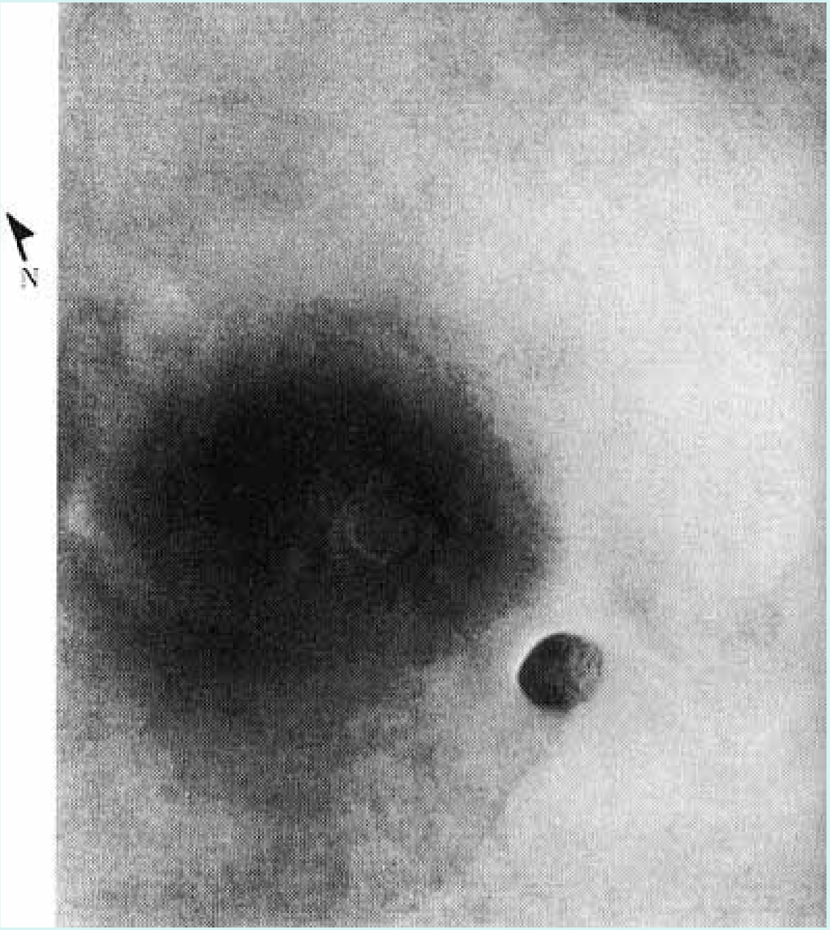
The largest moon of Mars:
Phobos

- A messanger of the Roman god of war
- Discovered by A. Hall in 1877

with a giant impact crater

Phobos Overflying Ascraeus Mons

Viking Orbiter 2 was about 13 000 km above the surface of Mars and about 8000 km above Phobos



NASA SP-441: VIKING ORBITER VIEWS OF MARS

http://history.nasa.gov/SP-441/contents.htm

The second moon of Mars:
Deimos

- The Roman god of dread
- Discovered by A.Hall in 1877

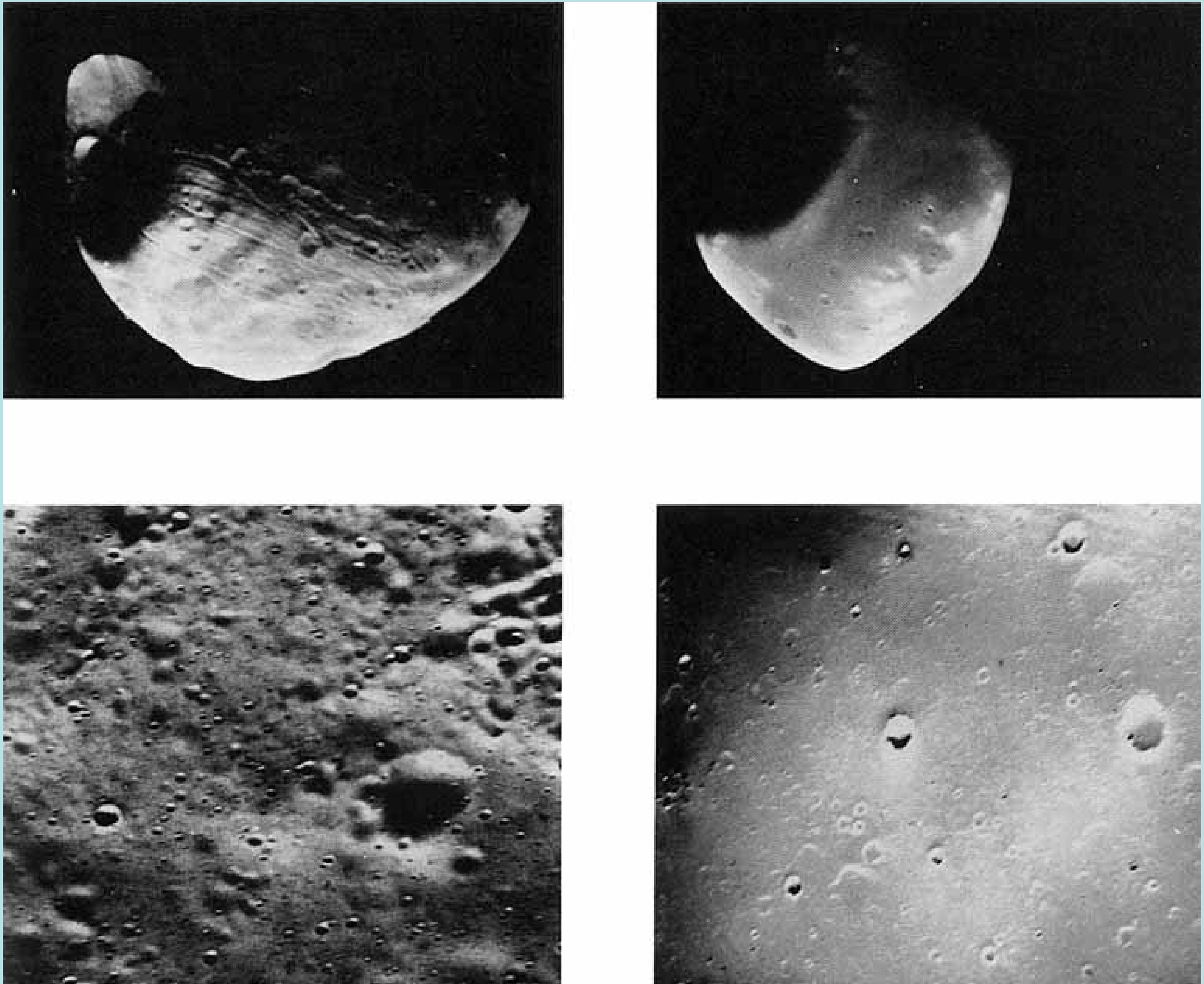
With a thick regolith layer of 100m-depth

Deimos from 30 Kilometers

NASA SP-441:
VIKING ORBITER

VIEWS OF MARS

Phobos and Deimos-Similar but Not Identical



NASA SP-441: VIKING ORBITER VIEWS OF MARS

The Moon and Phobos/Deimos

	R (km)	ρ (g/cm^3)	a (in unit of mother planet's radius R)
Earth	6378	5.52	
the Moon	1738	3.34	60.3
Mars	3397	3.93	
Phobos	13.4×11.2×9.2	1.53±0.10	2.76
Deimos	7.5×6.1×5.2	1.3 ±0.8	6.92

R: Equatorial Radius (km)

ρ : Mean Density (g/cm^3)

a: Semi-major Axis in unit of mother planet's radius R

Martian satellites are small with relatively low mass density and are located closer to mother planet.

Fact sheet of orbital elements
(see Appendix 1 in p.218)

Phobos   Deimos

- **Average distance from Mars**

  2.76 6.92 RM

- **Orbital eccentricity**

  0.017   0.0031

- **Orbital inclination to ecliptic of Mars**

  1   1.7 deg.

Two satellites of Mars are small

	Mass ratio (to mother planet)	Size ratio (to mother planet)
The Moon	1.2×10^{-2}	0.27
Phobos	2.0×10^{-8}	0.0033
Deimos	0.3×10^{-8}	0.0018

Phobos and Deimos are small "lumpy", heavily cratered objects.

Two satellites have extremely low mass density

Phobos 1.53 ± 0.10 g/cm³   Deimos 1.3 ± 0.8 g/cm³

Comparison with Asteroid' Density (g/cm³)

Britt et al. 2002 ASTEROID III, 485

- *1 Ceres (G) 2.12 ± 0.04*   *16 Psyche(M) 2.0 ± 0.6*
- *2 Pallas(B) 2.71 ± 0.11*   *45 Eugenia(F) 1.2+0.6 -0.2*
- *4 Vesta (V) 3.44 ± 0.12*   *121Herminone(C) 1.96 ± 0.34*
- *20 Massalia(S) 3.26 ± 0.6*   *253 Mathilde (C) 1.3 ± 0.2*
- *243 Ida (S) 2.6 ± 0.5*
- *433 Eros(S) 2.67 ± 0.03*

Why so low?

Two satellites are on orbits synchronous with Mars

	P (Earth days)	T (Earth days)
Phobos	1.026	0.32
Deimos	1.026	1.26

P = rotation period (length of day),

T = orbital period (length of year)

P of Mars is 1.026 Earth days.>>>>>>>>>>

Two satellites are synchronous with Mars.

Future of Phobos

Phobos is nearing Mars at a rate of 1.8 m/100yrs, and consequently Phobos will reach Mars in 50 million years.

Phobos may eventually be torn apart when the tidal forces of Mars overcome the cohesive bond between its particles. Phobos, already inside the "Roche Limit" where internal gravity alone is too weak to hold it together, could conceivably become a ring plane about Mars within the next 50 million years.

On the other hand, ***the Moon moves further away*** from the Earth due to a misalignment of ocean tidal bulge with Earth-Moon line.

Surface structure of two satellites: shape

Phobos

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Viking data at http://www.solarviews.com/cap/mars/phobos5.htm

Deimos

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A near catastrophic impact formed a large depression on the south pole and blanketed the most satellite surface by a thick layer of ejecta (over 50m) (Shingareva 2002,

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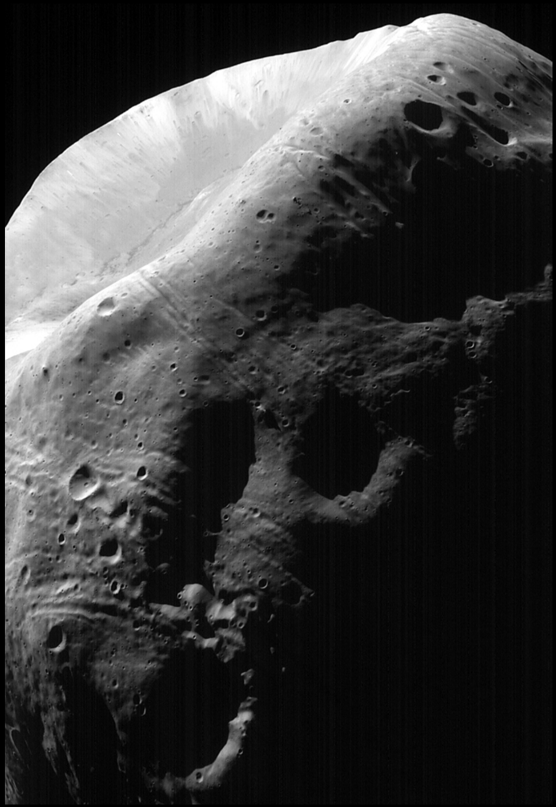
Surface features on Phobos

Most prominent feature: Stickney



largest crater (〜10km in size)

Impact causing streak patterns

Another feature on Phobos is Grooves

- Straight appearance less than ***30m deep*** and typically ***100 to 200 m wide***, and ***lengths of nearly 20km***
- (1) **Fracture hypothesis**
- (2) Secondary cratering hypothesis

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The grooves are observed on every asteroid

- These grooves are currently believed to form where loose, incohesive regolith drains into underlying gaping fissures (Thomas et al. 1979)
- The grooves' width and the spacing of beads along them are proportional to the depth of the regolith

(Horstman and Melosh 1989)

High Resolution View of Grooves on Phobos

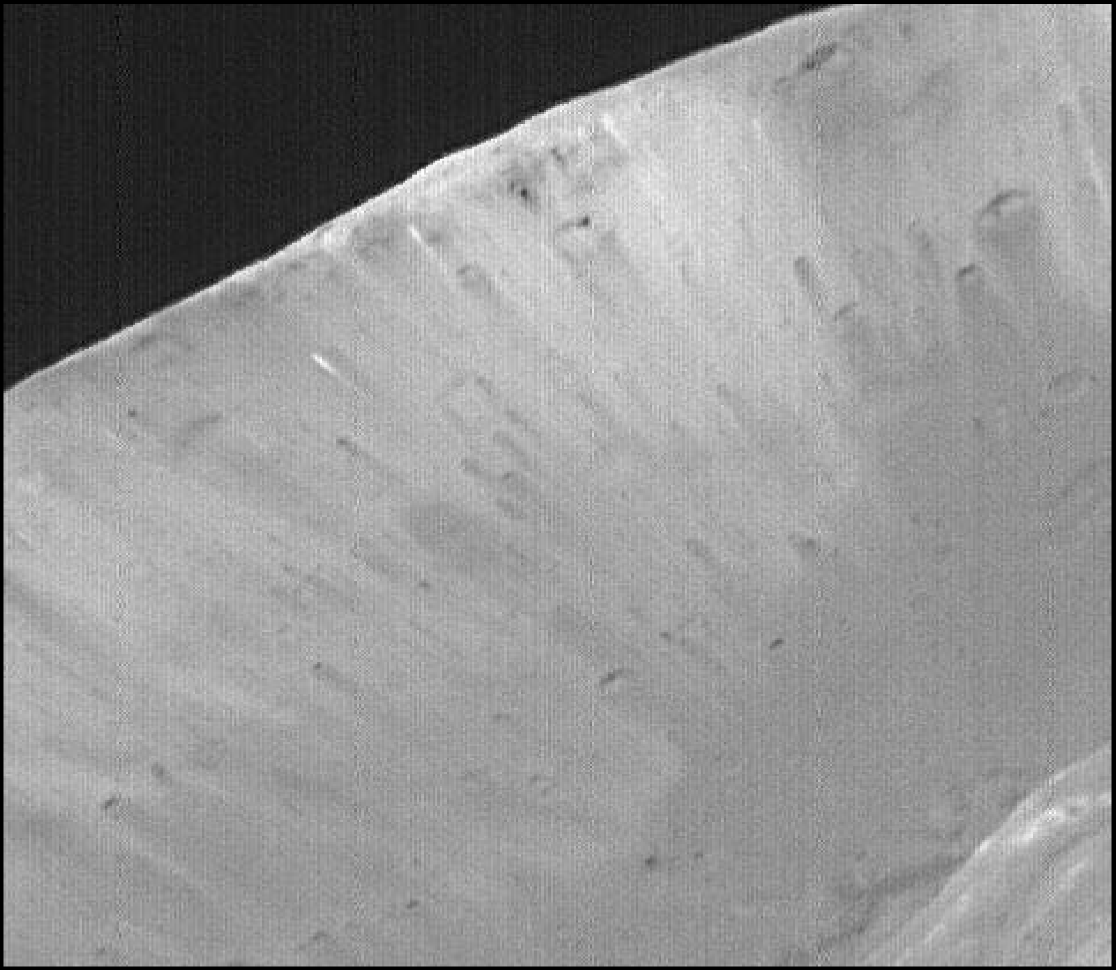
NASA SP-441: VIKING ORBITER VIEWS OF MARS

High-Resolution MOC Image of Phobos' Stickney Crater

(http://photojournal.jpl.nasa.gov/catalog/PIA01335)

Evidence of boulders

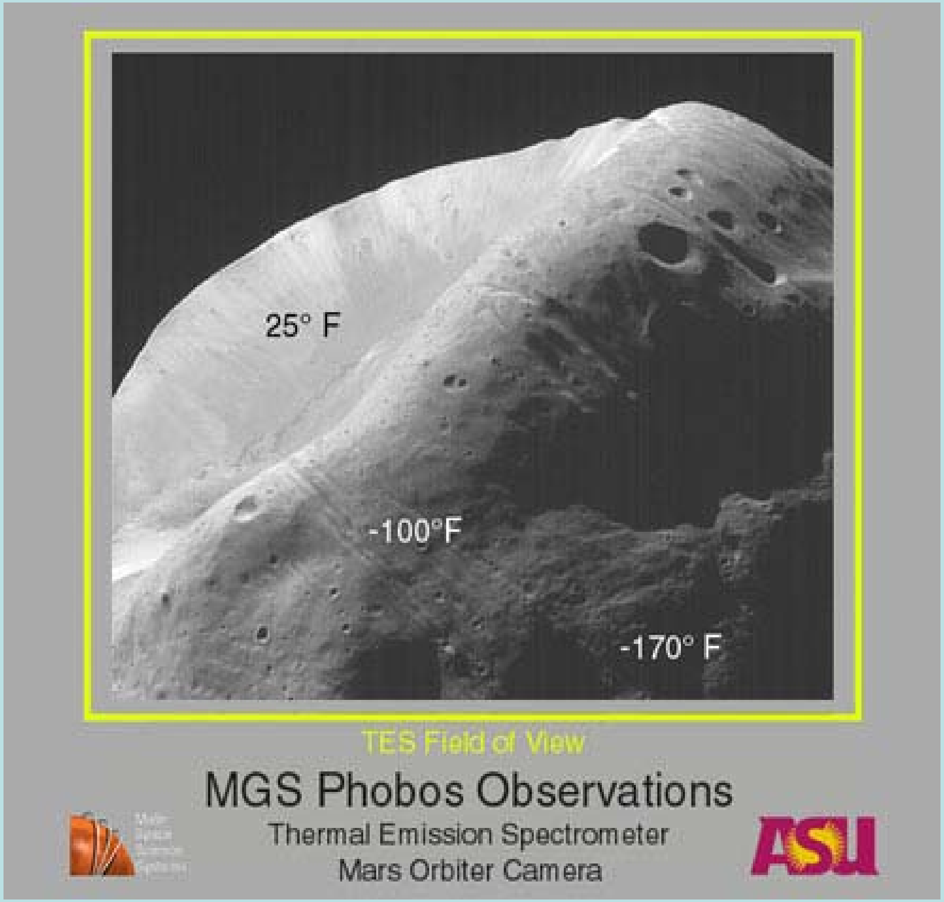
(a few 10m size) sliding down the sloped inner surface of Stickney



Surface appears to be covered by thick fine dust

Large temperature difference between sunlit and dark places

269K in illuminated side, while 161K in dark side



low thermal conductivity >>>>>Existence of a layer of small regolith particles

Heterogenity of surface properties on Phobos

Leading Side:

The hemisphere that faces forward, into the direction of motion of a satellite that keeps the same face toward the planet.

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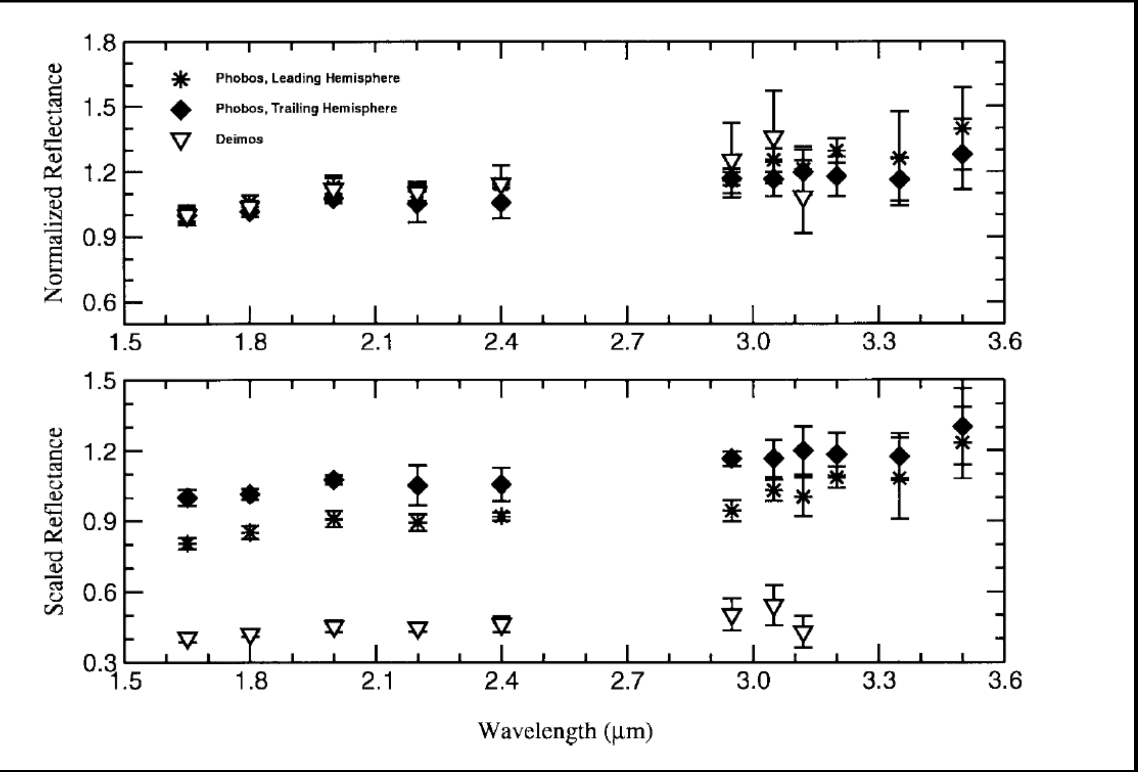
No color difference among the trailing and leading hemispheres of Phobos, and Deimos

NASA IRTF on Mauna Kea



Higher reflectance of Phobos, than Deimos, because of size difference.

Higher reflectance in the trailing side because of higher albedo.

Rivkin et al. (2002, Icarus 156, 64)

A difference of albedo

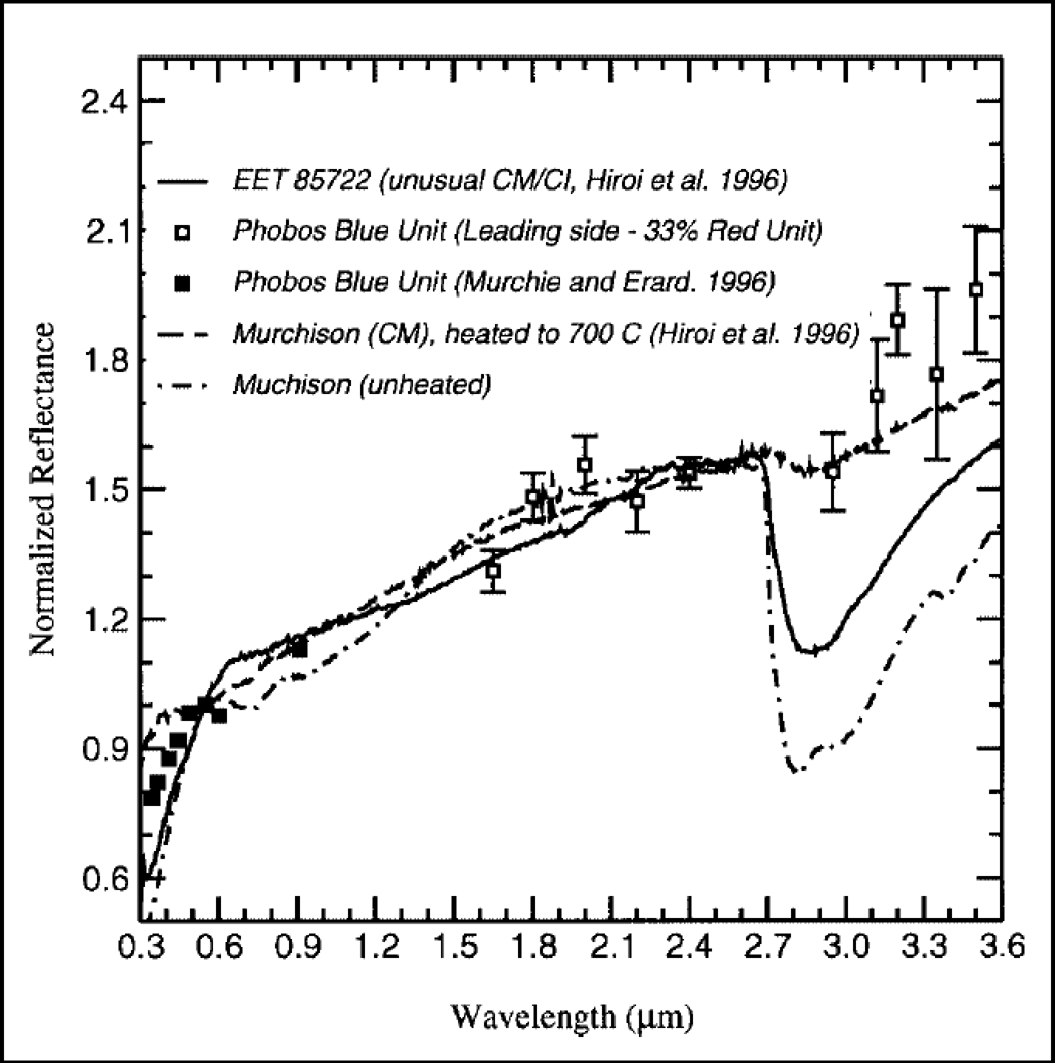
A difference of

(1) Surface materials

(2) Surface roughness

(3) Size of regolith particles

Spectral analogs for the martian satellites to meteorites



Murchison:

a CM chondrite

A lack of prominent absorption at 3 μm suggests the anhydrous nature of two satellites.

after Rivkin et al. (2002, Icarus 156, 64)

Origin of Phobos/Deimos

- **I. Accretion in circum-Martian orbit**
  - No reasonable scenario from dynamical point of view

- **II. Permanent capture of asteroids/ comets**
- No obvious mechanism for energy dissipation to capture of these small bodies; nor should such capture yield equatorial orbits.

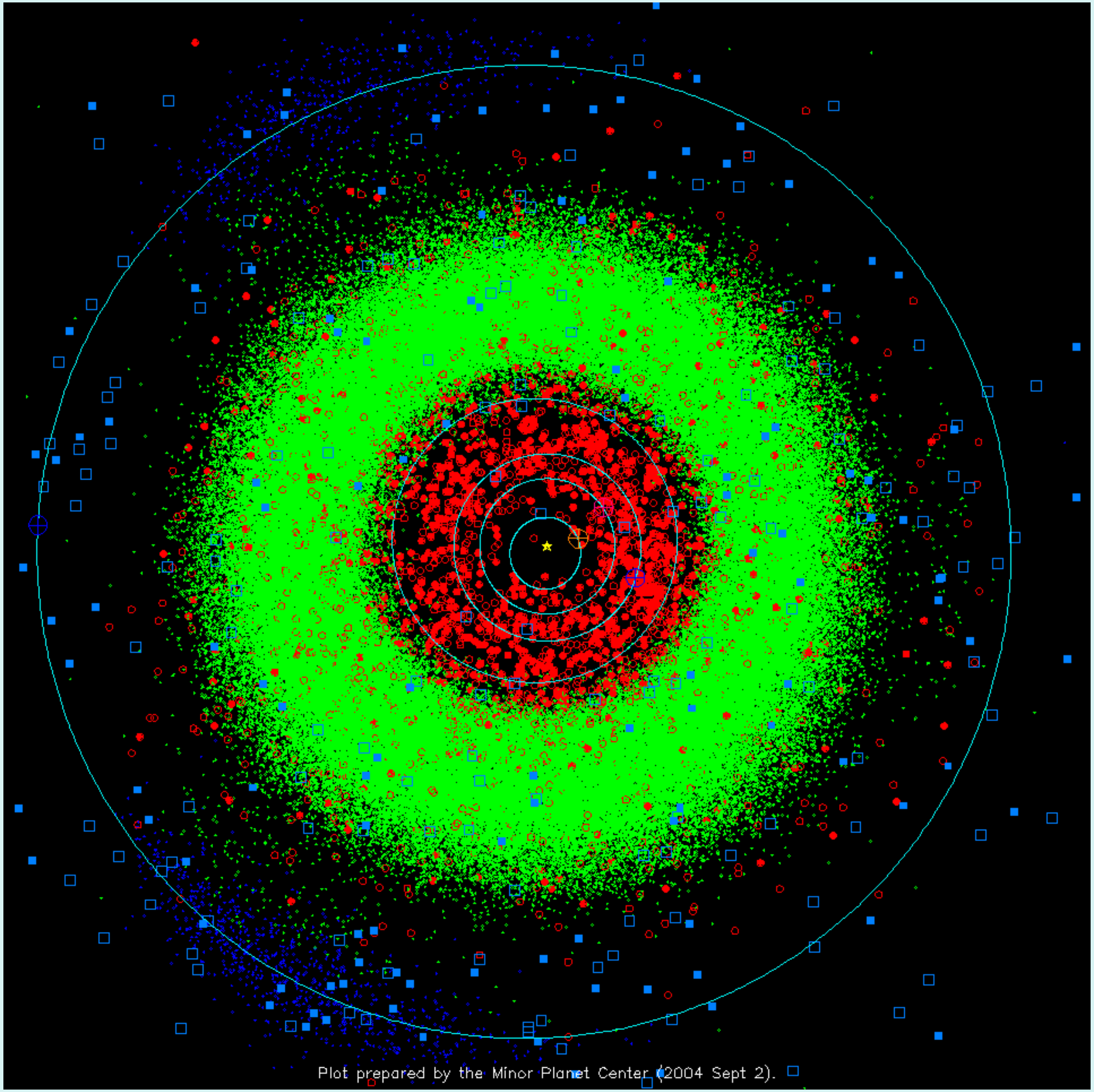
- Equatorial orbits of the satellites>>>the obliquity of Mars changed very slowly compared to the orbital periods of the moons >>>Mars acquired the moons only after its formation
- **(its mechanism still uncertain)**

New hypothesis for capture of a large Mars-Moon during or shortly after the formation of the planet

(Singer 2003, Sixth international conference on Mars).

- Capture of ***a large Mars-Moon***.
- ***Fracture*** of the Mars-Moon due to tidal force within the Roche limit.
- Larger pieces were driven into Mars by tidal friction.
- Phobos/Deimos are ***surviving remnants***, but Phobos will disappear in 50 million years. On the other hand, Deimos will survive against tidal friction.

Capture of asteroids/comets by the planet



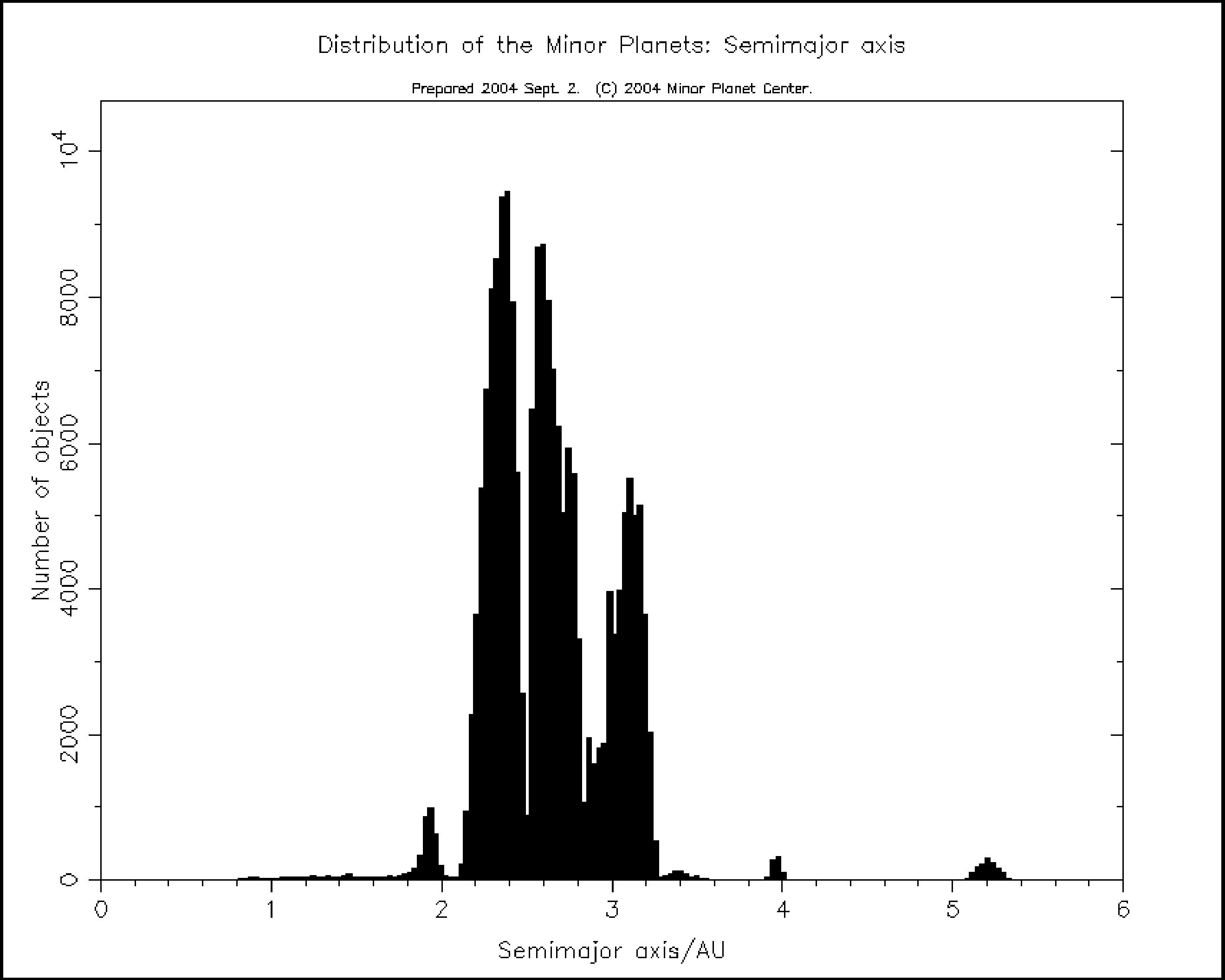
Objects with perihelia within 1.3 AU are shown by red circles. Numbered periodic comets are shown as filled light-blue squares. Other comets are shown as unfilled light-blue squares. **http://cfa-**

Transportation of main-belt asteroids(MBAs) to inner solar system

- Dynamical **resonance** by Jupiter (e.g. 3:1 at 2.5AU of Kirkwood gaps)

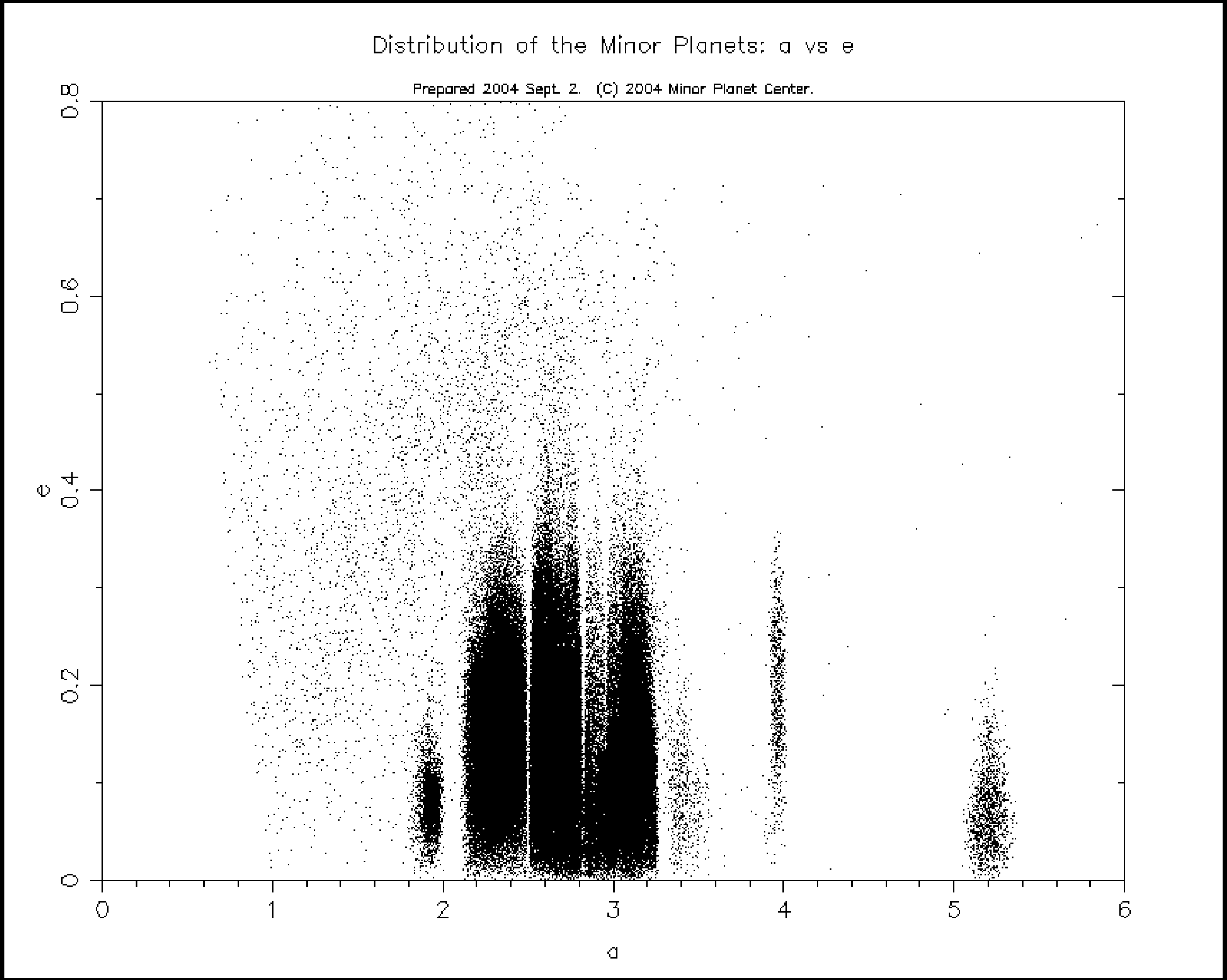
- **Additional effect to supply MBAs to gaps continuously is needed!**

- **Yarkovsky effect** (due to anisotropic thermal emission) leads MBAs to resonance region.



See gap at 2.5AU (3:1), one of Kirkwood gaps

http://cfa-www.harvard.edu/iau/lists/MPDistribution.html



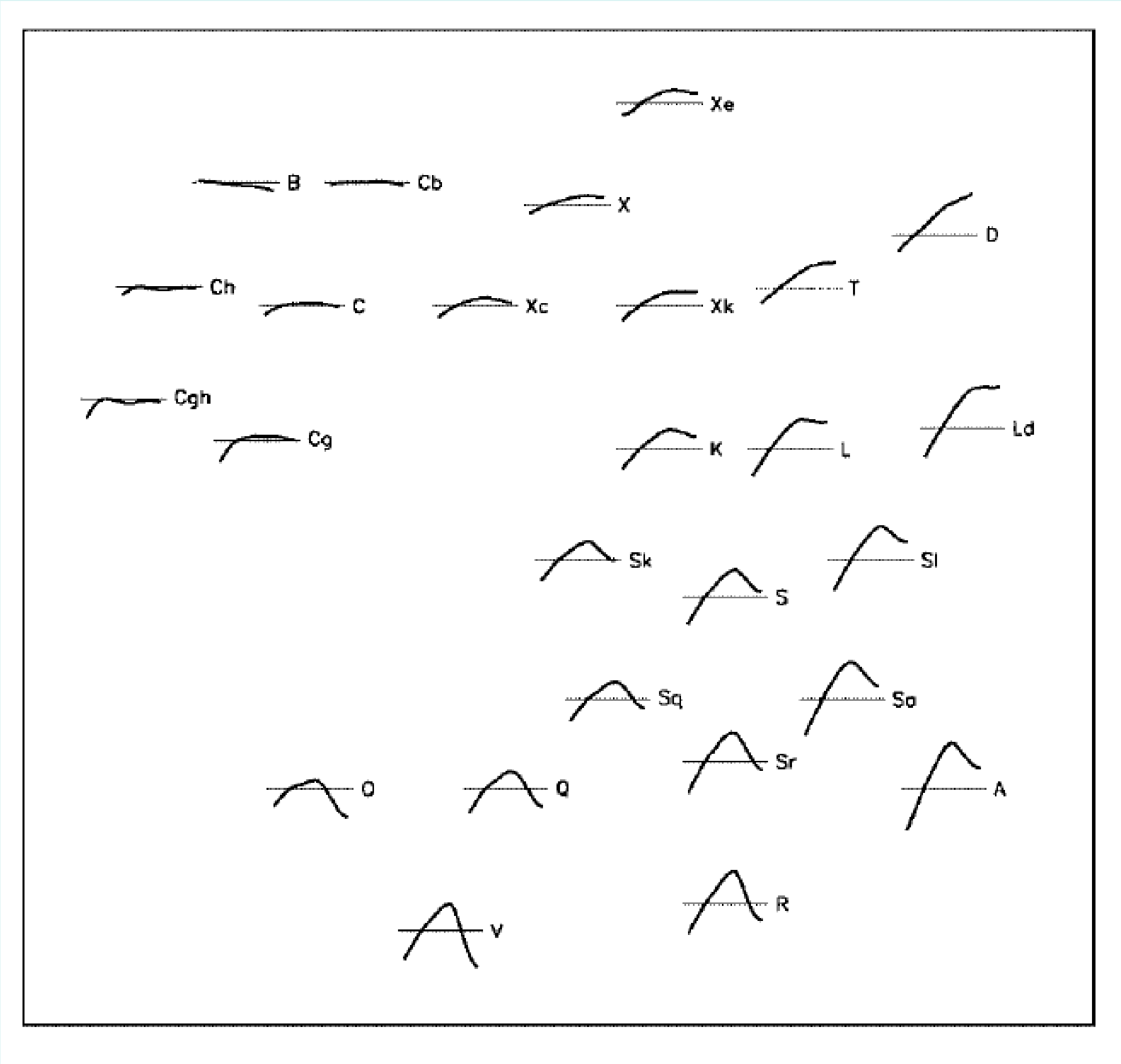
http://cfa-www.harvard.edu/iau/lists/MPDistribution.html

Martian satellites are similar to C-type asteroids

- S-type, inner asteroid belt

- C-type, outer asteroid belt
  consisting of more primitive materials

26 SMASSII taxonomic classes derived the spectral interval of *0.44-0.92 μm*



1447 asteroids

In Tholen taxonomy; 41%(C

33%(S)

11%(EMP>>X)

Bus and Binzel (2002, Icarus 158, 146-177)

Summary and questions

(1) Why have two satellites low mass density?

------related to the internal structure of small bodies

(2) How was a thick regolith layer made ?

------related to the dust ring formation

(1) Why have two satellites low mass density?

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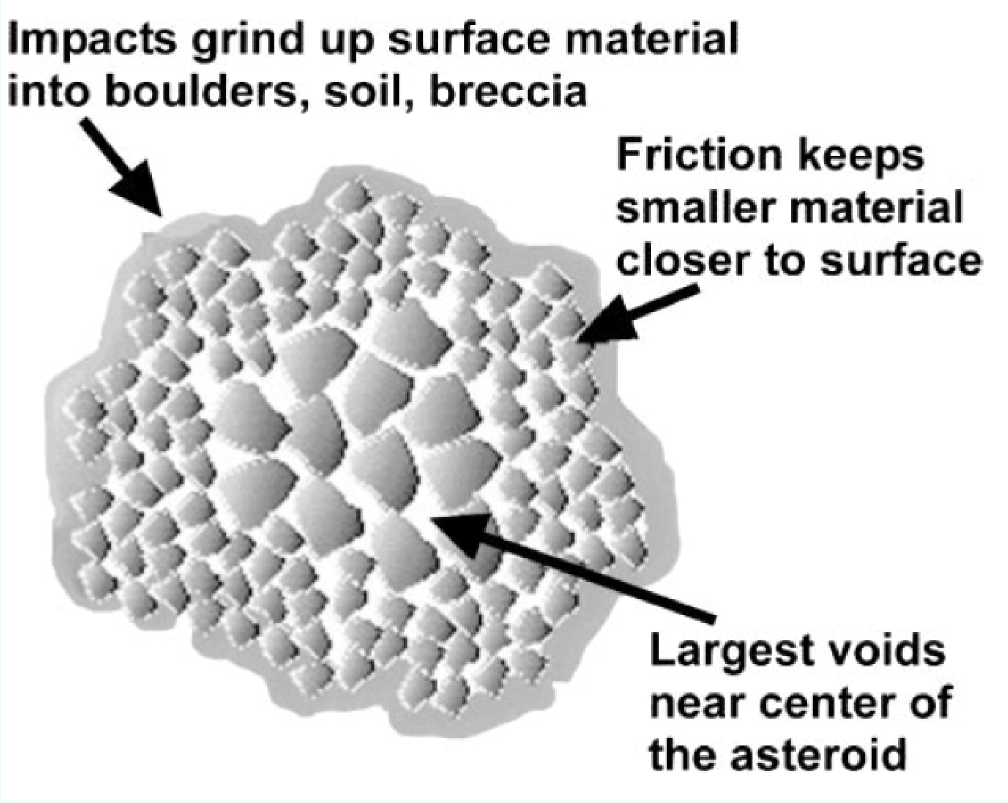
Mass density(g/cm^3)	**(C)1.3 ± 0.2**	**(S) unknown**	**(S) 2.6 ± 0.5**
Mean radius(km)	**26.5 ± 1.3**	**6.1 ±0.4**	**15.7 ±0.6**

Low mass density
- Internal structure of asteroid

Rubble piles



What “Rubble piles”?

- After a ***catastrophic disruption*** of parent body, some remnants made an aggregate due to mutual gravitational forces.

Gravitational forces between two 100m bodies

- **F/A =** $(Gm_1m_2/r^2)\,/(\pi r^2) = 3x10^2$ ***dyne/cm²***

VERY weak forces

- **Tensile strength of materials**

  Water-ice (1-2) x 10^8 dyne/cm²

  Obsidian (2.8-6.9)x 10^8 dyne/cm²

What's rubble pile(continue)?

- When the units become attached or cemented to one another, it is called *a coherent rubble-pile* (or *a coherent aggregate*)
- Completely ***shattered and reassembled bodies***

How about the strength between rubble piles?

- **Answer had come from the evidence that no asteroids with shorter rotation period than *2 hours*.**

- **What's relation? This was explained by…….**

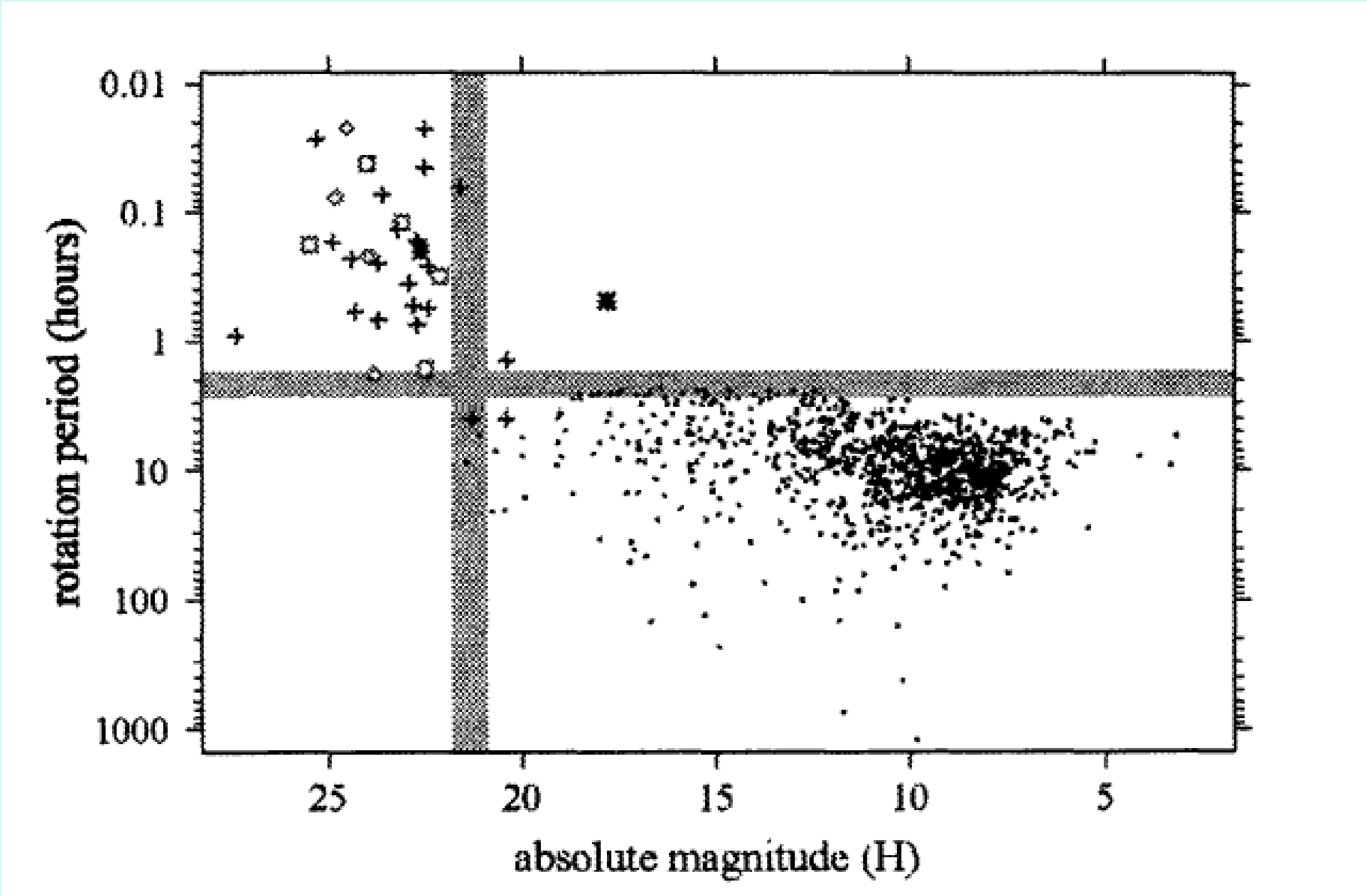
Rotational disruption of particle with mass m and radius r

- acceleration of gravity at the surface < centrifugal acceleration at the equator

- $Gm/r^2 < \omega^2 r$
- $P = 2\pi/\omega$
- ↓
- $P < 3.3 / \rho^{1/2}$ (hours)

Wake-up and do the exercise!

- Please make a graph of absolute magnitude of asteroid vs. its spin period listed in p.221, appendix 3.



Ionolithic fast-rotating asteroids
Vhiteley, R. J. ;Hergenrother, C. W. ;Tholen, D. J.
n: Proceedings of Asteroids, Comets, Meteors - ACM 2002. ESA SP-50, 2002, p. 473 - 480

No asteroids brighter than 20 mag. with shorter rotational period than 2 hours exist.

rotational disruption occurs

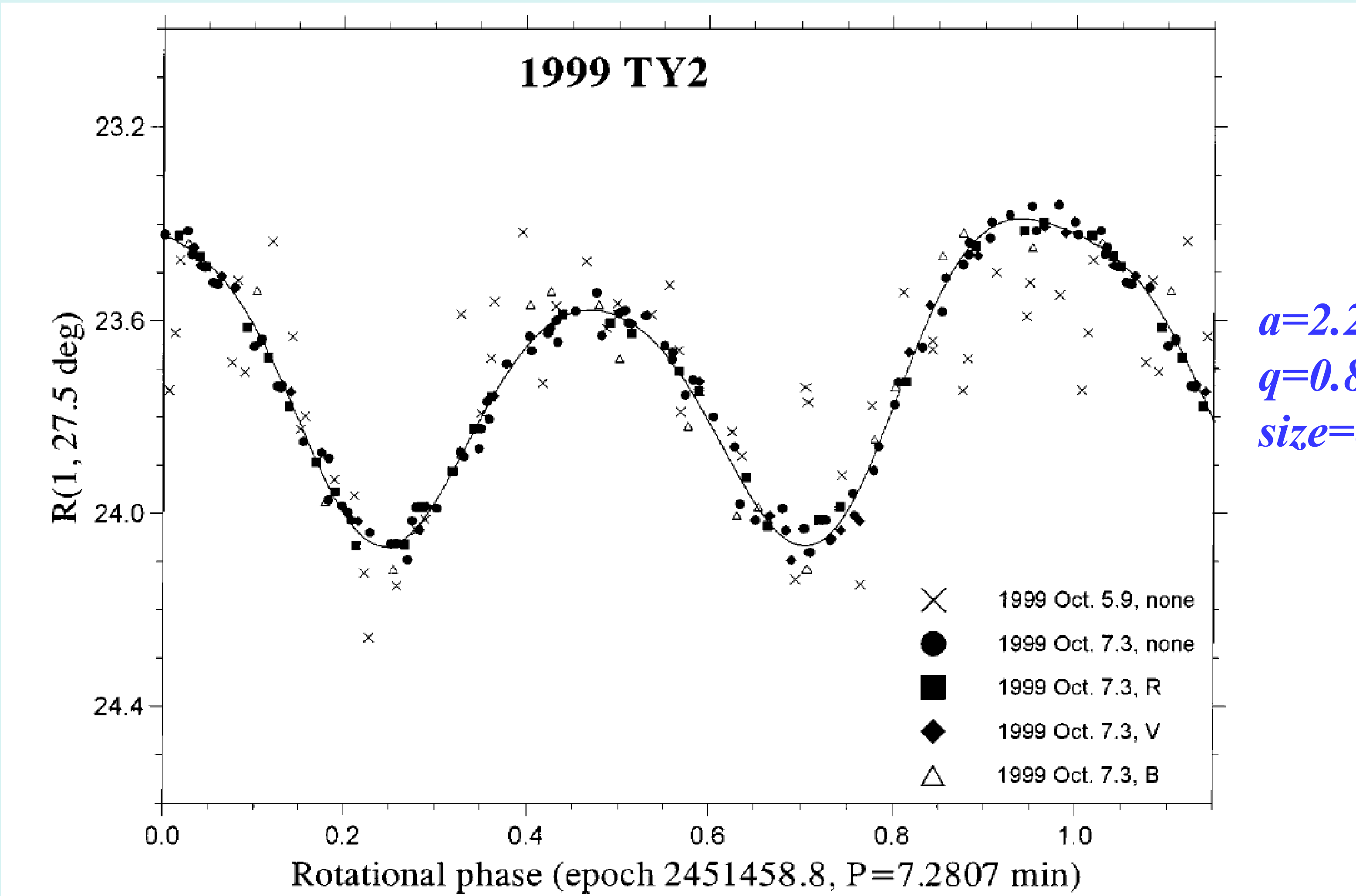
<<< confirm the rubble pile hypothesis

Inner structure of asteroid

- Gravitationally bounded rubble piles.
- Some bonds may be strengthened by cementing due to thermal metamorphosis

- It has been believed so till 2000, but……

Discovery of asteroids with high rotational speed



a=2.267AU
q=0.892AU
size=80m

Fast rotating asteroids

	q(AU)	a(AU)	i(deg)	P(min)	size(m)
1999TY2	0.892	2.267	23.1	**7.2807±0.0003**	**80**
1999SF10	0.953	1.270	1.1	**2.4663 ±0.0005**	**60**
1998WB2	0,820	1.983	2.4	**18.8 ± 0.3**	**120**
1998KY26	0.984	1.233	1.5	**10.7015 ± 0.0004**	**30**
1995HM	1.139	1.460	4.0	**97.2**	**130**

Pravec et al. (2000, Icarus 147, 477-486)

Monolithic fast-rotating asteroids

Whiteley et al.(2002)

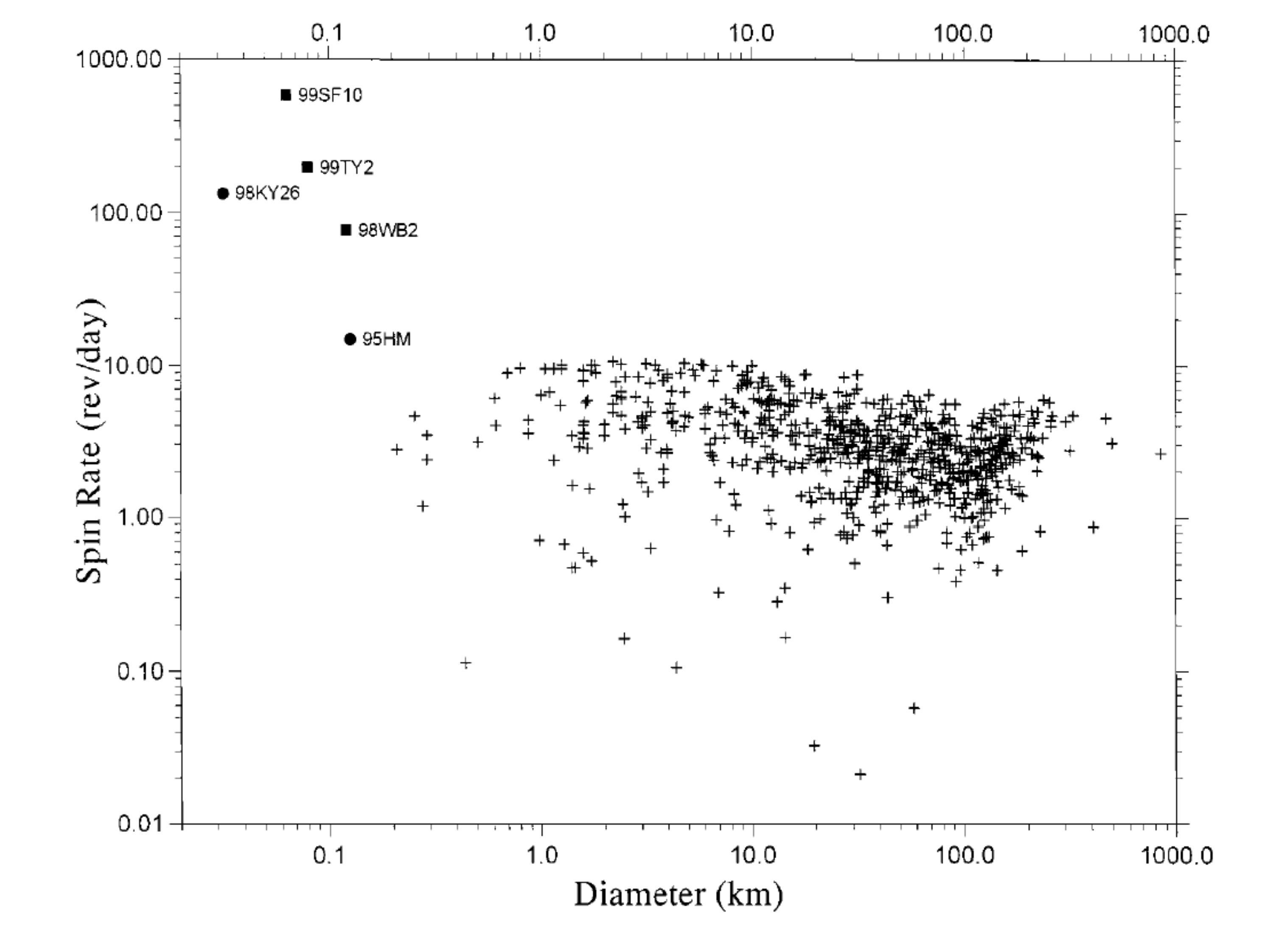
- ∽40 asteroids
- **78 seconds** ($2000DO_8$) <<<<<<<
- 97.2 minutes (1995HM)
- 107.5 minutes($2000EB_{14}$)

- H(absolute magnitude) ∽ **22 mag**.
  critical point

In the solar system, the absolute magnitude *H* is defined as the apparent magnitude the object would have if it were at a heliocentric distance of 1 AU.

Since *H* ∽ *-2.5 log (Flux), Flux* ∽ *a geometrical cross section of object,*

then ***H=22*** *magnitude* corresponds to a diameter of about ***0.2km***.



Pravec et al. (2000, Icarus 147, 477)

Monolith

- Below ∽100m almost all objects observed to date rotate faster than the classical limit (P<2.2 hours).
- Internal structure to be governed by their tensile strength.
- NOTE that its strength is not so large!

1998KY26 (∽ 30m diameter)

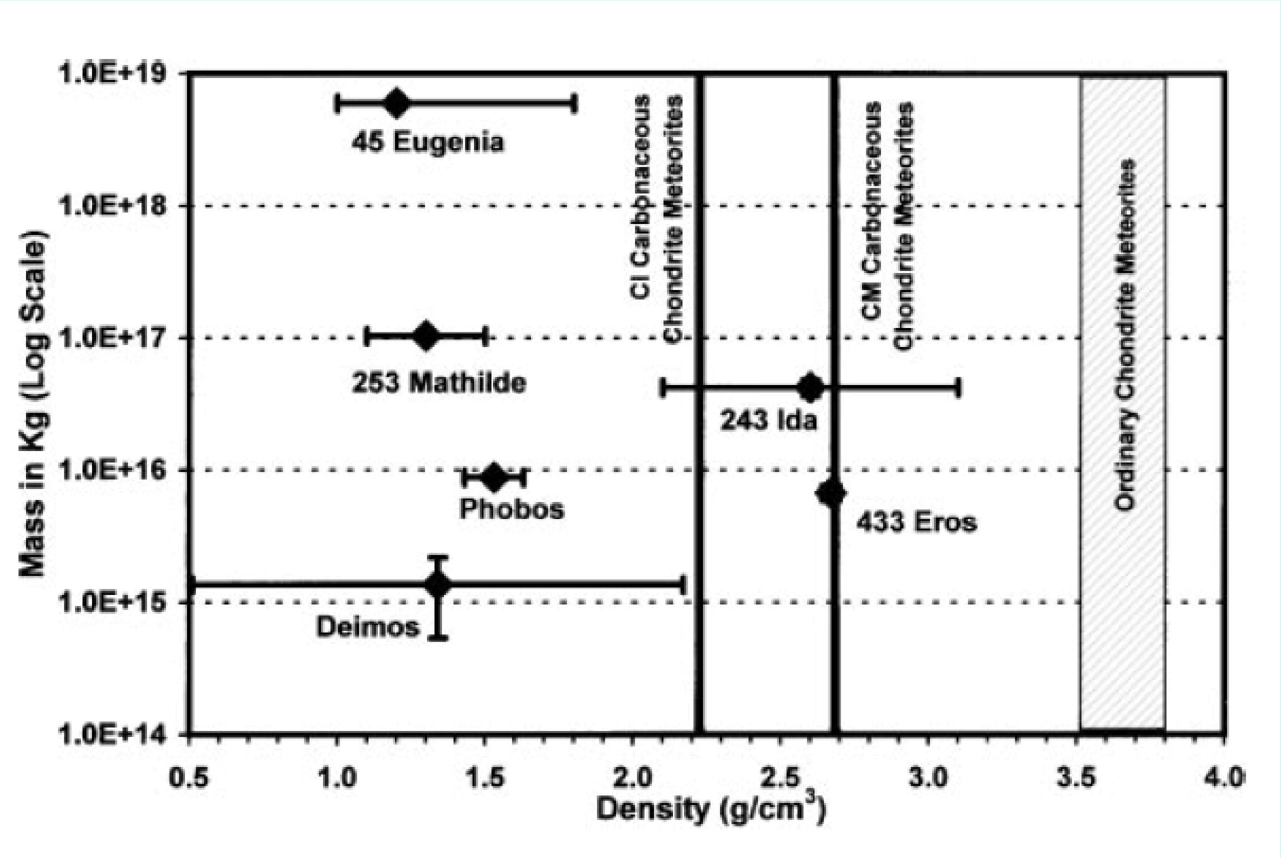
required tensile strength = *300 dyn/cm²*,

the same order of gravitational force, and orders of magnitude weaker than snow.

- (Binzel et al. 2003, Planetary and Space Sci. 51, 443-454)

Mass density of satellites and meteorites

Britt and Consolmagno(2001, Icarus 152, 134)



CM are possible analogue for Phobos and Deimos.

Low mass densities of satellites suggest a presence of a large amount of inner porosity

Low-Density Materials and Asteroidal Macroporosity

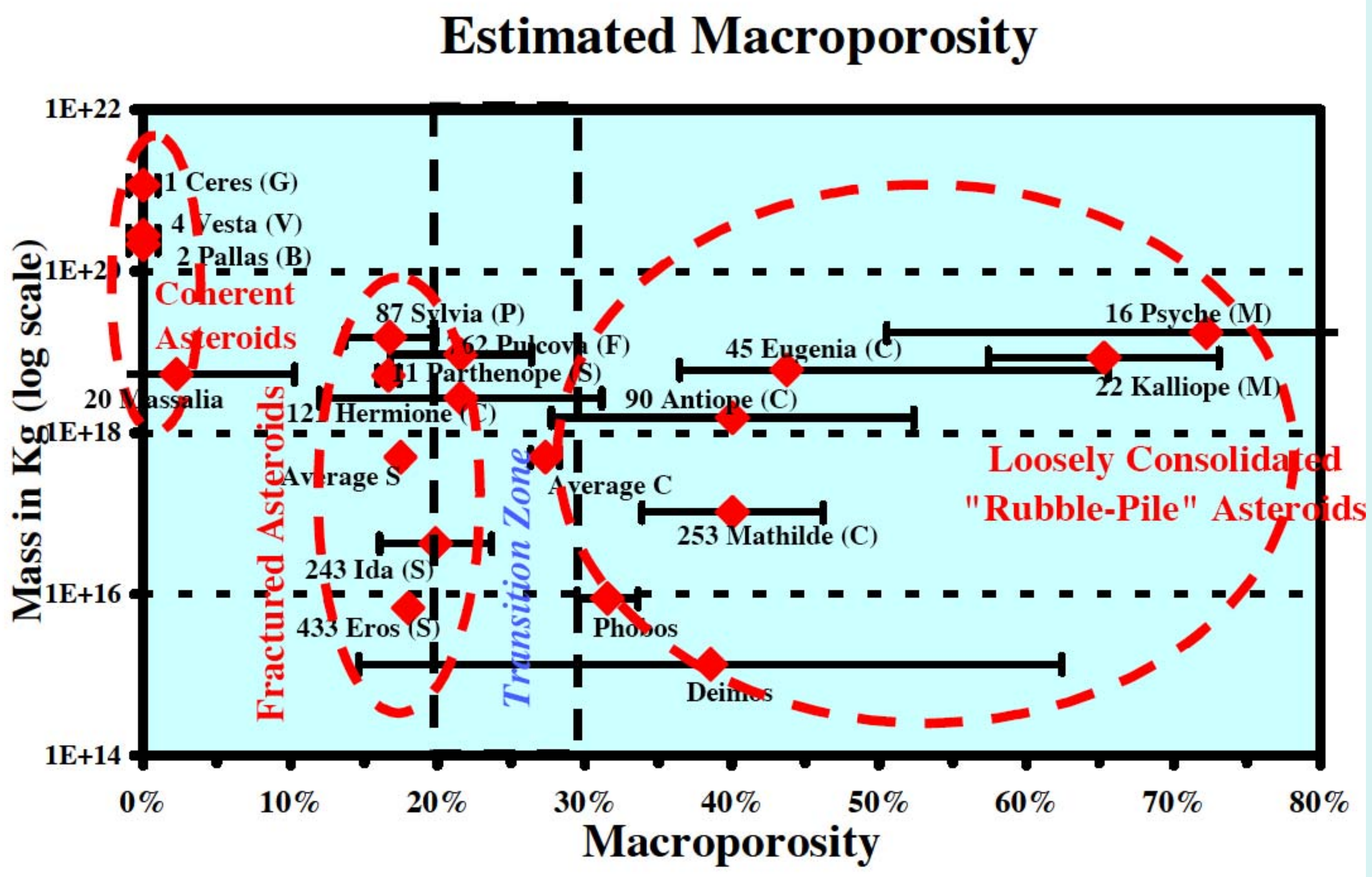
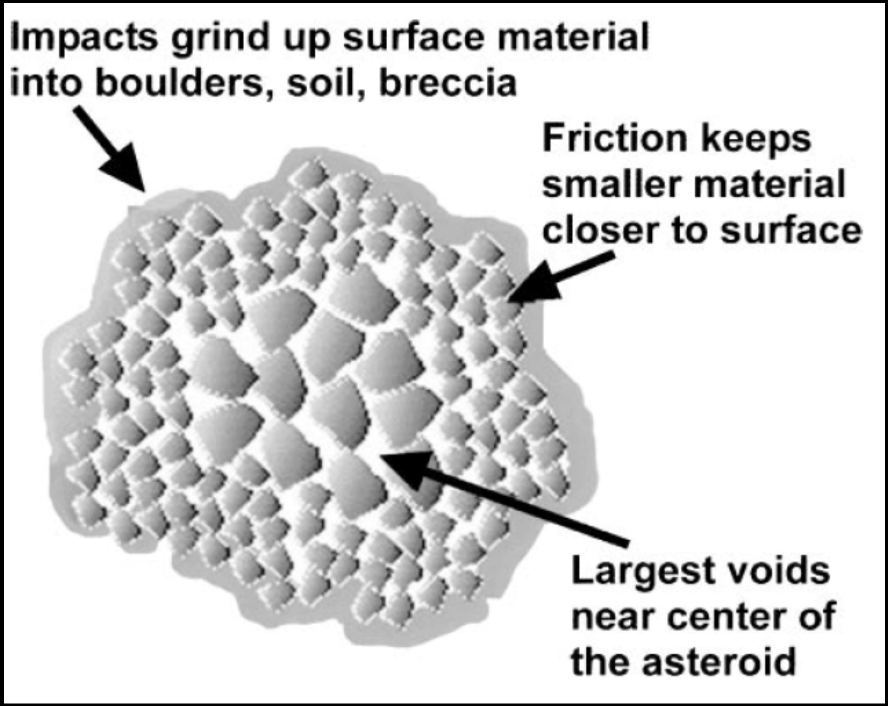


Figure 1: Estimated Macroporosity of Measured Asteroids

onsolmagno and Britt (2002, 33rd Annual Lunar and Planetary Science Conference, March 11-15, 2002, Houston, exas, abstract no.1701)

High porosity in Phobos/Deimos

- Bodies consist of 70-60% in volume carbonaceous chondrite and **30-40% porosity**



(2) How was a thick regolith layer made ?

Bombardments of micro-meteoroids on the surface produce the **ejecta**.

(1) A part of ejecta returns back on the surface, and makes a **regolith layer**.

(2) Some escape from the parent satellite, but do not escape from Mars.

(3) Then, they form **dust rings**.

(4) Escape velocity from Phobos; 12.5 m/s

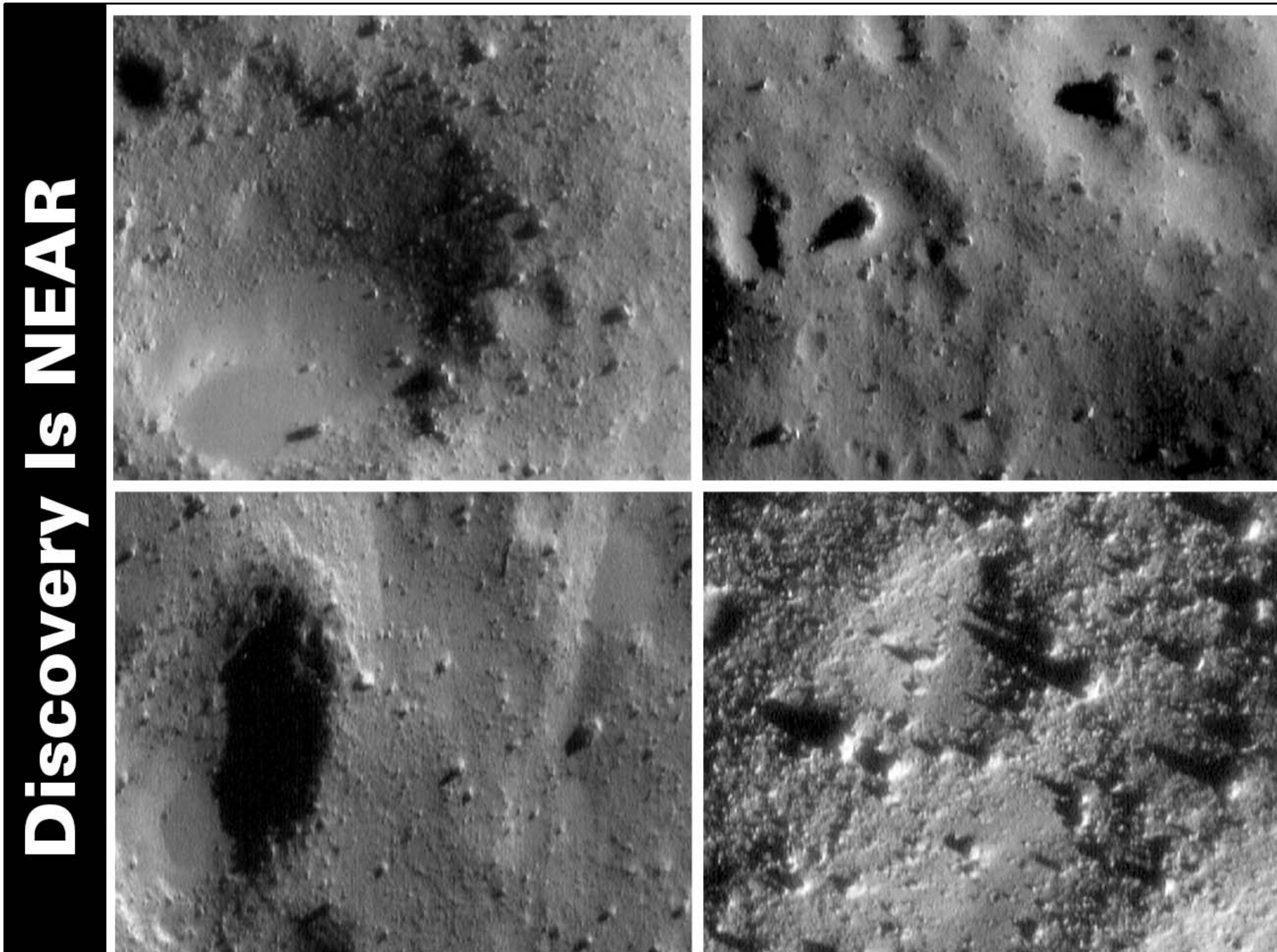
(5) from Mars; 5.02 km/s

Boulder (85m-size) on Phobos, ejected from Stickney

MGS/MOC Release 16
Sept. 2003

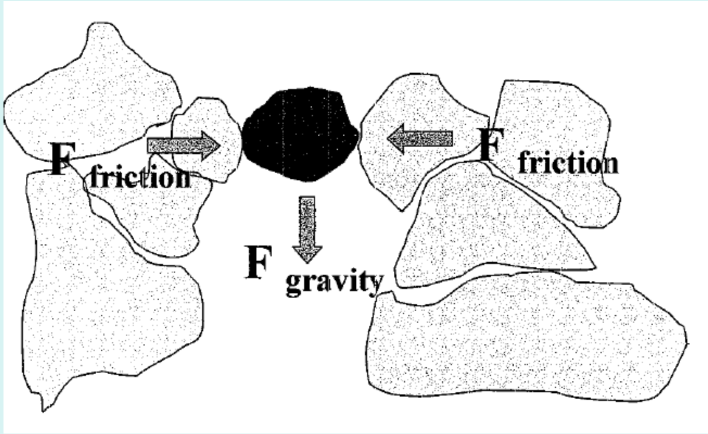
NASA/JPL/Malin Space Science Systems

Closed-up images of the surface of asteroid Eros



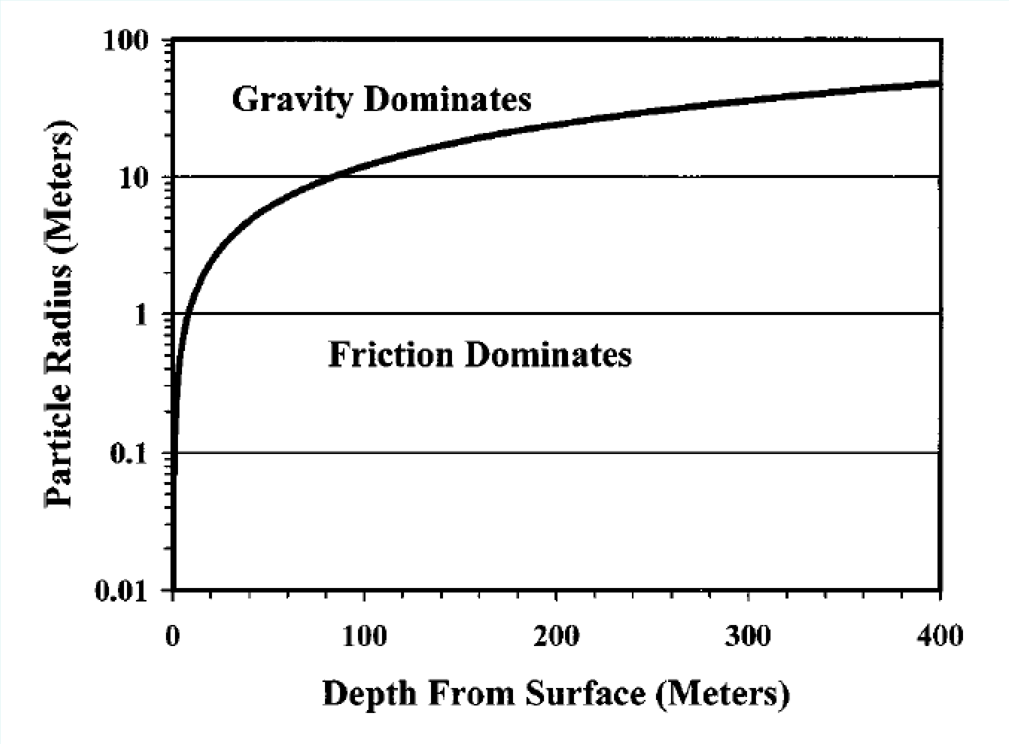
Images of Eros acquired by NEAR Shoemaker. (Upper Left) Taken January 27, 2001, from 8.4 miles (13.5 kilometers) away; (Upper Right) taken January 26 from 6.9 miles (11.1 kilometers) away; (Bottom Left) taken January 26 from 3.0 miles (4.9 kilometers) away; (Bottom Right) taken January 28 from a similar distance away.

Small particles on the surface



Smaller particles become dominant on the surface.

A particle of radius r is held in place at the sides by frictional contact with other particles.



Britt and Consolmagno(2001, Icarus 152, 134)

Some impact ejecta move around Mars :

Martian Dust Rings

Indirect Evidences by PHOBOS-2 spacecraft

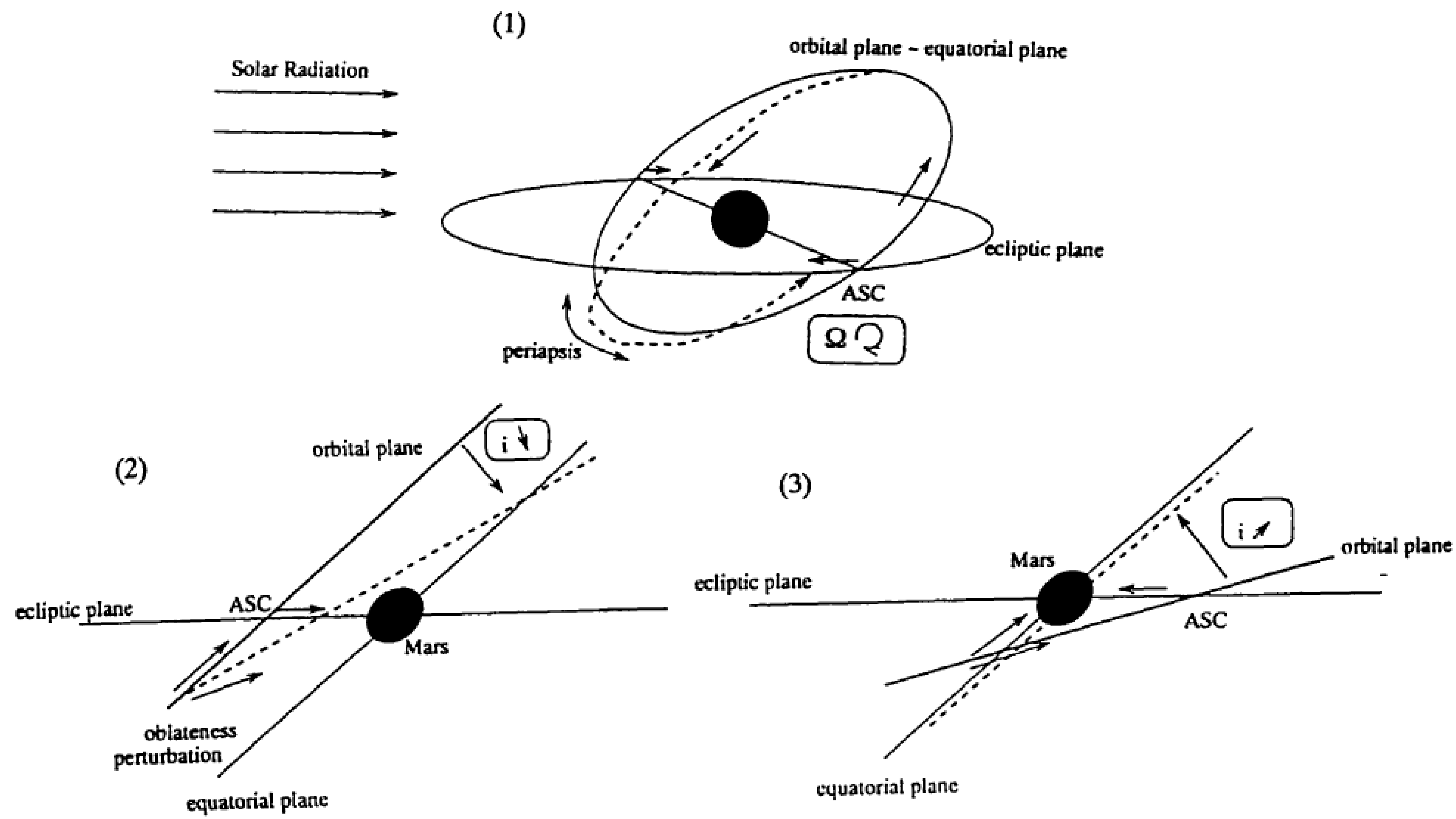
magnetic 'cavities'
(strong decreases of the magnetic field strength)
coincident with
strong plasma density increases (up to a factor ten)

Viking Orbiter 1 (1988) no evidence

Theoretical Prediction of dust rings

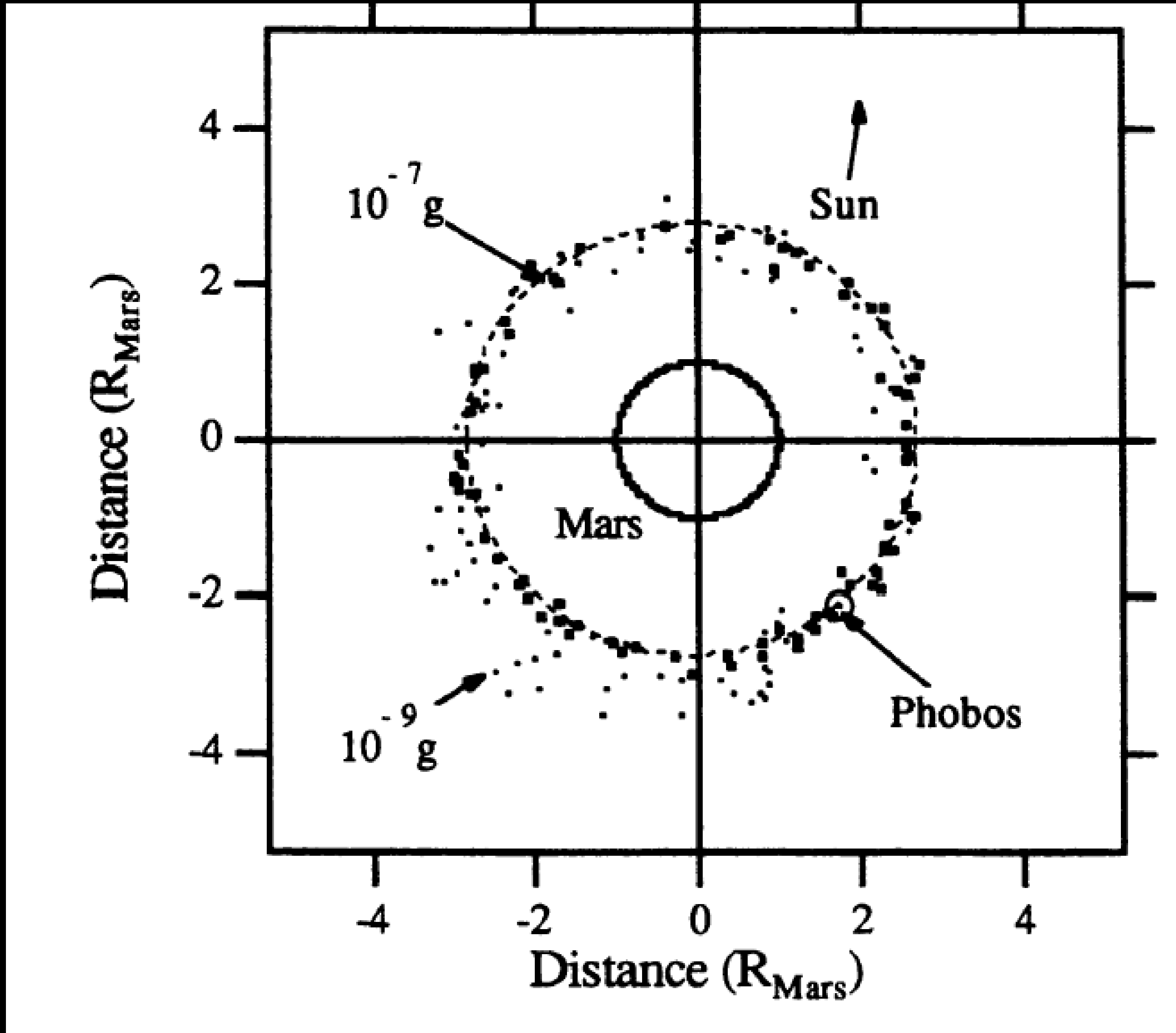
collisional fragments
ejected from the surface of satellites
form
dust rings along the Phobos/Deimos orbits

Orbital Evolution of Small Particles Ejected from Martian Satellites



Ishimoto, H. (1996) “Physics; chemistry; and dynamics of interplanetary dust” Astronomical Society of the Pacific (ASP 104) edited by Bo A. S. Gustafson and Martha S. Hanner, p.183

Phobos Dust Rings



MIC/NOZOMI had a plan to look for such dust rings

- Due to a loss of NOZOMI, we have no plan to search for the rings.

Conclusions; Martian satellites and asteroids

- The studies of **satellites** are strongly coupled with those of **asteroids**.
- However, the effect of Mars will change the situation for satellites, compare with that for asteroids.
- Therefore, from the research for satellites, we will be able to learn the origin and evolution of Mars.