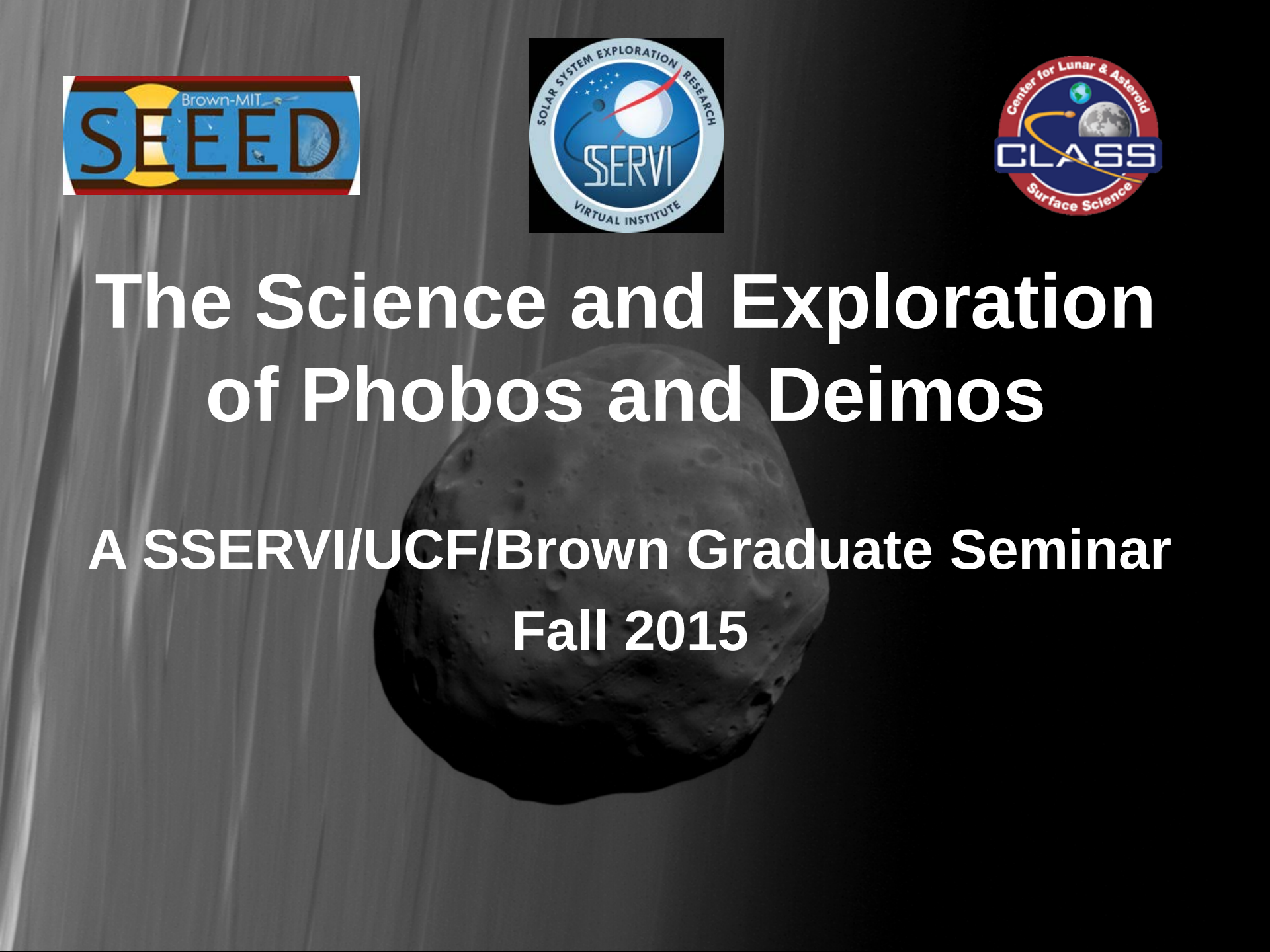


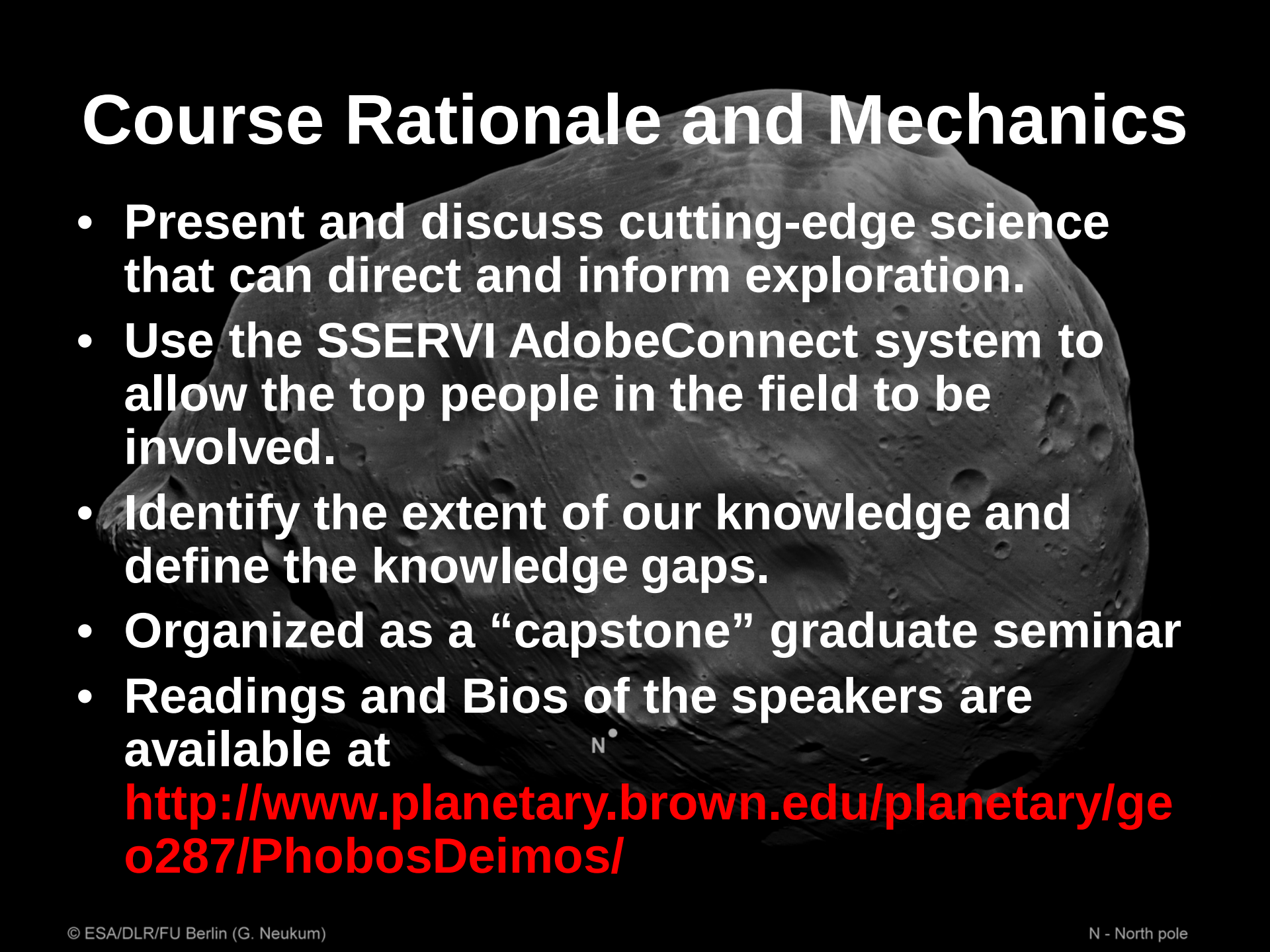
The Science and Exploration of Phobos and Deimos

A SSERVI/UCF/Brown Graduate Seminar

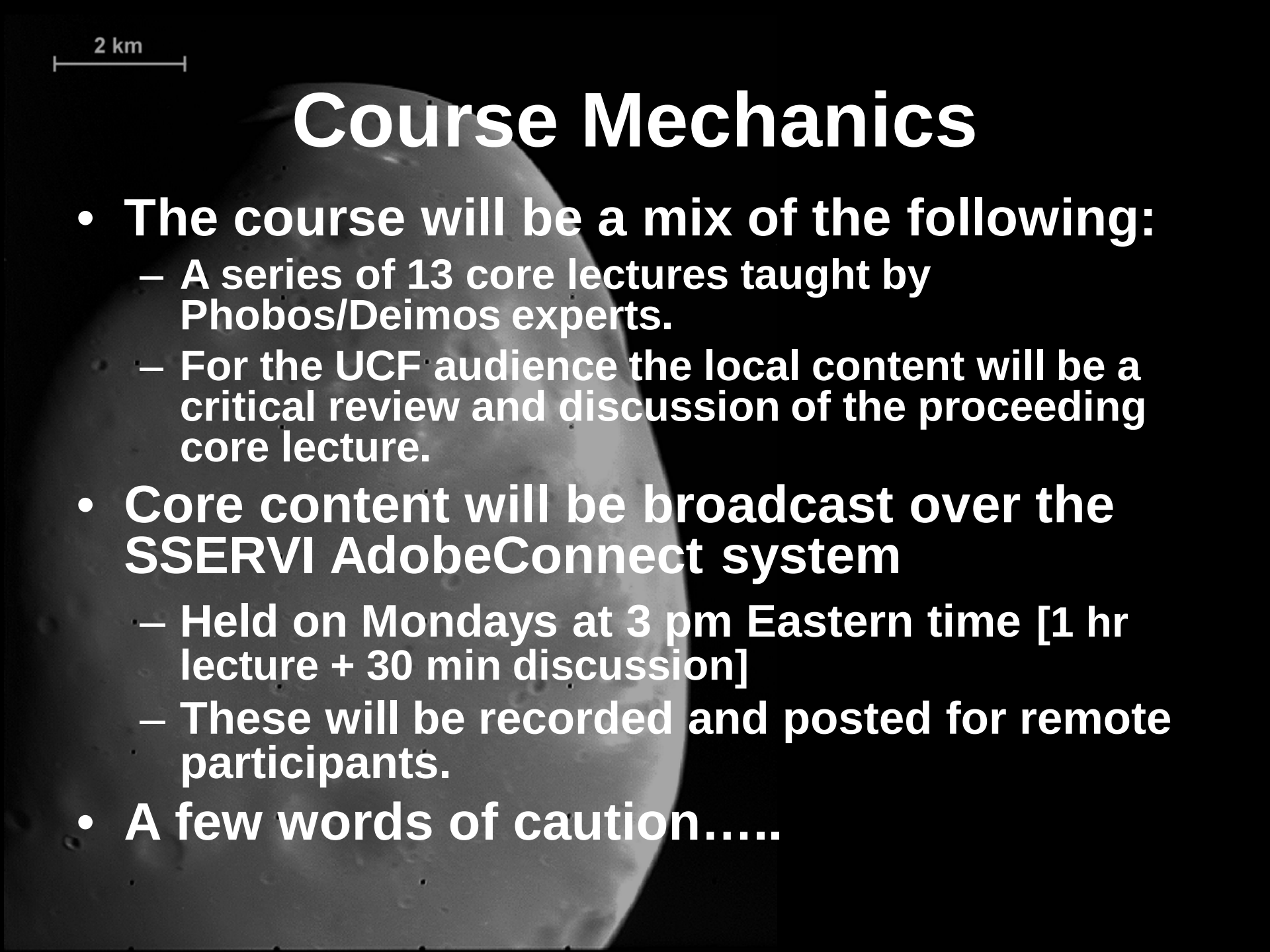
Fall 2015

Course Rationale and Mechanics

- Present and discuss cutting-edge science that can direct and inform exploration.
- Use the SSERVI AdobeConnect system to allow the top people in the field to be involved.
- Identify the extent of our knowledge and define the knowledge gaps.
- Organized as a “capstone” graduate seminar
- Readings and Bios of the speakers are available at http://www.planetary.brown.edu/planetary/geo287/PhobosDeimos/

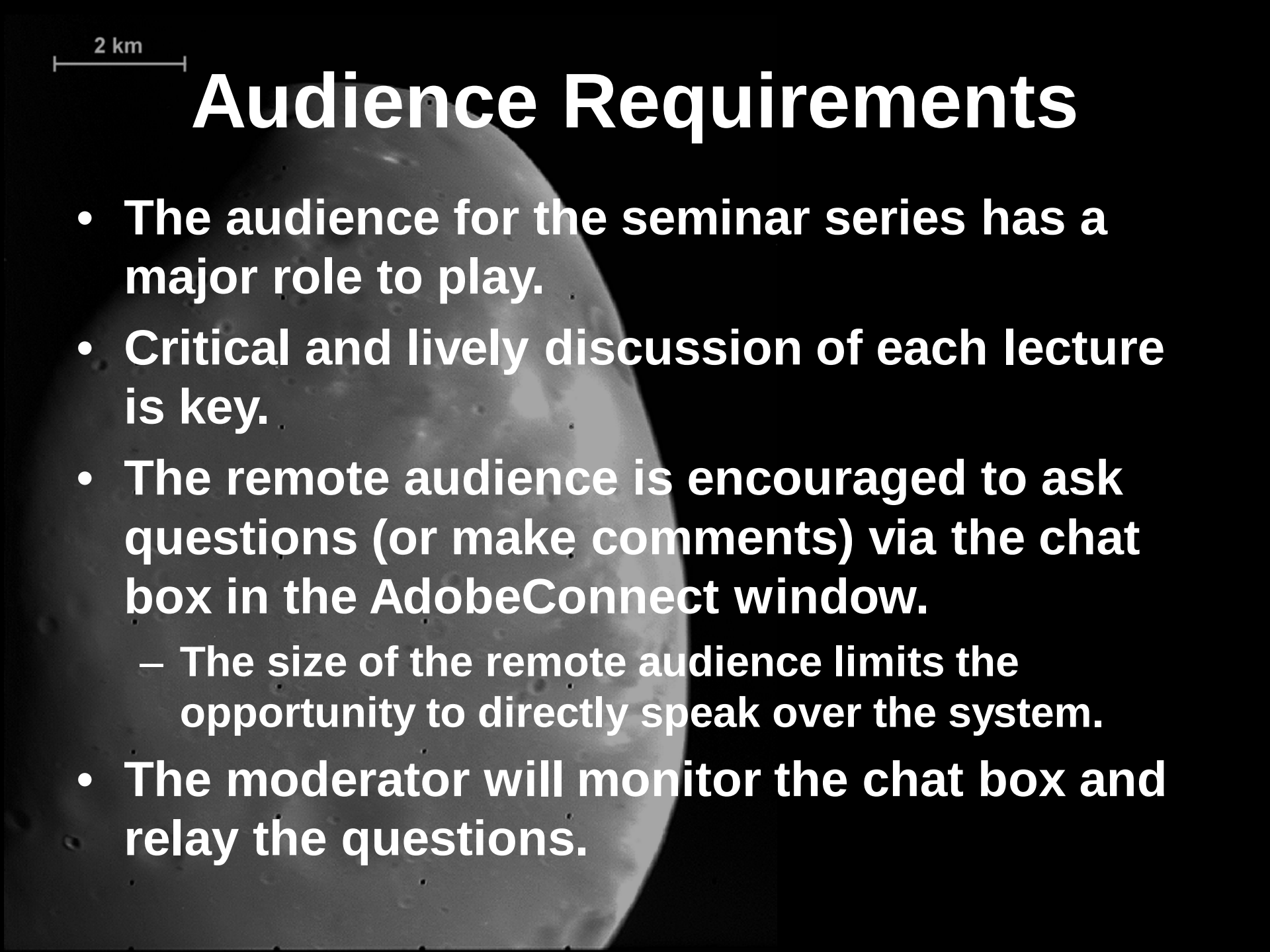


N - North pole



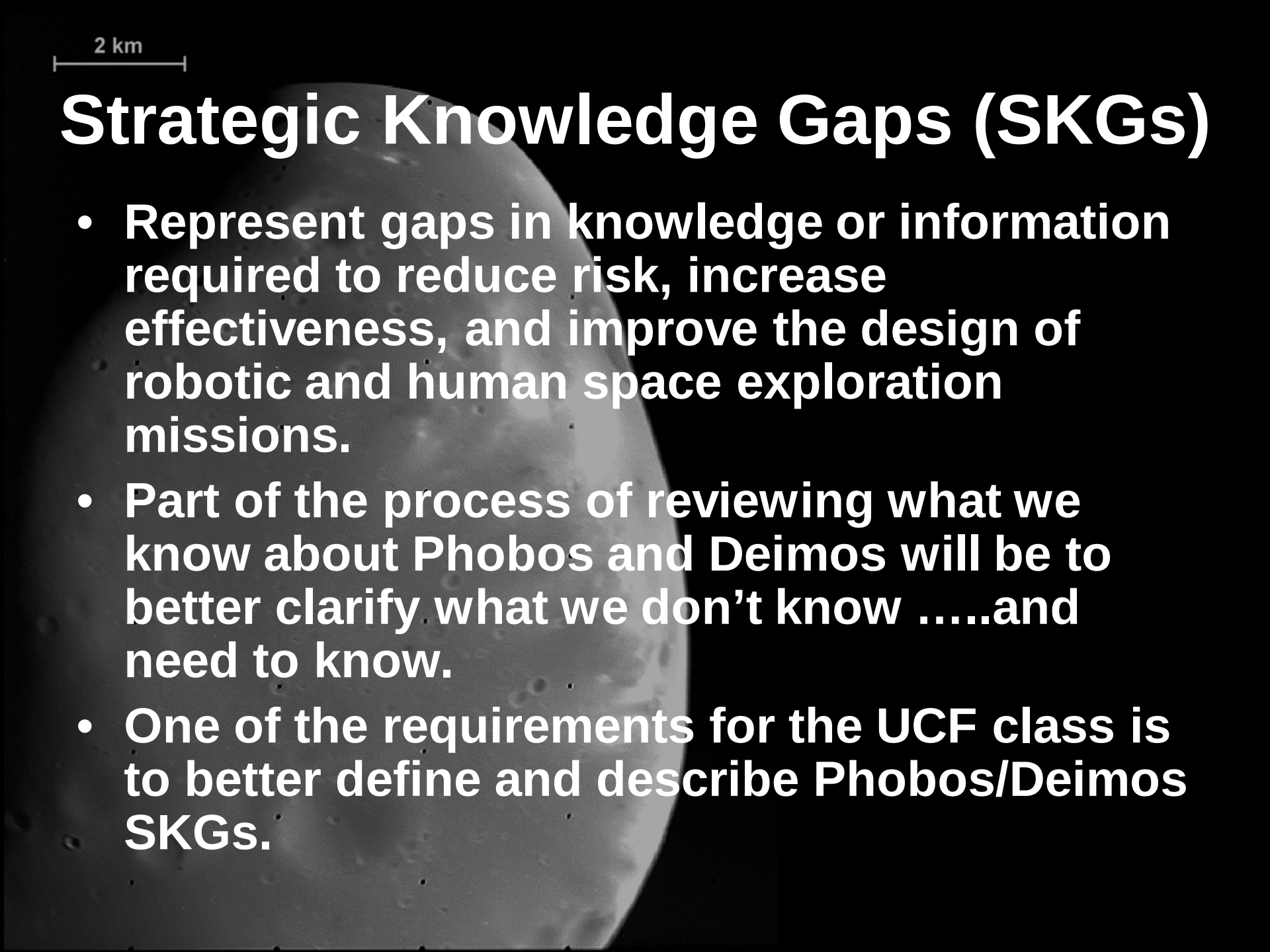
Course Mechanics

- The course will be a mix of the following:
  - A series of 13 core lectures taught by Phobos/Deimos experts.
  - For the UCF audience the local content will be a critical review and discussion of the proceeding core lecture.
- Core content will be broadcast over the SSERVI AdobeConnect system
  - Held on Mondays at 3 pm Eastern time [1 hr lecture + 30 min discussion]
  - These will be recorded and posted for remote participants.
- A few words of caution…..



Audience Requirements

- The audience for the seminar series has a major role to play.
- Critical and lively discussion of each lecture is key.
- The remote audience is encouraged to ask questions (or make comments) via the chat box in the AdobeConnect window.
  - The size of the remote audience limits the opportunity to directly speak over the system.
- The moderator will monitor the chat box and relay the questions.

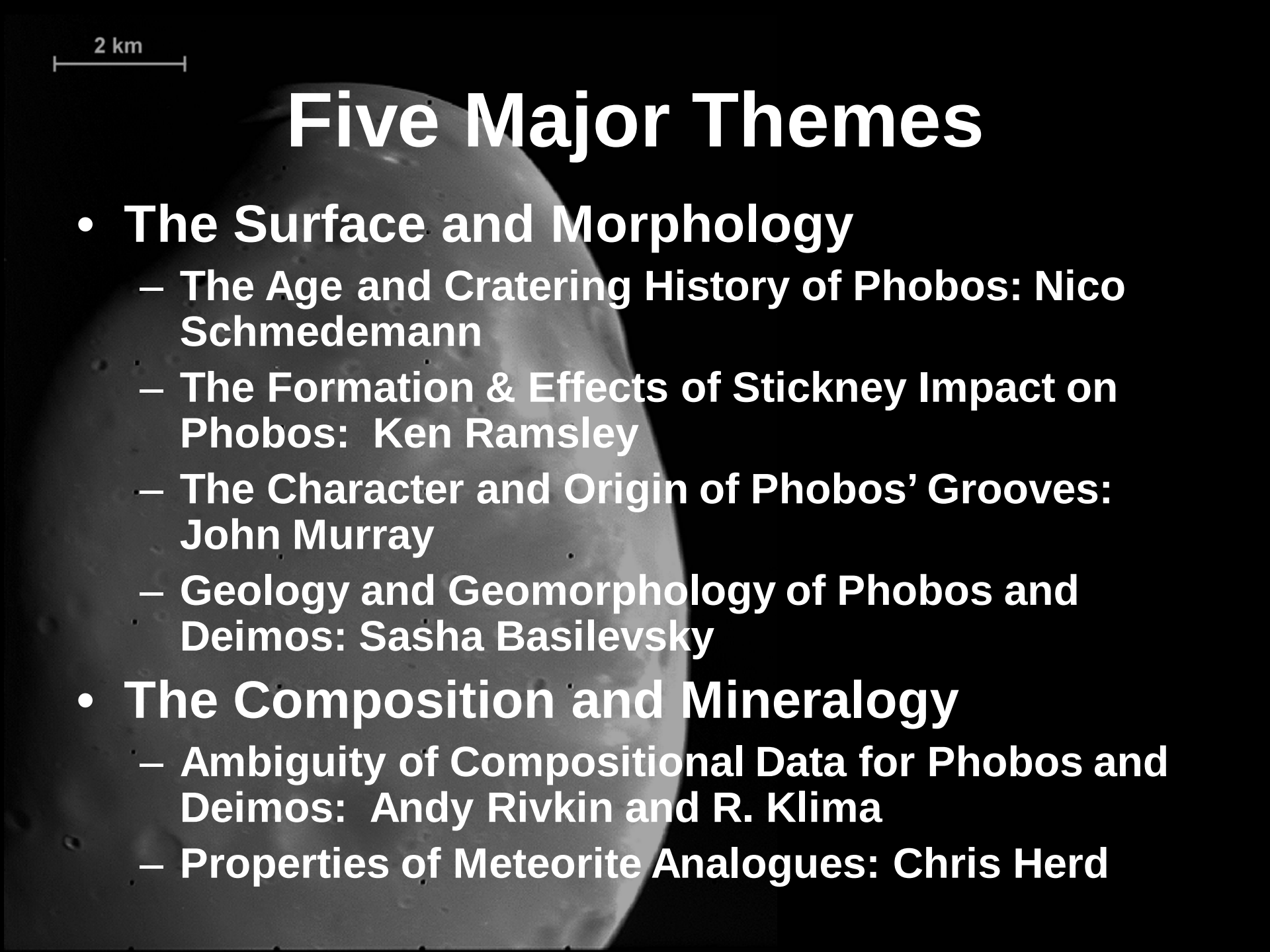


Strategic Knowledge Gaps (SKGs)

- Represent gaps in knowledge or information required to reduce risk, increase effectiveness, and improve the design of robotic and human space exploration missions.
- Part of the process of reviewing what we know about Phobos and Deimos will be to better clarify what we don’t know …..and need to know.
- One of the requirements for the UCF class is to better define and describe Phobos/Deimos SKGs.

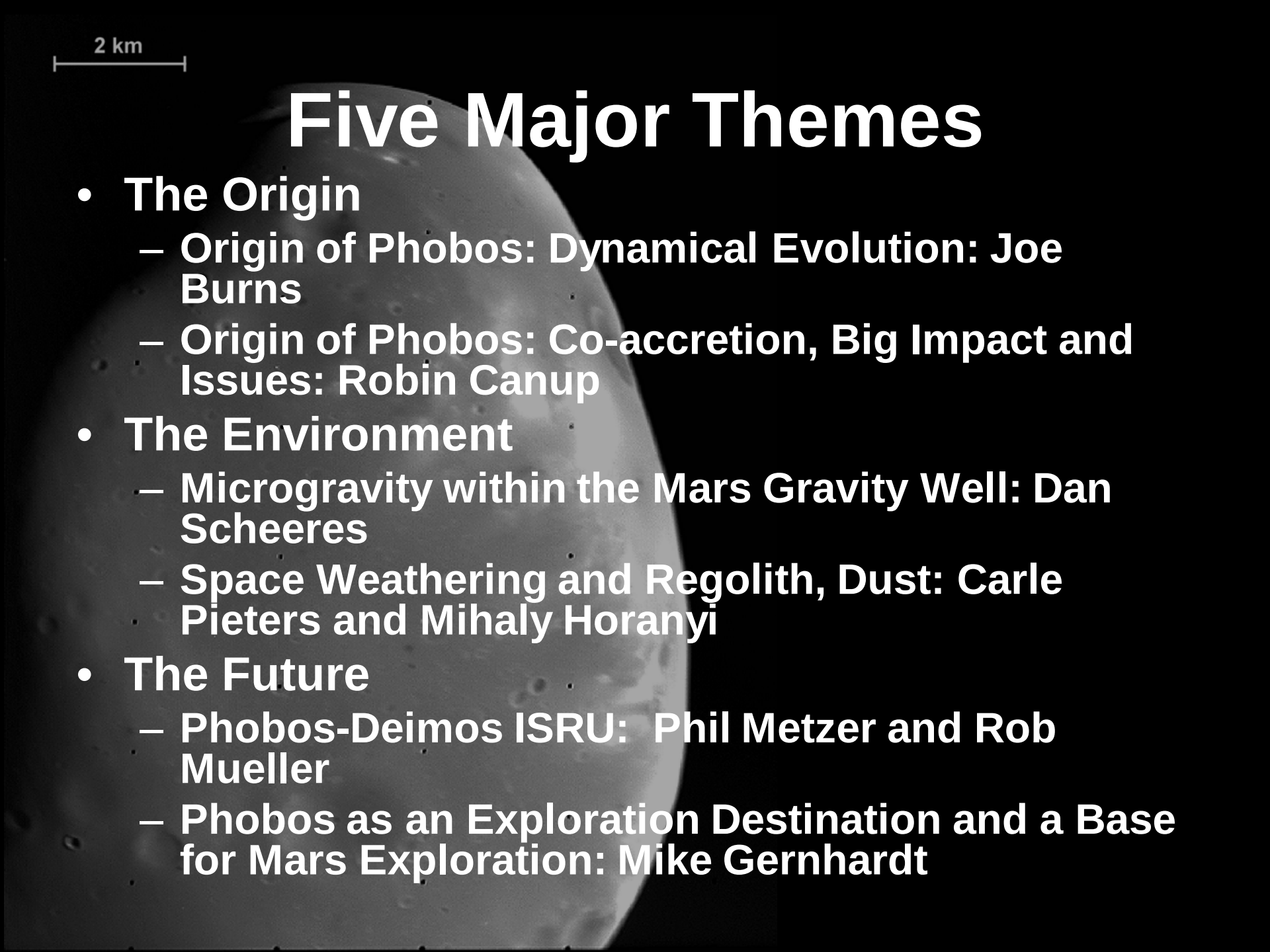
Core Lecture Schedule

Monday	Topic	Speaker
Sept 14	Introduction [discovery, physical properties, orbit…]	Dan Britt
Sept 21	The Age and Cratering History of Phobos	Nico Schmedemann
Sept 28	The Formation & Effects of Stickney Impact on Phobos	Ken Ramsley
Oct 5	The Character and Origin of Phobos' Grooves	John Murray
Oct 12	Ambiguity of Compositional Data for Phobos and Deimos	A. Rivkin/R. Klima
Oct 19	Geology and Geomorphology of Phobos and Deimos	Sasha Basilevsky
Oct 26	Origin of Phobos: Dynamical Evolution	Joe Burns
Nov 2	Origin of Phobos: Co-accretion, Big Impact and Issues	Robin Canup
Nov 9	Properties of Meteorite Analogues	Chris Herd
Nov 16	Microgravity within the Mars Gravity Well	Dan Scheeres
Nov 23	Space Weathering and Regolith, Dust	C. Pieters/M. Horanyi
Nov 30	Phobos-Deimos ISRU	P. Metzer, R. Mueller
Dec 7	Phobos as an Exploration Destination and a Base for Mars Exploration	Mike Gernhardt



Five Major Themes

- **The Surface and Morphology**
  - **The Age and Cratering History of Phobos: Nico Schmedemann**
  - **The Formation & Effects of Stickney Impact on Phobos: Ken Ramsley**
  - **The Character and Origin of Phobos' Grooves: John Murray**
  - **Geology and Geomorphology of Phobos and Deimos: Sasha Basilevsky**
- **The Composition and Mineralogy**
  - **Ambiguity of Compositional Data for Phobos and Deimos: Andy Rivkin and R. Klima**
  - **Properties of Meteorite Analogues: Chris Herd**

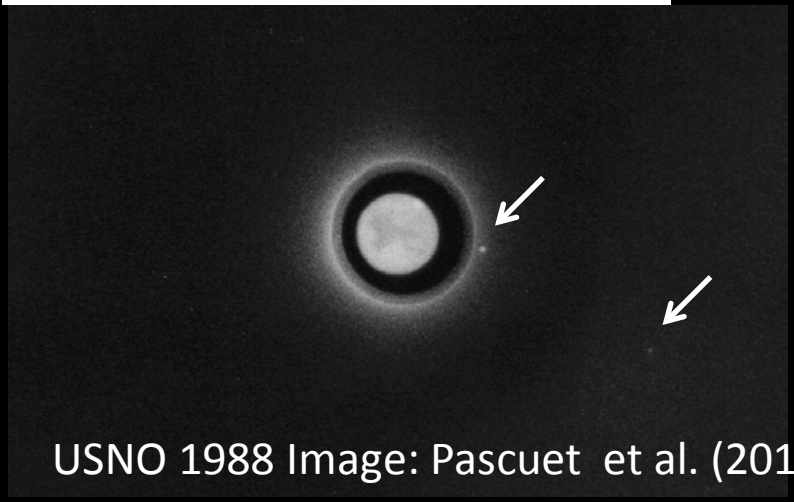


Five Major Themes

- The Origin
  - Origin of Phobos: Dynamical Evolution: Joe Burns
  - Origin of Phobos: Co-accretion, Big Impact and Issues: Robin Canup
- The Environment
  - Microgravity within the Mars Gravity Well: Dan Scheeres
  - Space Weathering and Regolith, Dust: Carle Pieters and Mihaly Horanyi
- The Future
  - Phobos-Deimos ISRU: Phil Metzer and Rob Mueller
  - Phobos as an Exploration Destination and a Base for Mars Exploration: Mike Gernhardt

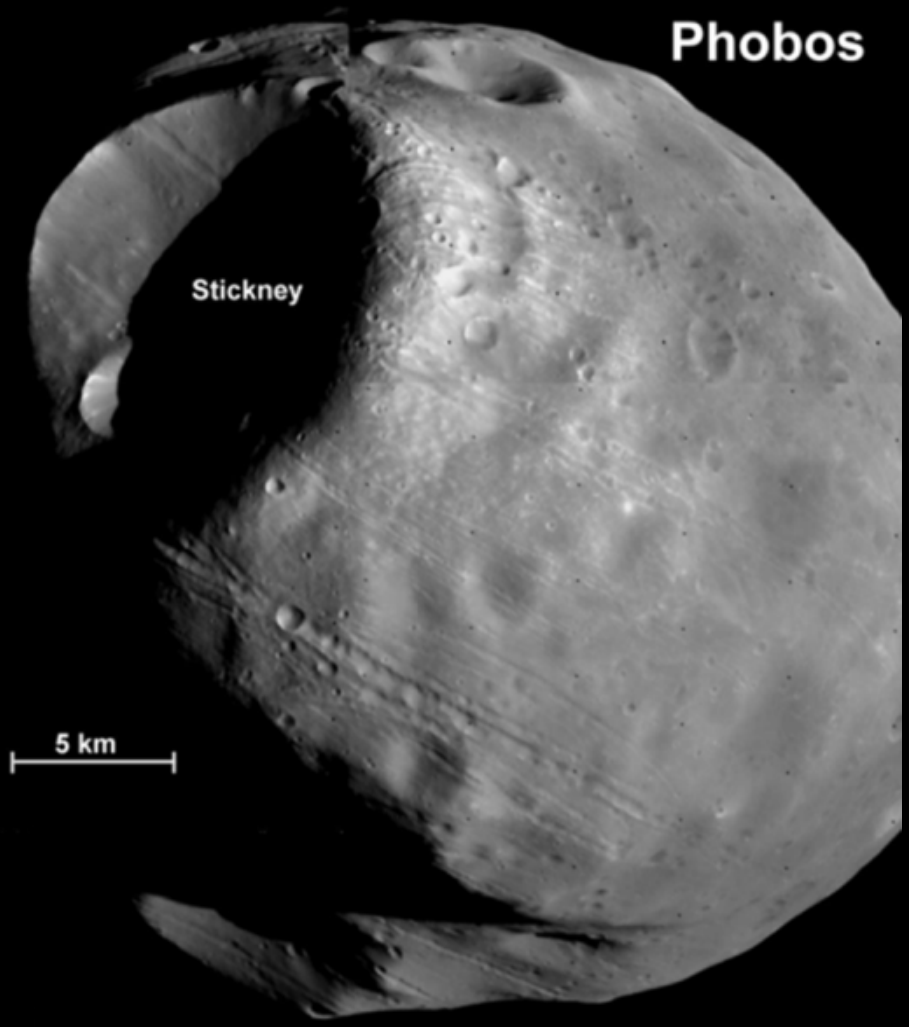
A Bit of History

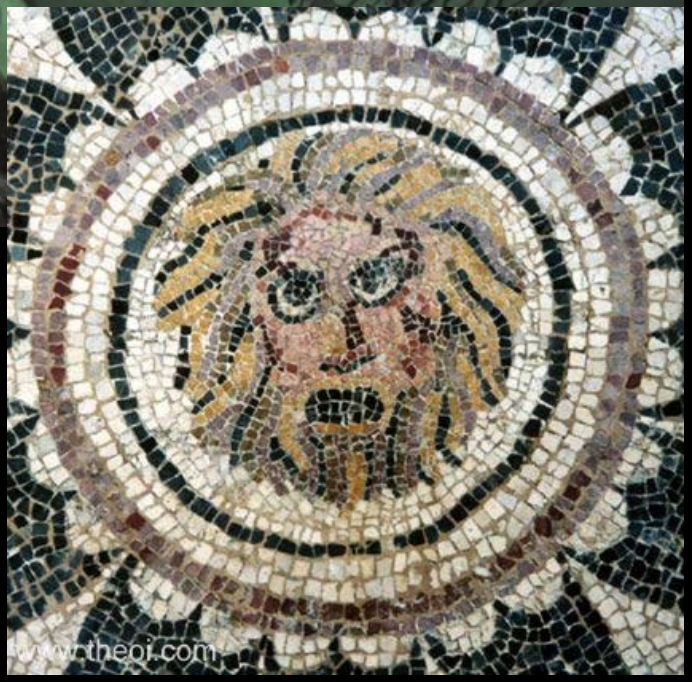
- **Phobos and Deimos were discovered by Asaph Hall of the US Naval Observatory August 1877.**
- **The discovery was visual….turns out that the dynamic range of the eye was better for these observations until the advent of CCD's**



USNO 1988 Image: Pascuet et al. (2014)

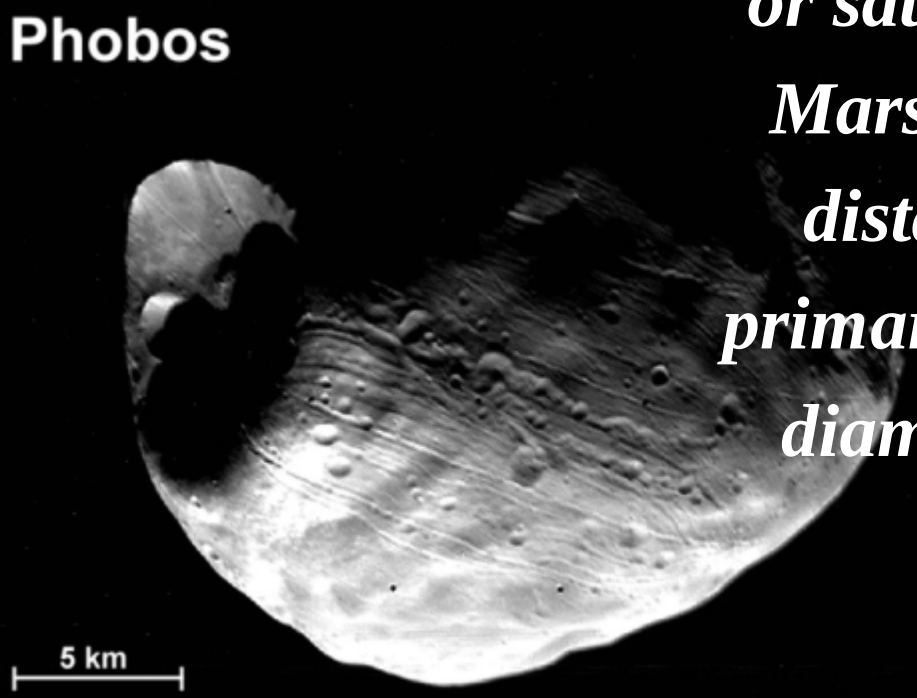
- This one observation lead to some pretty solid science.
  - Allowed determination of an accurate mass for Mars.
  - Suggested that small moons were common around other planets.
  - Its close orbit results in three moon-rises per Martian day.
- The major feature on Phobos, Stickney Crater, was named (in 1973) after Hall's wife Angeline Stickney Hall.
  - She was an accomplished mathematician who assisted Hall in his astrometry.
  - "However she demanded a man's wage while she assisted her husband in his computations, when he refused her, she refused to continue that work."





What's in a Name?

- Hall named the moons after mythological associates of the primary, Mars.
- Phobos (fear or horror) and Deimos (terror or dread) are the twin sons of Mars (god of war, Greek Ares) and Venus (goddess of love and beauty, Greek Aphrodite).
  - Note that Venus was married to Vulcan (god of blacksmiths, fire and volcanos).
  - Venus was also claimed as an ancestor of Julius Caesar (mother of Aeneas).
- Phobos and Deimos were Mars' companions in war. But there were a lot of other options.
  - His companions included his sister Eris (goddess of discord) and his daughter Adrestia (goddess of revolt and just retribution).
  - Not to mention Kydoimos (demon of the noise of battle), the Makhai (demons of battle), the Hysminai (demons of acts of manslaughter) or any of his ~100 children by ~40 consorts.



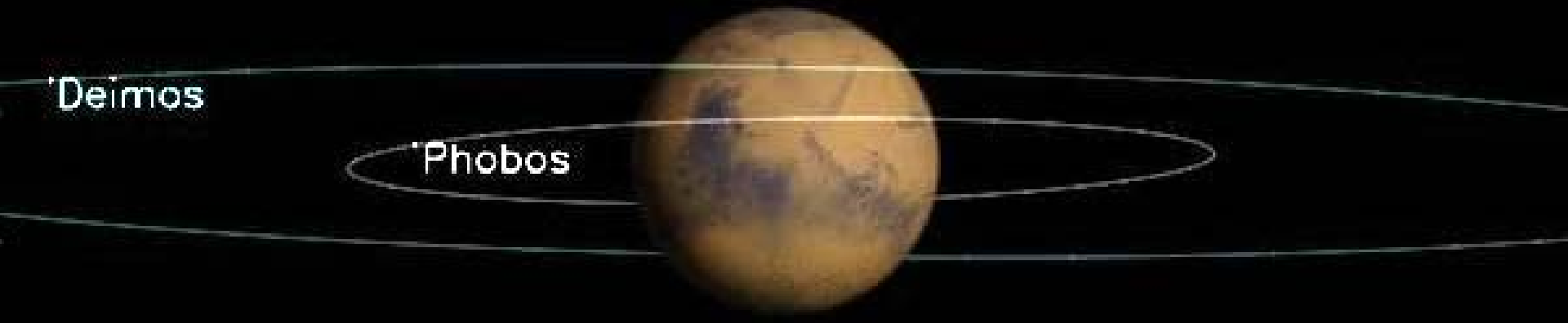
“They [Laputian astronomers] have likewise discovered two lesser stars, or satellites, which revolve about Mars, whereof the innermost is distant from the centre of the primary planet exactly three of his diameters, and the outer-most, five…”

Jonathan Swift, Gulliver’s Travels

(1726)

151 years prior to the moon’s discovery by Asaph Hall of the US Naval Observatory

Orbits and Physical Properties



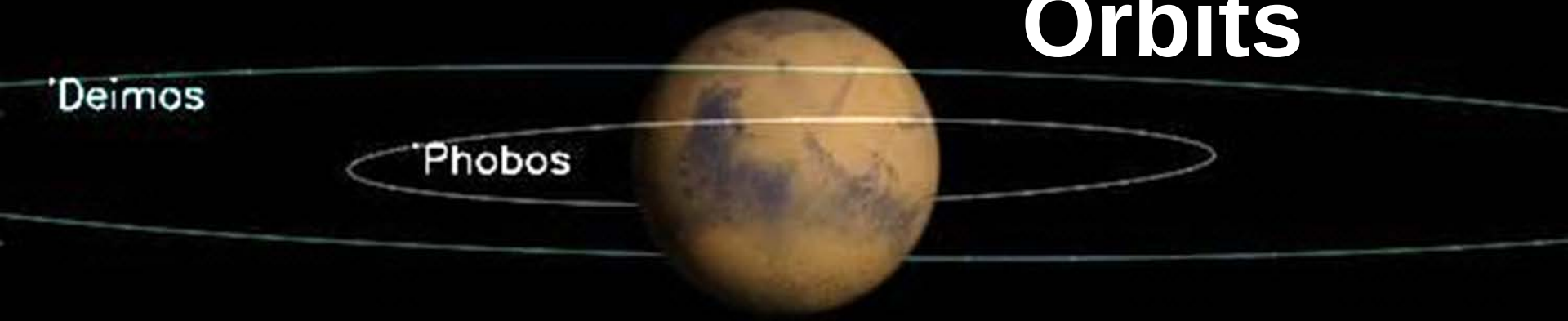
Phobos

- 9,377.2 km (2.76 Mars radii)
- About 23 km in diameter
- Albedo 7.1%
- Bulk Density 1.87 g/cm3
- Surface gravity 0.0057 m/s2
- Escape velocity 11.39 m/s
- Orbital Period 7 h 39.2 min

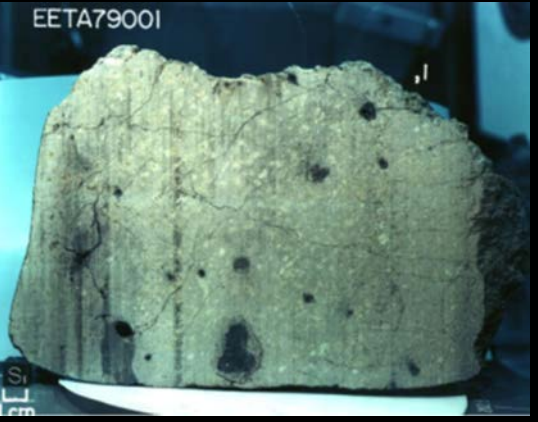
Deimos

- 23,459 km (~7 Mars radii)
- About 6 km in diameter
- Albedo 6.8%
- Bulk Density 1.47 g/cm3
- Surface gravity 0.003 m/s2
- Escape velocity 5.556 m/s
- Orbital Period 30 h 18.7 min

Orbits



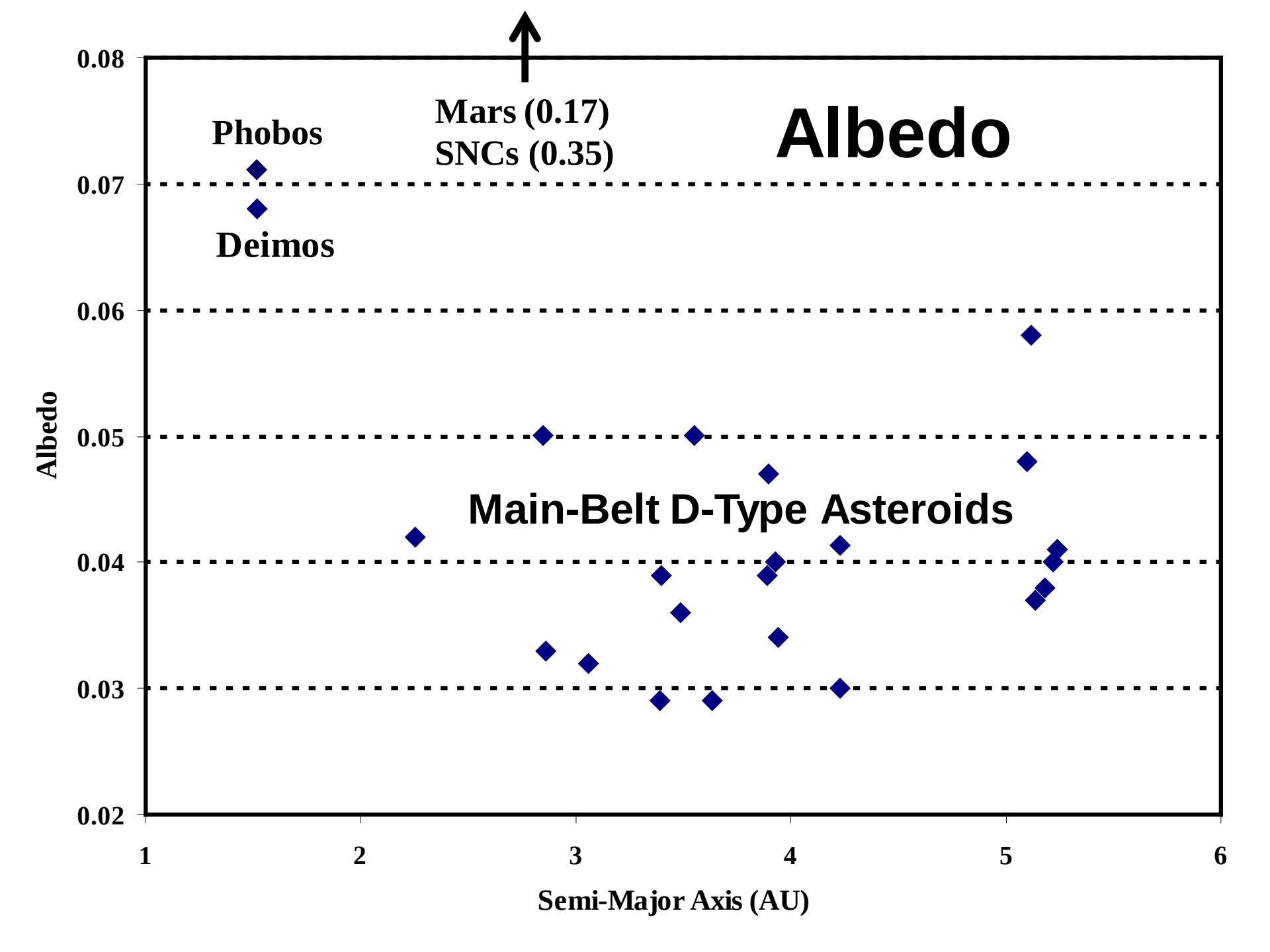
- Both are tidally synchronized to Mars
  - Always presents the same side to Mars
- Both have nearly circular orbits with very low inclinations.
- Deimos is just beyond the Mars geostationary orbit (20462 km vs 23460 km)
- Deimos is gaining orbital energy from tidal interactions with Mars.
- Phobos is losing orbital energy and has a decaying orbit (collision with Mars in ~45 million years).



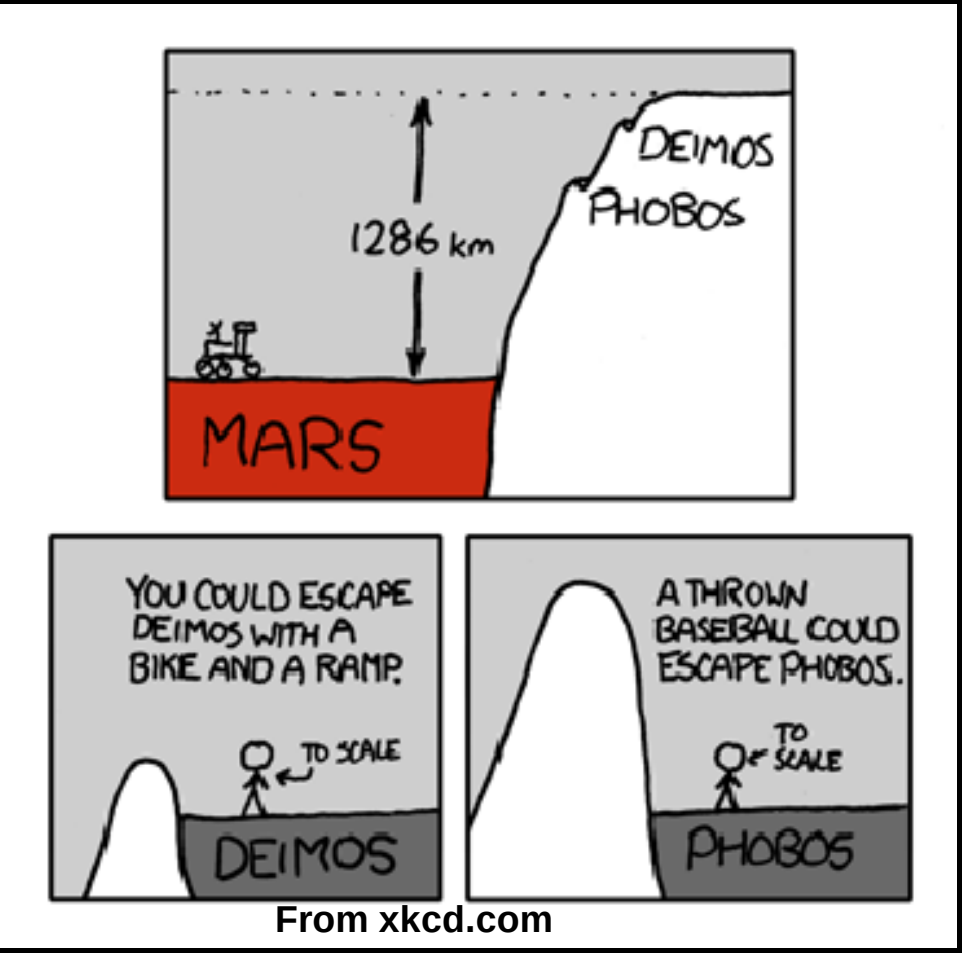
Density

Object	Bulk Density	Porosity
Phobos	1.87 g/cm^3	?
Deimos	1.47 g/cm^3	?
Orgueil (CI)	1.57 g/cm^3	34.9%
Average CM	2.20 g/cm^3	24.7%
Average L Chondrite	3.30 g/cm^3	8.0%
Average SNC	3.08 g/cm^3	9.0%

- Both Phobos and Deimos are probably rubble piles with substantial porosity.

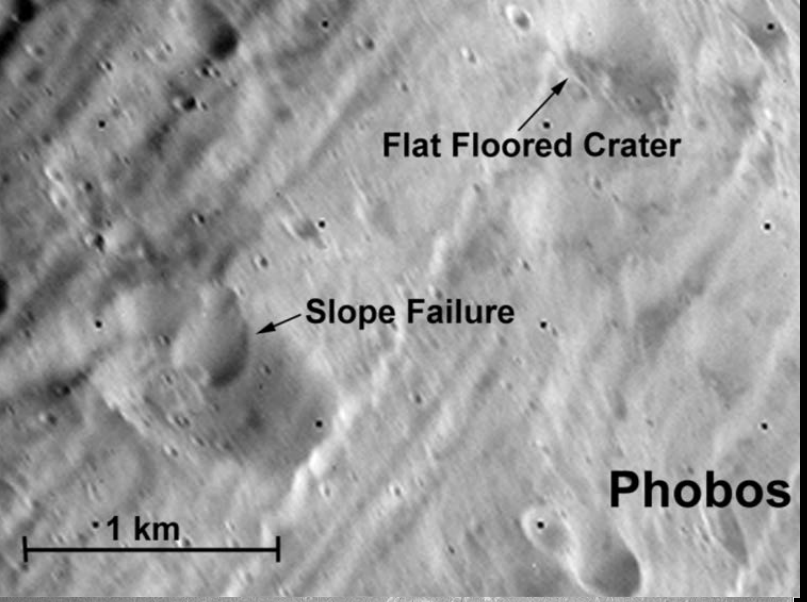

Albedo
Mars (0.17)
SNCs (0.35)
Phobos
Deimos
Main-Belt D-Type Asteroids
0.08
0.07
0.06
0.05
0.04
0.03
0.02
Albedo
1
2
3
4
5
6
Semi-Major Axis (AU)

Gravitational Environment



From xkcd.com

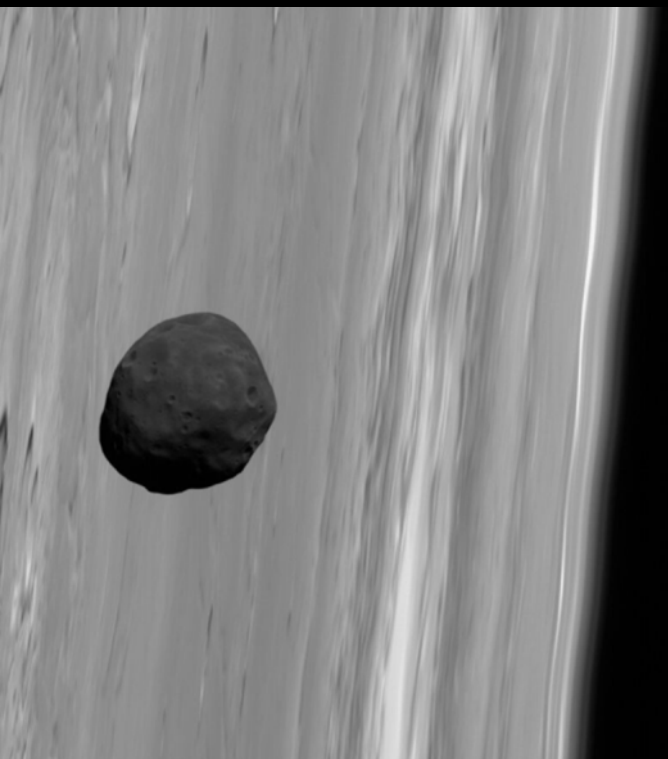
- Unique for small bodies
- Low self-gravity, but deep in the Martian gravity well.
- Low to moderate velocity ejecta would be retained in the Mars system and some could be reaccreted.



Regolith

- Evidence of a thick, loose regolith
- Helped by the unique gravitational environment.
- On Phobos the regolith may be as thick as 200 meters.
- On Deimos, evidence of “dusty streaks”

Image PIA17356 at NASA/JPL

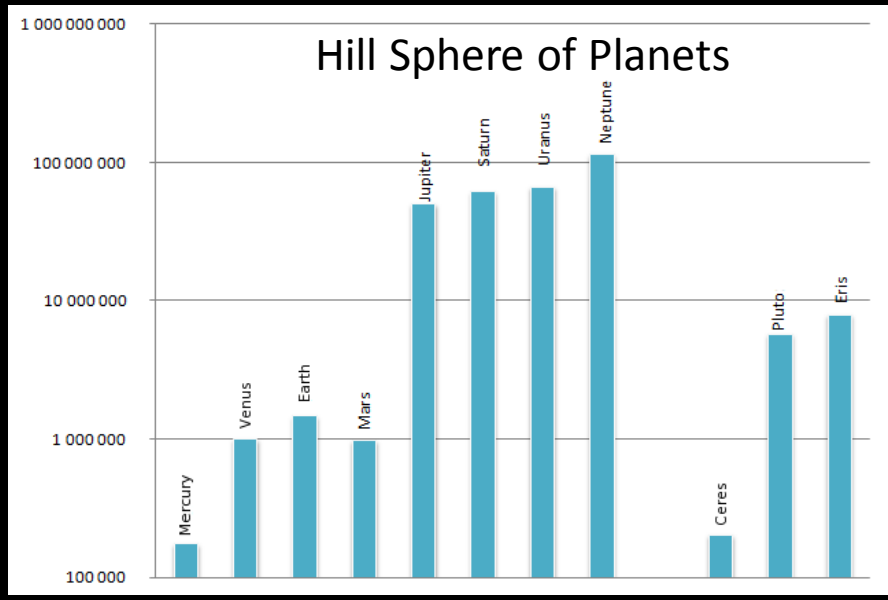


Views

- **Phobos has some pretty spectacular views……**
- **From the surface it is about half the apparent size of the Sun**
- **From Phobos the apparent size of Mars is 42.5 degrees ……about 6400 times larger than our Moon from Earth.**

The Origin of Phobos and Deimos: Captured Asteroid

- **Evidence: Low density, low albedo, spectral D-class similar to outer asteroid belt small bodies.**
- **Source: From high flux of Jupiter-scattered planetesimals?**
- **Problem: Capture requires energy loss within the Hill Sphere and the low inclination, circular orbit is hard to achieve.**

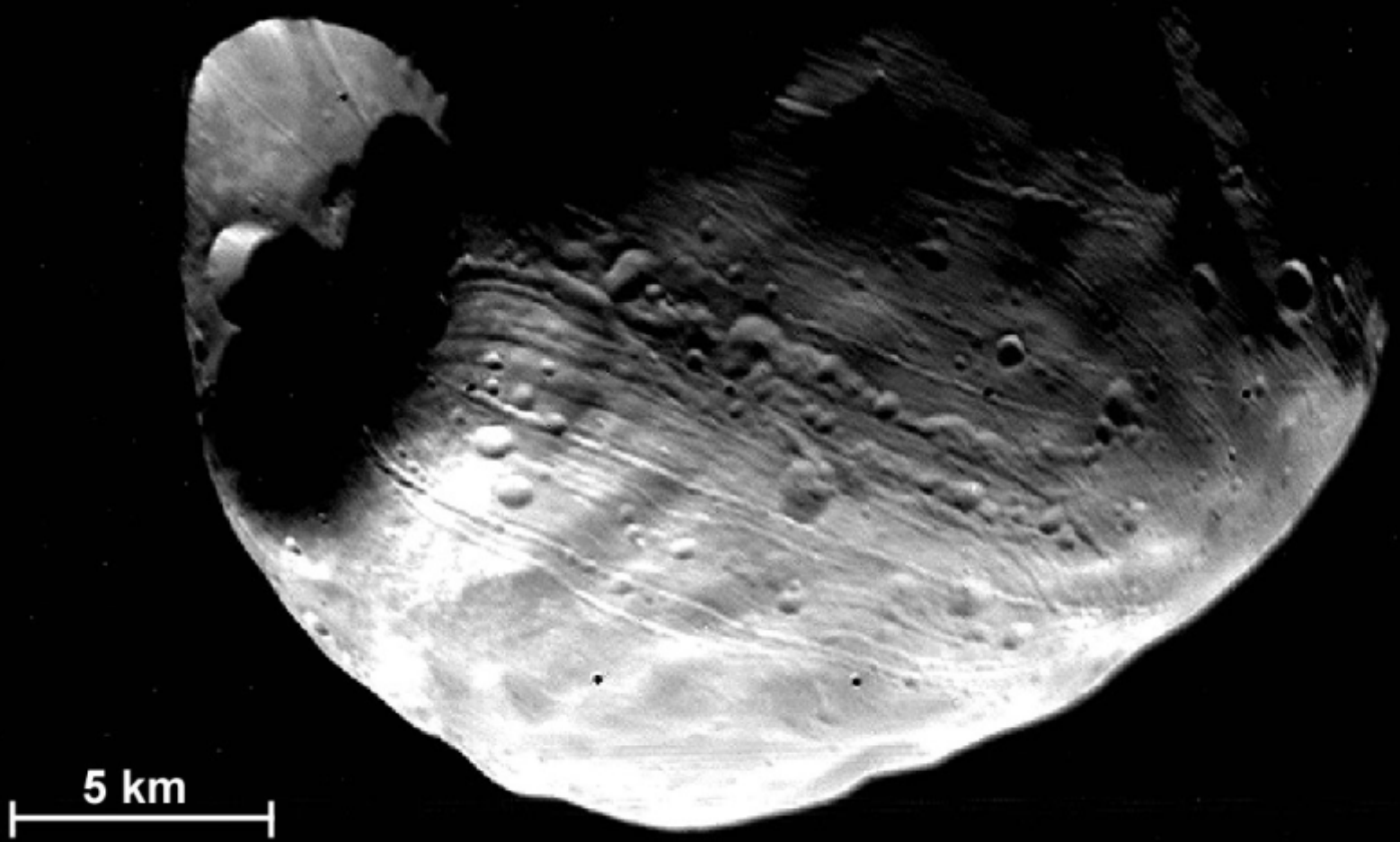


The Origin of Phobos and Deimos

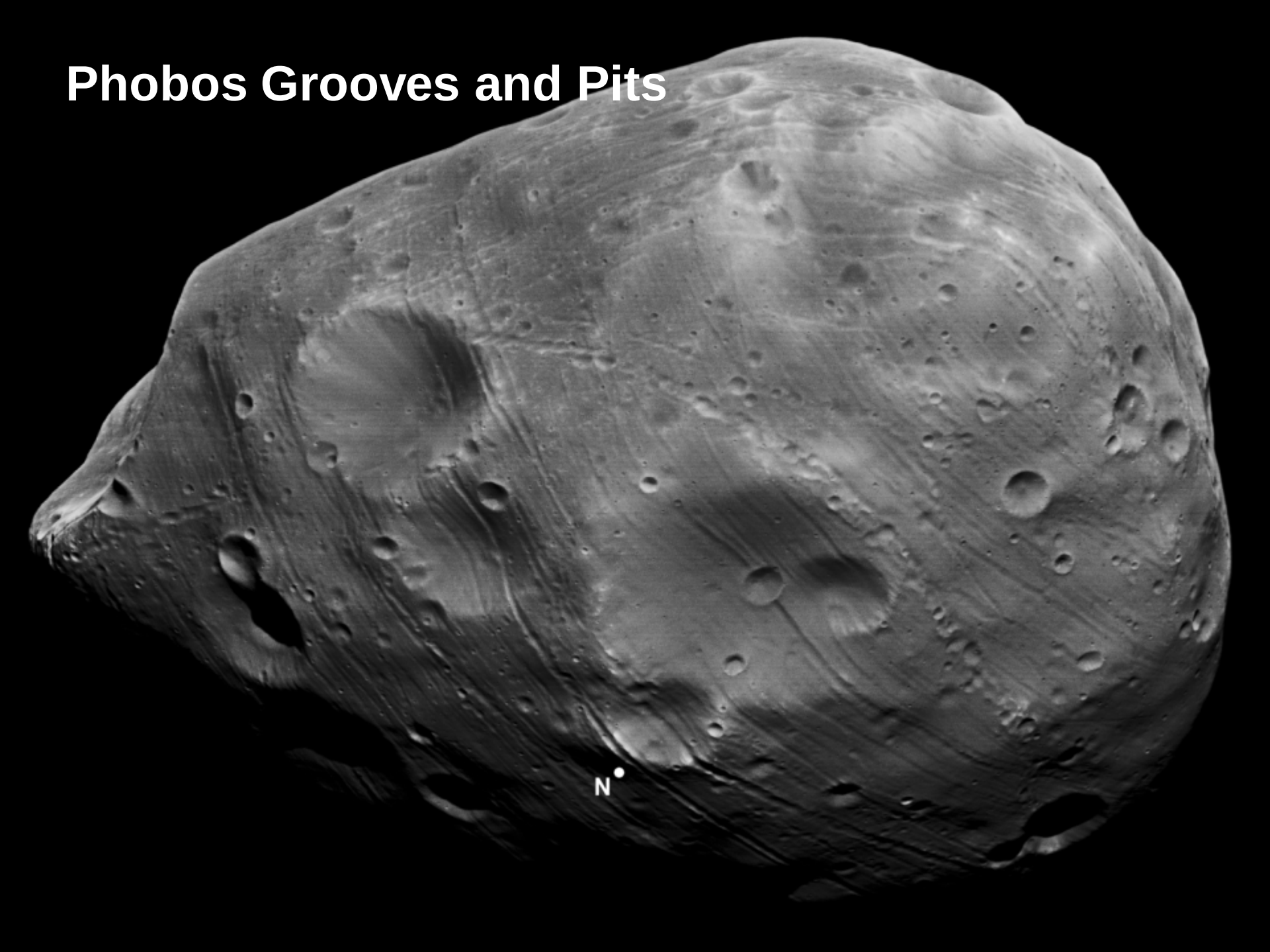
- **Formed from Mars Ejecta**
  - Evidence: Albedo on high end of primitive bodies, shallow absorption features, dynamics work better.
  - Source: Early Mars heavy bombardment
  - Problems: Albedo is too low, Mars-material content appears low, requires extra impulse for orbit.
- **Accreted In Place**
  - Evidence: "Consequence of planetary formation", dynamics work better.
  - Source: Mars space nebular material
  - Problems: Expect material in Mars space to be high-albedo, mafic. Albedo too low.

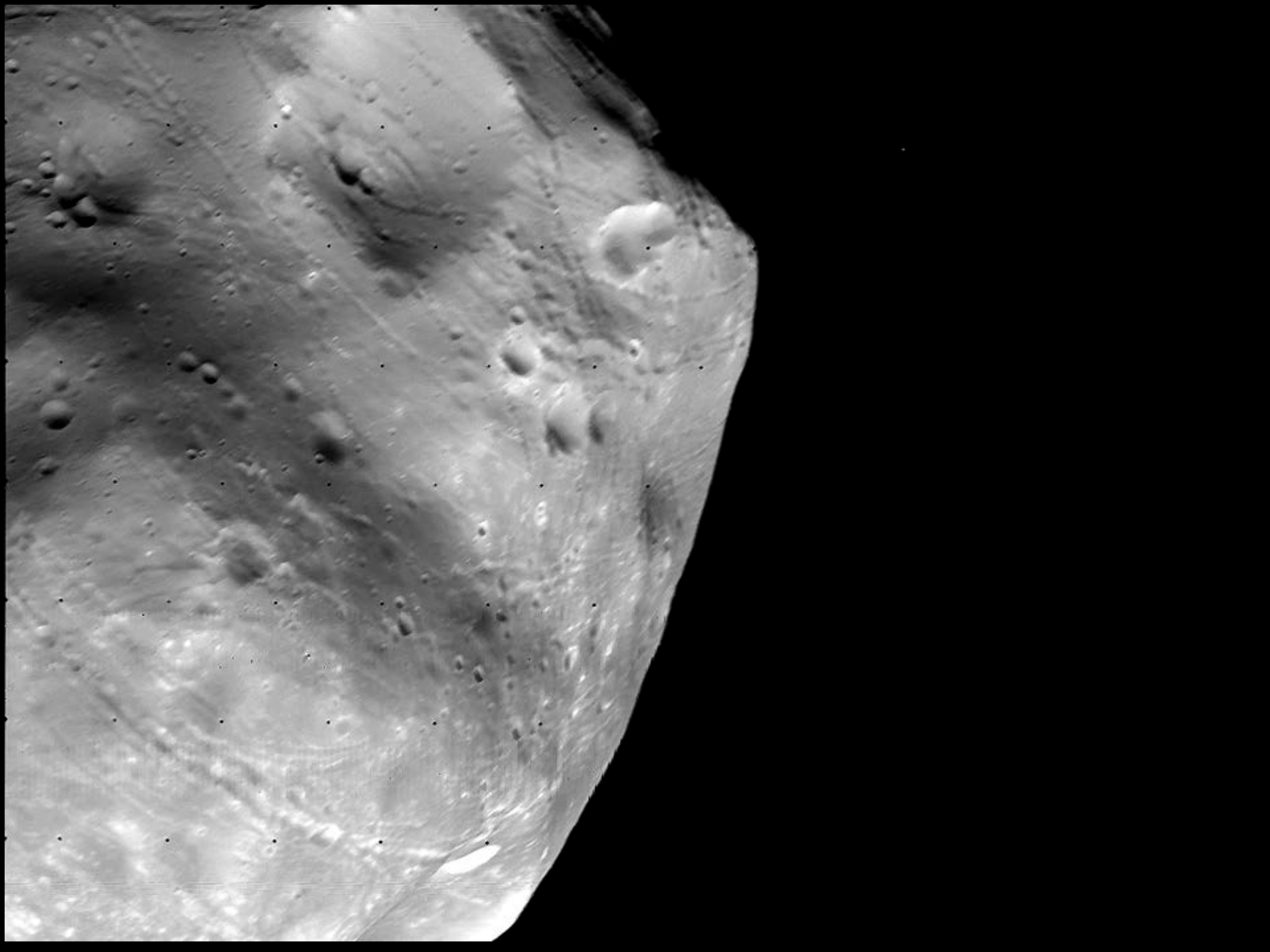

Sutters Mill

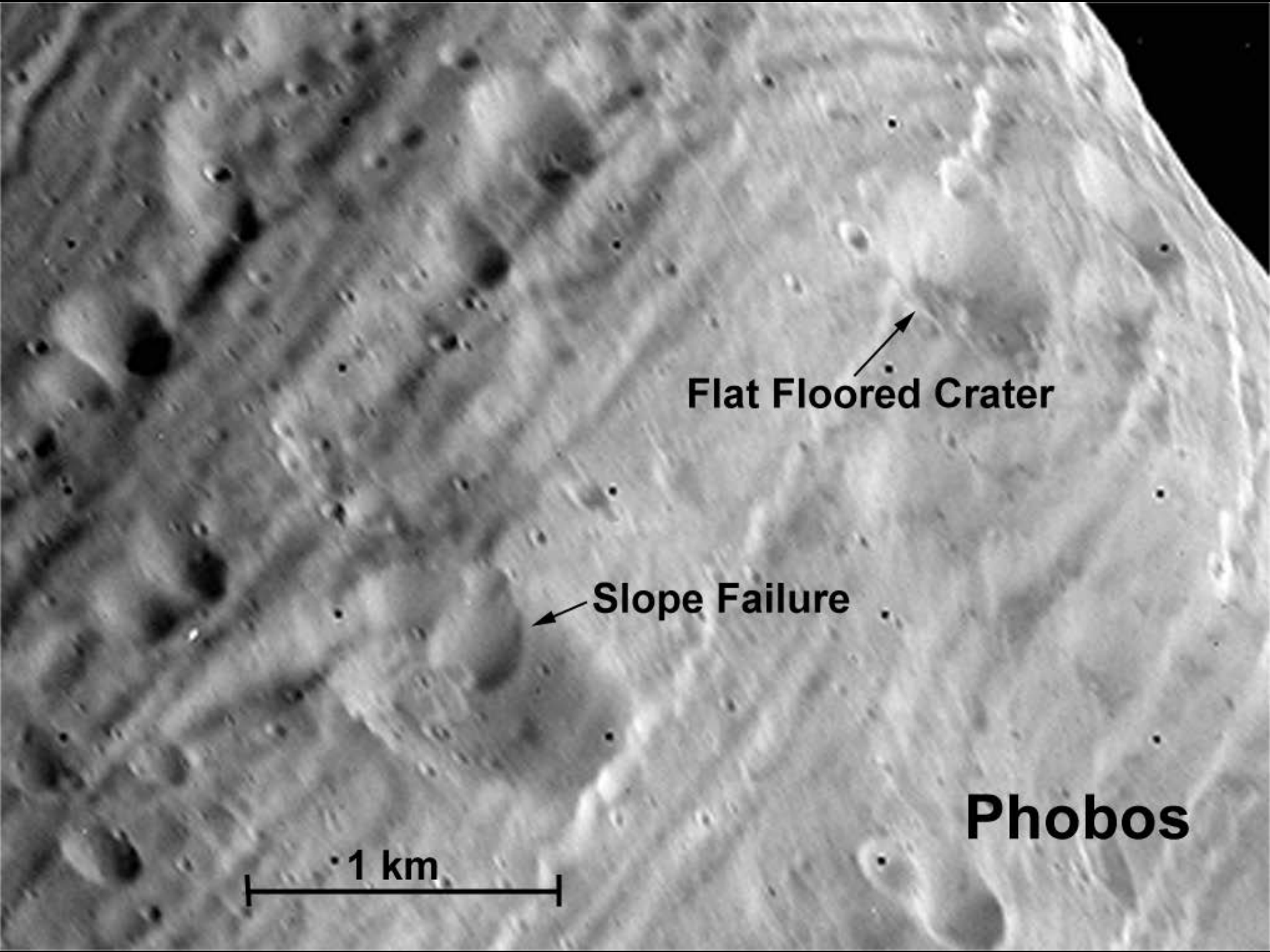
Phobos

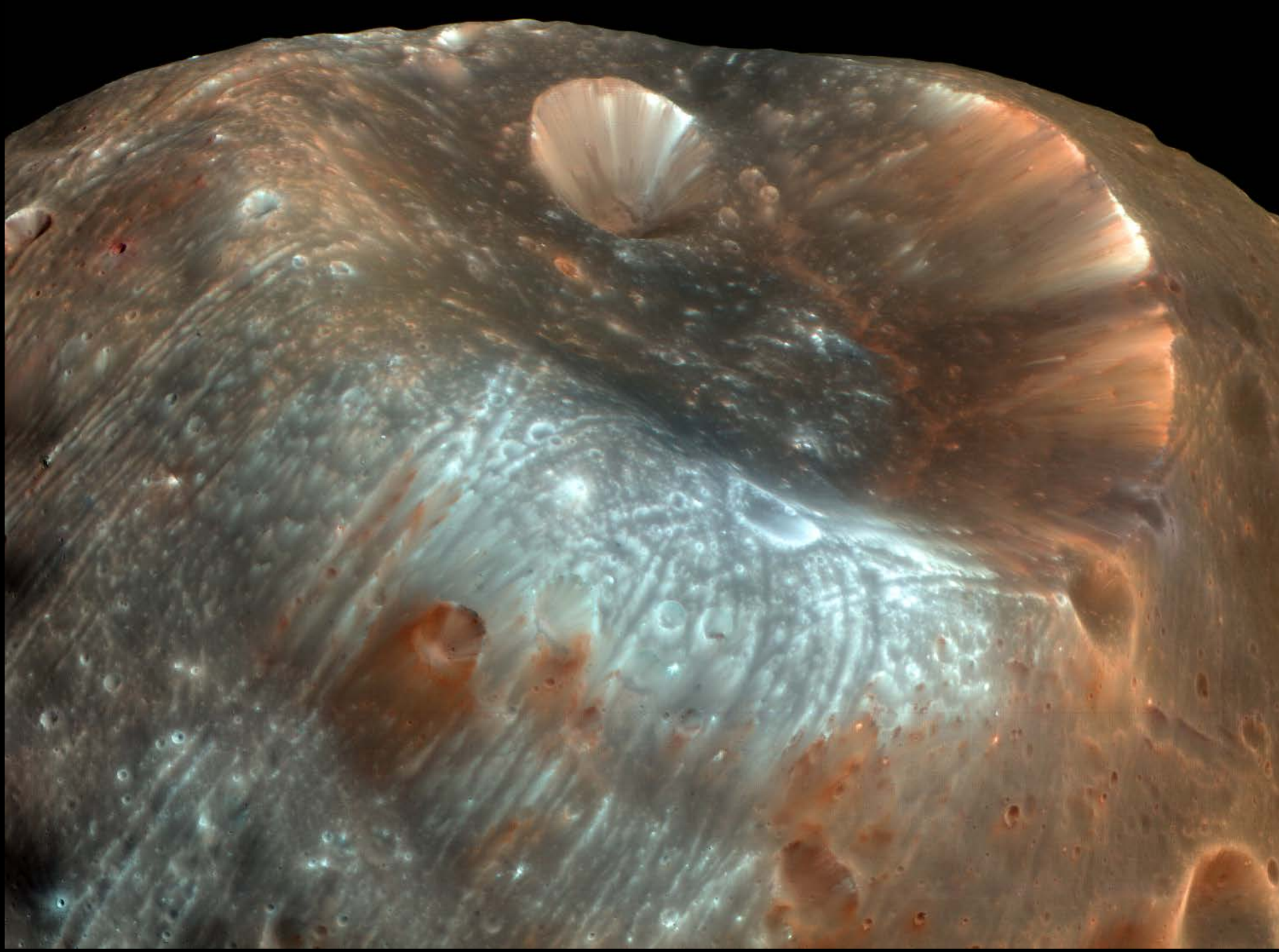


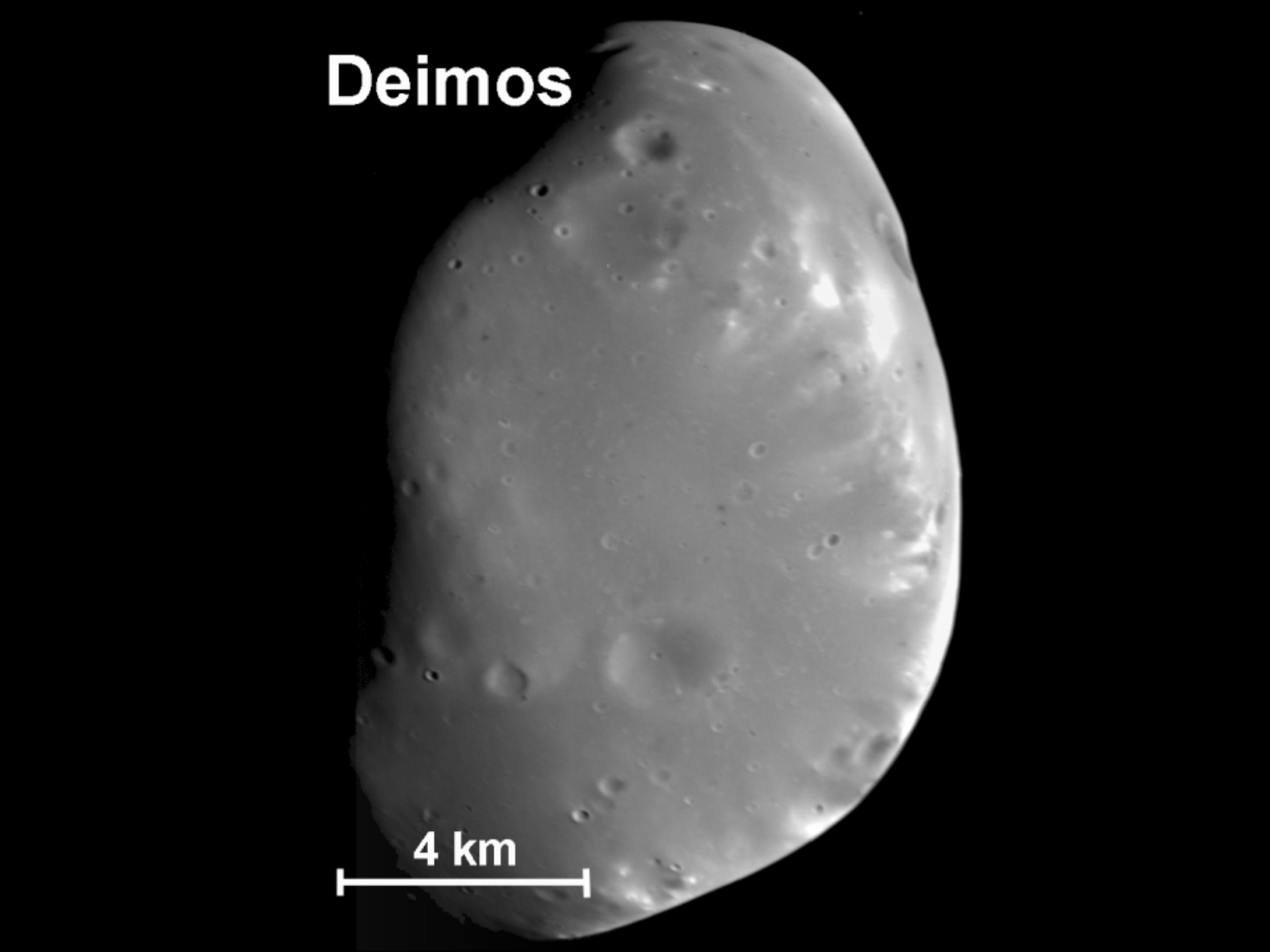
Phobos Grooves and Pits

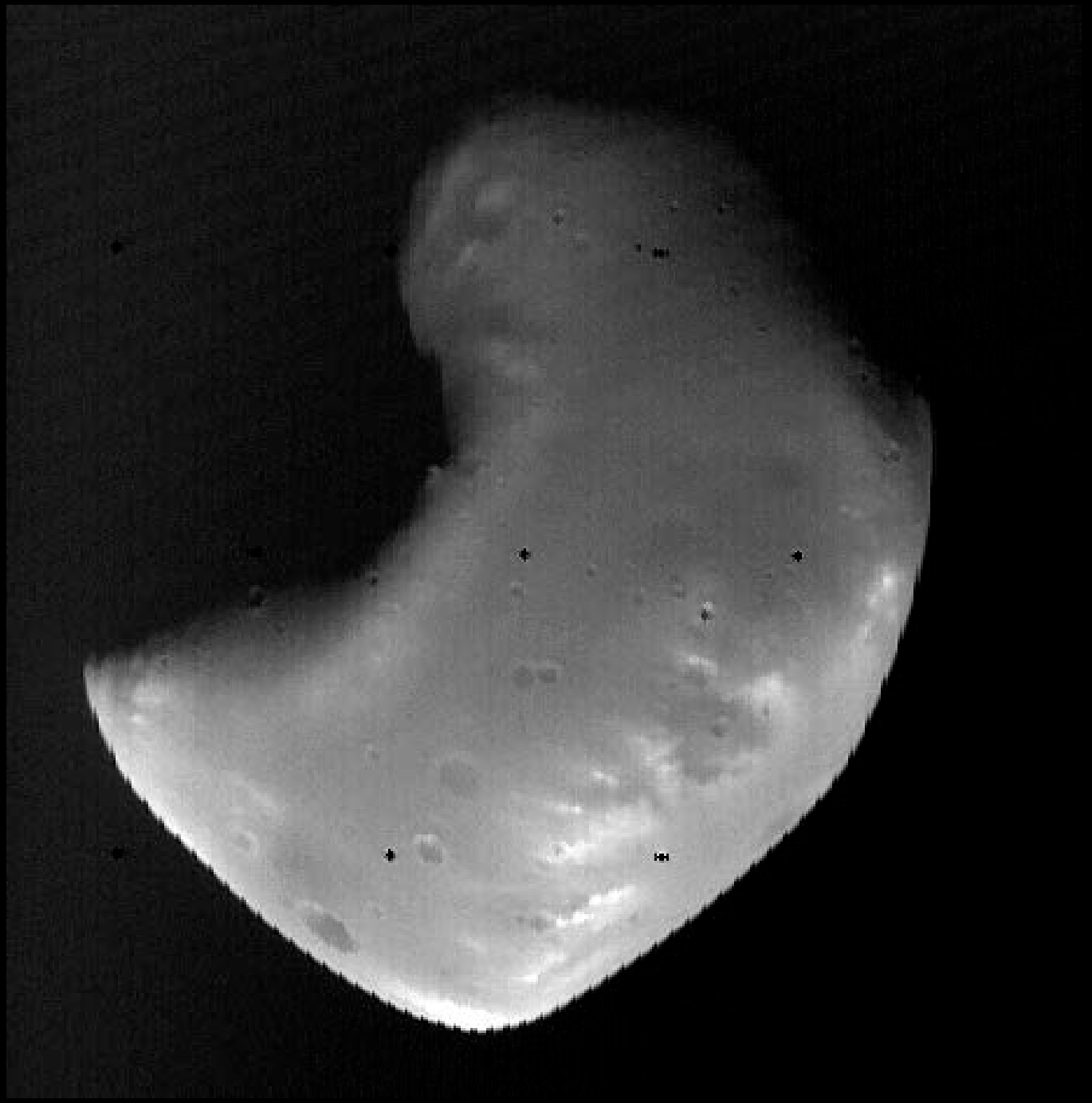


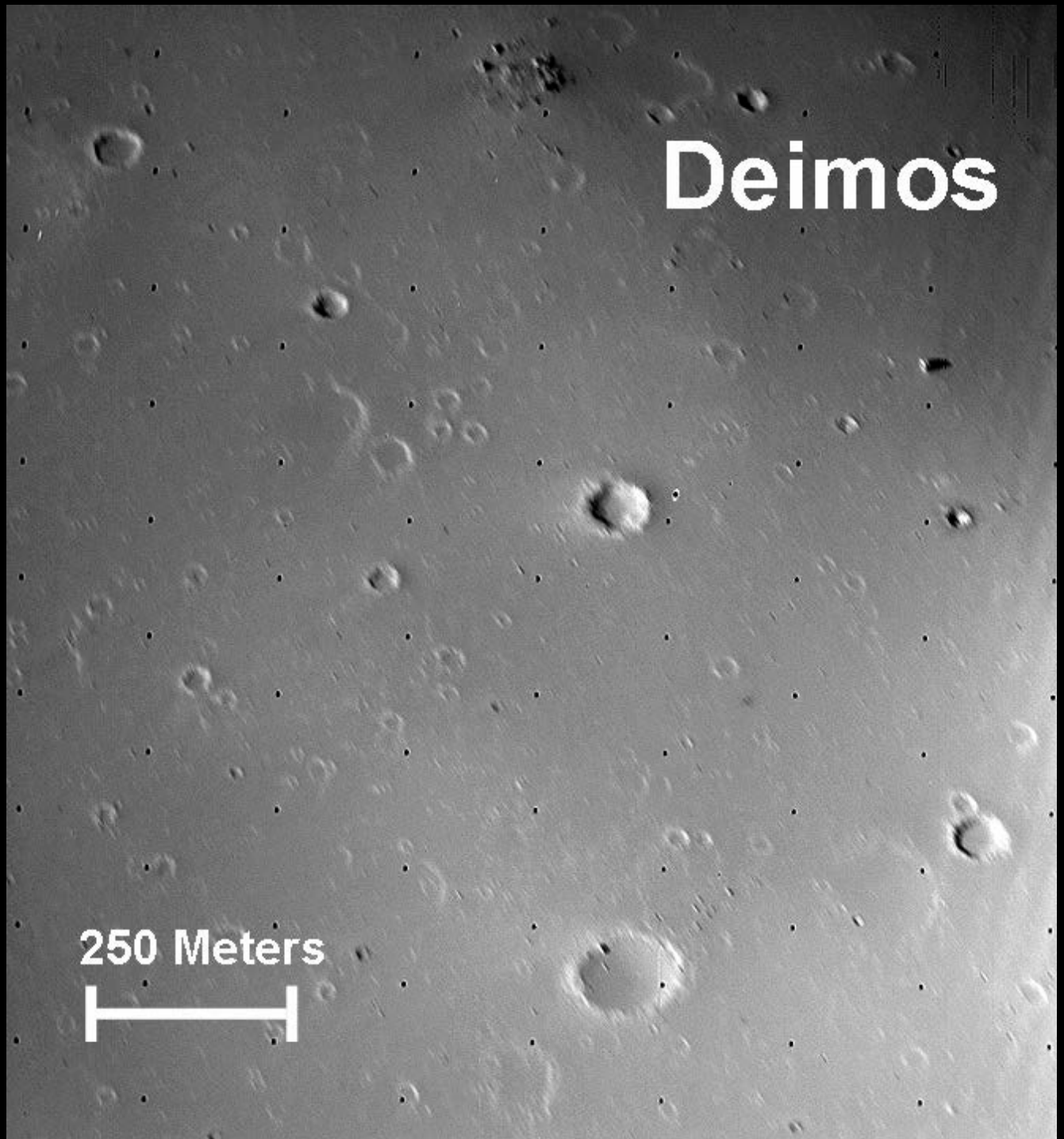



Flat Floored Crater
Slope Failure
Phobos
1 km

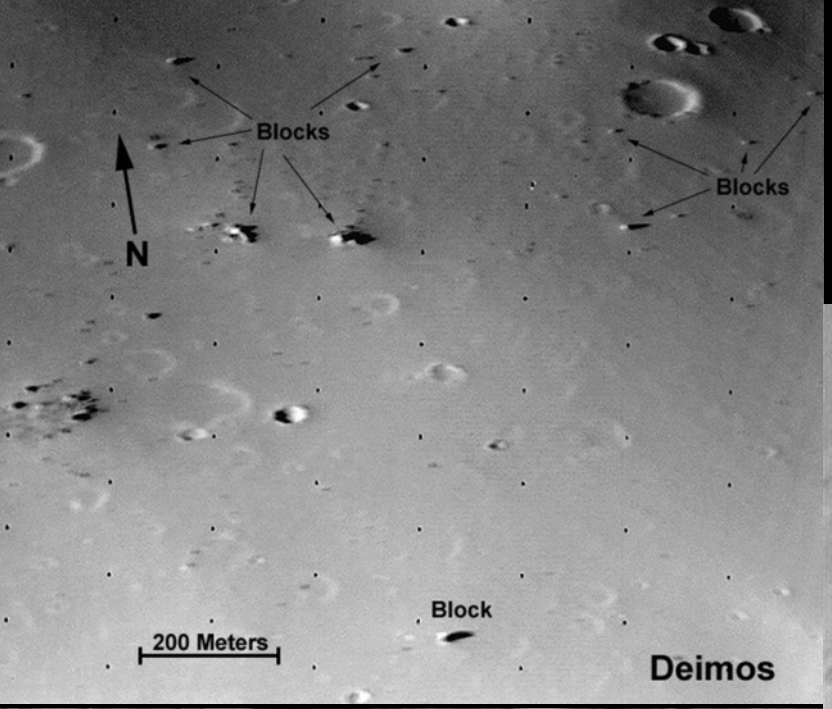



Deimos
4 km

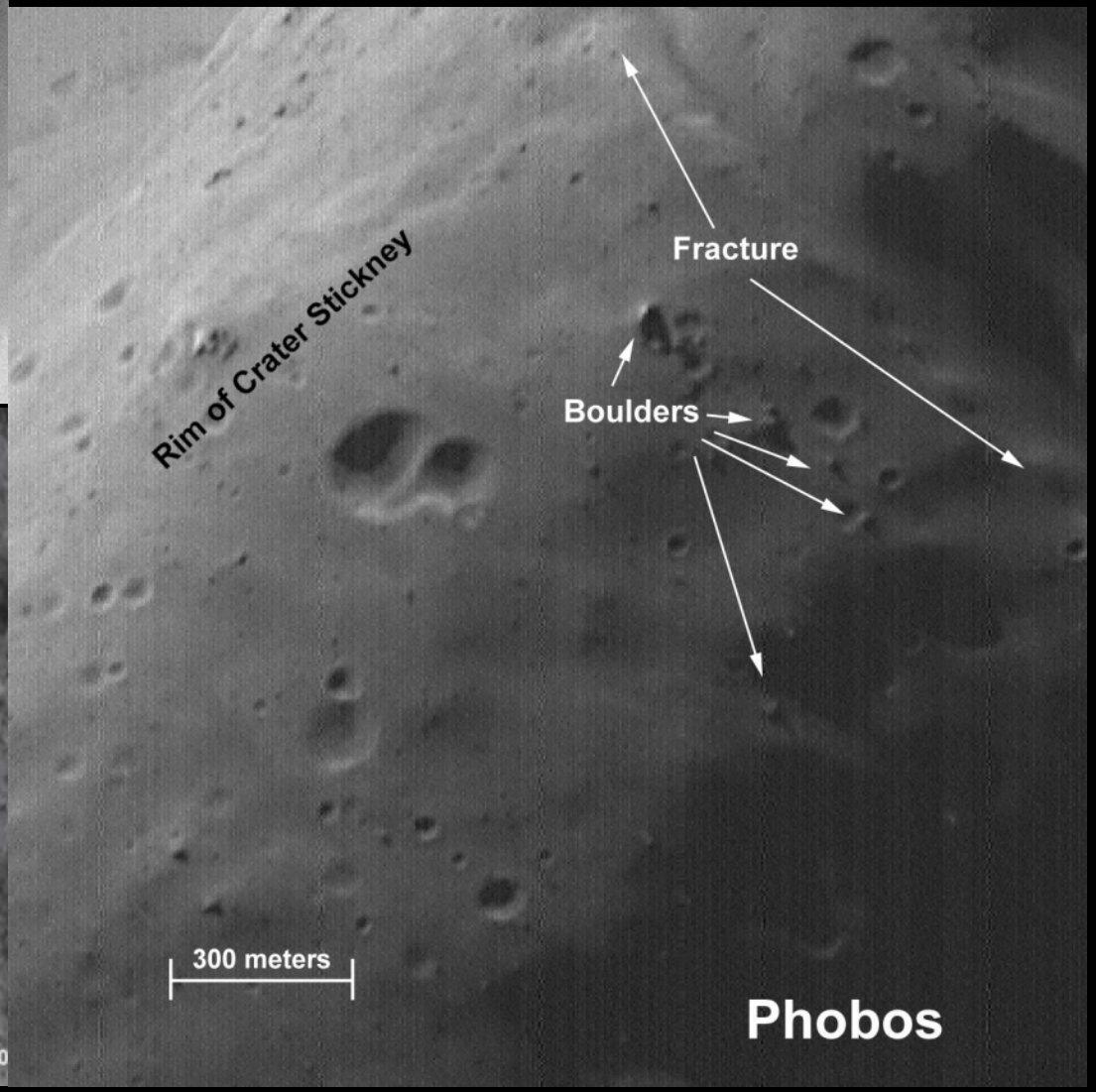


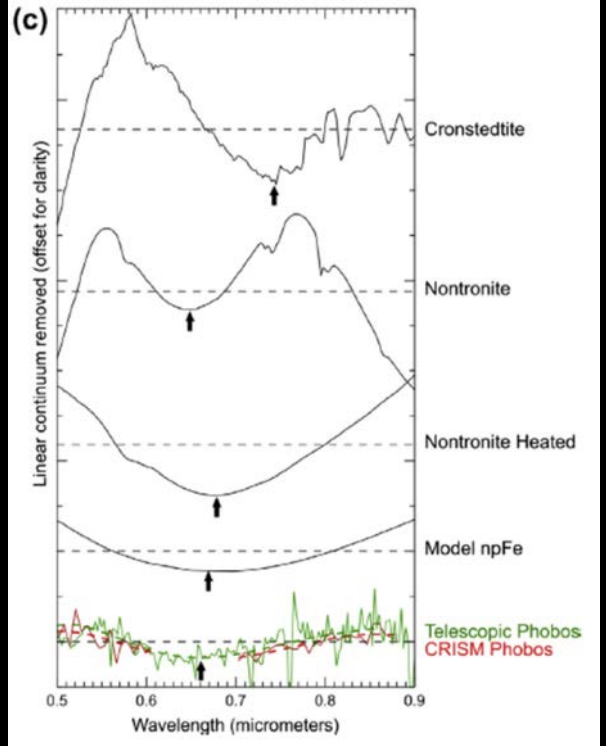

Deimos
250 Meters

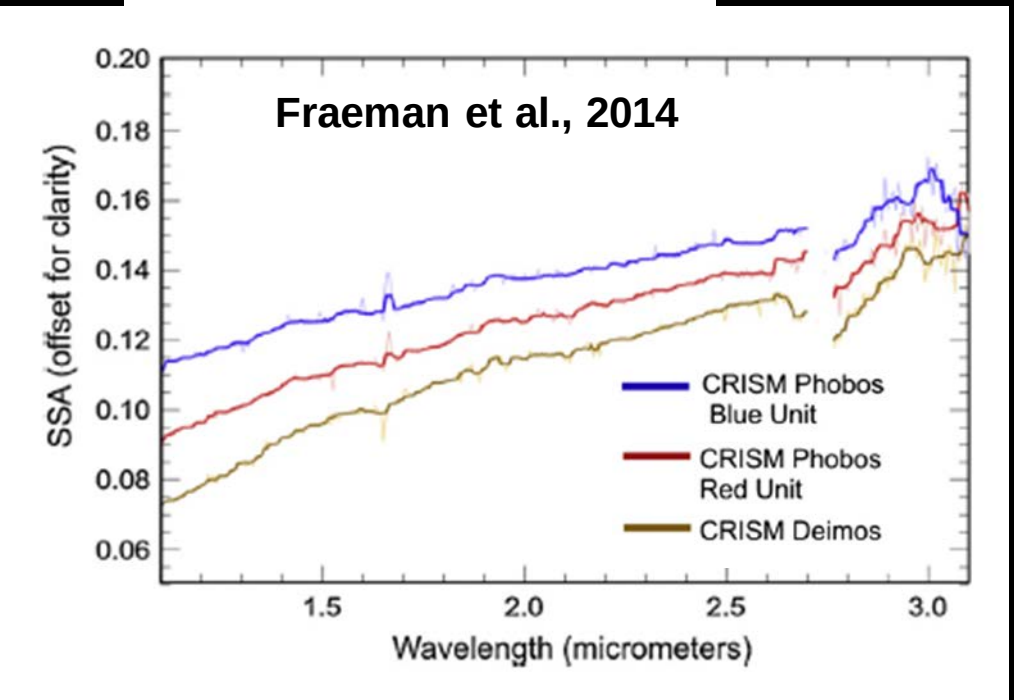
Boulders


Blocks
Blocks
N
Block
200 Meters
Deimos


433 Eros
200 Meters
NEAR/JHU Image 20010

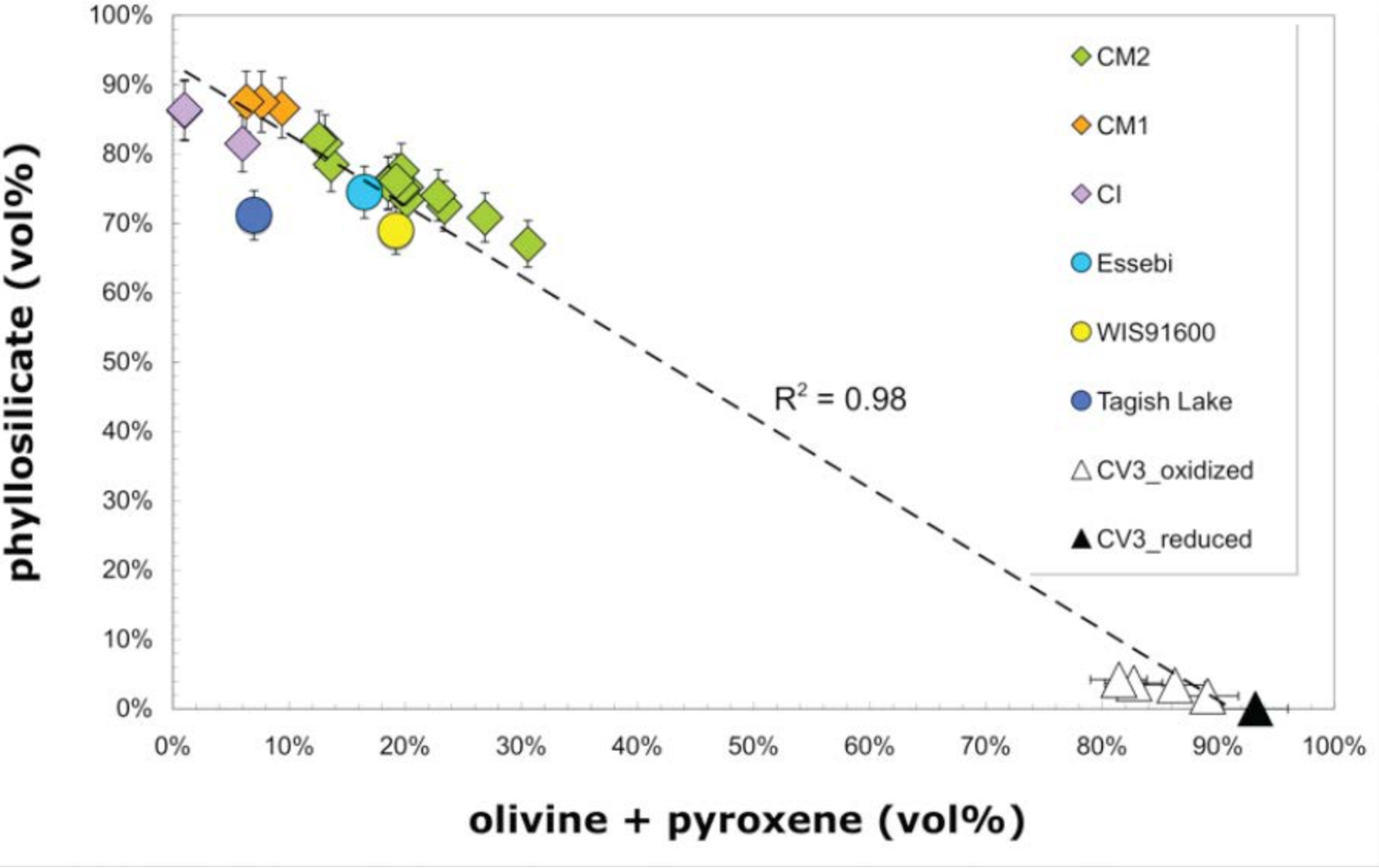

Rim of Crater Stickney
Fracture
Boulders
300 meters
Phobos





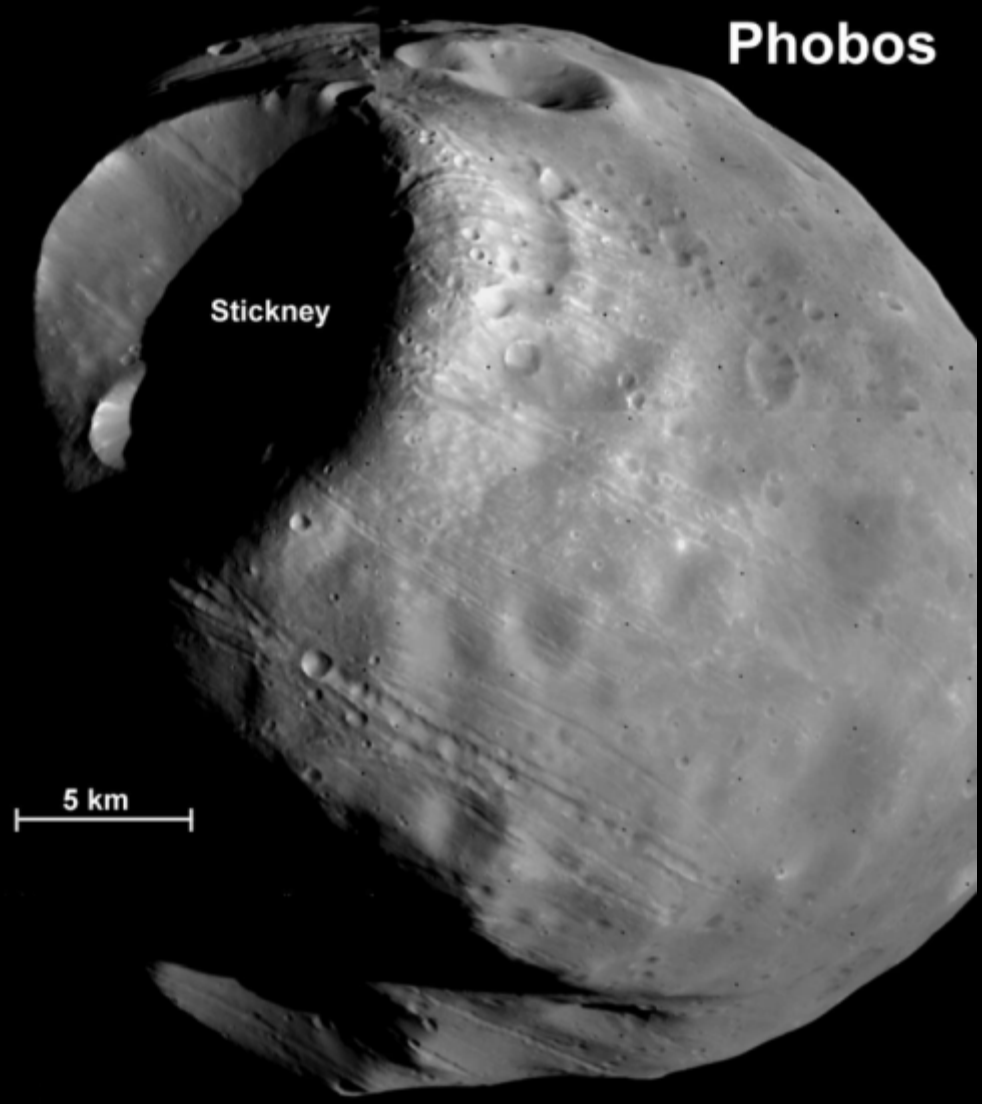
Spectral Data

- 3 μm band depth limited to < 5-10%
- Weak 2.8 μm M-O-H band in CRISM data
- No 1 or 2 μm features, but weak 0.65 μm feature consistent with desiccated Fe-phyllosilicate or Fe0 particulates embedded in a neutral matrix.
- Best spectral analogs are red, low albedo asteroids (C, D, P, and T-class) and metamorphosed CI/CM chondrites


phyllosilicate (vol%)
olivine + pyroxene (vol%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
R² = 0.98
CM2
CM1
CI
Essebi
WIS91600
Tagish Lake
CV3_oxidized
CV3_reduced

Why Go to Phobos and/or Deimos?

- **Stepping Stone to Mars**
  - **Allows for Martian voyages without the major risk factor of dropping into a deep gravity well.**
- **Source of Potential Resources**
  - **Low albedo suggest a mineralogy that may be rich in volatiles and other potentially useful minerals.**



Why Go?

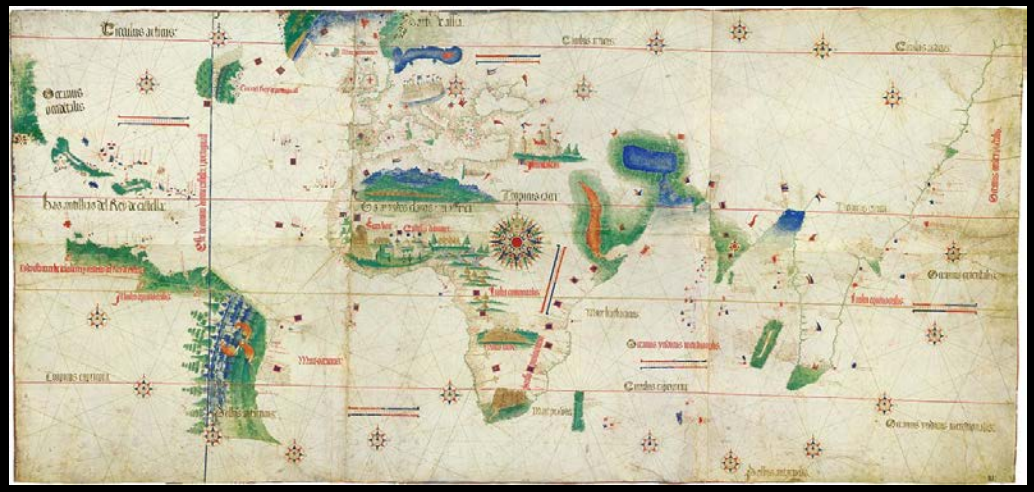
- **Bases for Surface Exploration**
  - **Their mass and location close to Mars can provide critical shielding from the space radiation and cosmic ray environments**
  - **Nearby base to support telepresence and remote surface operations (40 ms two-way light time from Phobos).**

Phobos/Deimos ISRU

- What sort of In-Situ Resources are available will depend on the origin and mineralogy (fuel, consumables, manufacturing feedstock).
  - Phyllosilicates and water-ice?
  - Carbon compounds?
  - Silicates (yields oxygen, metals)
  - Iron oxides, iron sulfides (oxygen, sulfur, metal)
- Regolith: Shielding for crew habitats.
- Additive manufacturing: What can be made out of regolith?
  - Heat shields (lifting bodies, blunt shields, aerobraking bodies, Earth return shields)
  - 3-D printing with regolith metals

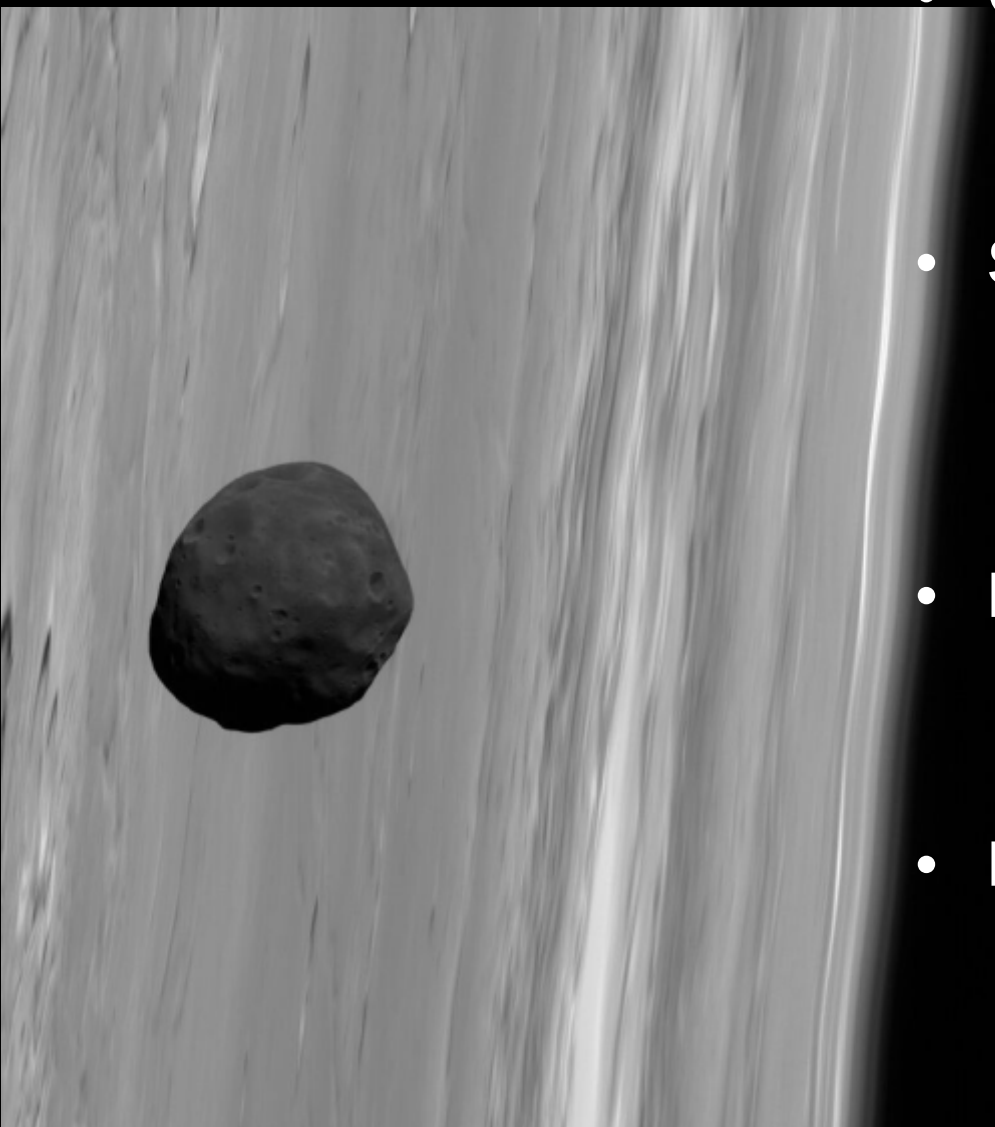
ISRU-1500's Style

- A serious problem for all the early expeditions was basic support….food, ship repair, crew replacement.
- This is the "gear-ratio" concept…..



- You cannot carry enough food and supplies long distances to support extended stays and exploration in the new territories.
- All the European exploring countries quickly established advanced bases to provide ISRU to support their exploration goals.
  - Havana was developed as a central supply and refit hub for the Spanish Caribbean.
  - Manila served that role in the far east…..advanced bases were critical.
- Same story for other European exploring countries
  - New England served that role for the English possessions
  - Goa in India for Portugal
  - Cape Town and Java for the Dutch

Science Questions for Phobos/Deimos Exploration



- **Composition**
  - Origin (captured or accreted?)
  - Potential for Resources (water, carbon compounds….or not)
- **Structure**
  - Internal structure (rubble, voids?)
  - Depth of regolith
  - Resources at depth?
- **Regolith properties**
  - Depth and particle size
  - Angle of repose and compaction
- **History**
  - Age of Phobos/Deimos
  - Impact flux and history
  - Conditions in Mars space

Phobos/Deimos SKGs

- **Surface/Exploration Science**
  - What is the composition? Are there organic or volatile resources on Phobos/Deimos?
  - How can we exploit these recourses to support Mars system exploration?
  - What are the geotechnical properties of Phobos/Deimos? What is the physical nature of the regolith
  - What is the structure of a rubble pile small body?
- **Surface Ops**
  - Particle size, thermal properties, hazards, angle of repose.
  - Docking technologies, mobility
  - Microgravity effects on ops
- **ISRU Development**
  - Materials handling in micrograv. Shielding construction
  - Extraction technologies for organic-rich regoliths
- **Exploration hazards in Mars Space**
  - Mars orbital debris environment
  - Radiation hazards