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First International Conference on the Exploration of Phobos and Deimos, 5-7 Nov 2007: Summary and Recommendations

Pascal Lee[1,2,3]

[1]Mars Institute, NASA Research Park, Bldg 19, Suite 2047, Moffett Field, CA 94035-0006, USA.
[2]SETI Institute
[3]NASA Ames Research Center

Corresponding Author: Pascal Lee
E-mail: pascal.lee@marsinstitute.net

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Title Figure: Announcement banner of the *First International Conference on the Exploration of Phobos and Deimos*. Artwork by Walter Myers. *(Image Credit: Mars Institute / Walter Myers).*

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Abstract

The *First International Conference on the Exploration of Phobos and Deimos: The Science, Robotic Reconnaissance, and Human Exploration of the Two Moons of Mars* was organized by the Mars Institute, the Lunar and Planetary Institute, and NASA Ames Research Center, and held at NASA Ames Research Center, Moffett Field, California, USA, on 5-7 Nov 2007. The Conference gathered 49 registered participants from over 10 countries. Three plenary technical sessions were convened, dedicated to the science, robotic reconnaissance, and human exploration of Phobos and Deimos. A fourth and final technical session was held to summarize discussions and formulate recommendations for the future. During this synthesis session, the determination of the origin of Phobos and Deimos was unanimously identified as the single most important scientific objective remaining in the exploration of the moons of Mars. The determination of the H_2O content of Phobos and Deimos was identified as the single most important objective in relation to planning the future human exploration of Mars. Conference attendees recommended making the scientific exploration of both Phobos and Deimos a high priority in near-term international efforts to explore near-Earth space. The Conference also included a display of historical memorabilia relating to American astronomer Asaph Hall, discoverer of Phobos and Deimos, and the "*Destination: Mars*" space art exhibition sponsored by the International Association of Astronomical Artists (IAAA), the Mars Institute, and NASA.

1. Introduction

The *First International Conference on the Exploration of Phobos and Deimos: The Science, Robotic Reconnaissance, and Human Exploration of the Two Moons of Mars* (hereafter "the Conference") was organized by the Mars Institute, the Lunar and Planetary Institute, and NASA Ames Research Center, and held at NASA Ames Research Center at Moffett Field, CA, USA, on 5-7 November 2007. The Conference was the first international meeting to focus on Phobos and Deimos, and on how their exploration relates to that of the Moon, Mars, and the solar system beyond. The conference served as an open international forum bringing together scientists, engineers, space exploration professionals, and students interested in discussing the status and advancement of the exploration of Mars' satellites, and the exploration of Mars itself through them.

The Conference was convened at a time of renewed interest in the exploration of Phobos and Deimos, with several international spacecraft missions and concept studies underway. The Conference was an opportunity to:

- Review scientific knowledge and key remaining unknowns regarding Phobos and Deimos, including their connection to Mars and the rest of the solar system and its processes;
- Review and coordinate upcoming robotic reconnaissance efforts to Phobos and Deimos, including the role such missions might play in support of Mars sample return; and
- Discuss the potential roles of Phobos and Deimos in consideration of future human exploration missions to the Moon, Mars, and Near-Earth Objects (NEOs).

An anticipated outcome of the Conference was a clearer definition of the place Phobos and Deimos should hold in future planetary exploration, both robotic and manned, and recommendations regarding possible next steps.

The Conference had the format of a workshop and comprised single-track plenary technical sessions for oral presentations (invited talks and selected oral contributions) and discussions, and a poster session. The technical sessions were open to registered participants only and focused on three areas relating to the exploration of Phobos and Deimos: Science, Robotic Reconnaissance, and Human Exploration, with the following questions serving as guides:

- *Science*: What outstanding issues remain to be addressed at Phobos and Deimos? How might they be resolved?
- *Robotic Reconnaissance:* How might near-term robotic spacecraft missions collaborate? How might missions to Phobos and/or Deimos support Mars sample return?
- *Human Exploration:* What might humans do on Phobos and Deimos and how might they use these moons to explore Mars? What precursor robotic missions might be needed?

A fourth technical session was dedicated to formulating a synthesis of the results of the Conference and examining the next steps needed in the exploration of Phobos and Deimos, with the goal of offering recommendations on how best to proceed.

The following sections offer a summary of the communications presented during each session, in the form of either talks, posters, print-only, or open discussions. The present technical paper is not a critical peer review of the papers presented at the Conference, nor a review of our current knowledge about Phobos and Deimos, but a summary of the main topics presented, the key discussions held, and where applicable, the consensus agreements reached.

In parallel with the technical sessions, a series of special events were organized: four keynote talks; an Asaph Hall memorabilia display sponsored by the Mars Institute, NASA Headquarters, and the NASA Public Affairs Office; and the "*Destination: Mars*" space art exhibition sponsored by the International Association of Astronomical Artists (IAAA), the Mars Institute, and NASA.

2. Science

The Science Session included invited review talks and new contributions. The salient information and new data presented are summarized below.

2.1 Origin and Composition

Gladman (2007) discusses the outstanding mystery of the origin of Phobos and Deimos, and reviews both the asteroid capture and circum-Mars accretion hypotheses, and the difficulties each presents. One interesting *a priori* possibility is that Phobos and Deimos are the last remnants of planetesimals formed at 1.5 AU. He argues that remote-sensing interpretations of Phobos and Deimos might be impeded by contamination from asteroidal dust veneers, and that large ejecta blocks likely offer the best chance of accessing material truly representative of Phobos and Deimos's bulk. He also indicates that, based on the martian meteorite flux and Phobos's small accretion cross-section, only ~3000 pieces of ejecta greater than 1 m in size would have struck Phobos is the last 4 billion years, and that survival of such fragments upon impact at typical velocities of 2 km/s, is unlikely, making the prospects of finding significant amounts of martian meteoritic material on Phobos or Deimos bleak (Gladman 2007). "*The Phobos regolith is more polluted by the main belt than by Mars*", by a factor of about 30 (Gladman 2007).

Rivkin (2007) presents a review of our current (poor) understanding of the composition of Phobos and Deimos, based in particular on visible and near-infrared spectroscopy, and discusses the origin of the satellites implied by the different possible compositions. He notes that "*The first spacecraft data returned for the satellites arrived nearly forty years ago. Yet fundamental information about the composition of these bodies is still a matter of some controversy, and almost nothing about them is universally accepted*" (Rivkin 2007). Phobos presents two distinct spectral units: a "red" unit and a "blue" unit. Phobos's red unit is spectrally similar to Deimos and to D-type asteroids, and is not well matched by any known meteorite class. Phobos's blue unit is geographically associated with the rim area of Stickney Crater and is spectrally similar to dehydrated carbonaceous chondrites. There is no H_2O signature at the surface of Phobos or Deimos, but subsurface H_2O cannot be ruled out (Rivkin 2007).

Desportes (2007) offers a detailed review of the spectral properties of Phobos. Based on remaining uncertainties regarding the nature and origin of Mars's inner satellite, he recommends that future orbital investigations include: i) infrared imaging spectrometry at 1-2 μm and at 3-6 μm wavelength for the detection of potential mafic mineral and hydration features, respectively; ii) thermal emission spectrometry to characterize surface thermo-physical properties (e.g. thermal inertia to understand the upper regolith's textures and structure) and assist with mineralogy investigations; iii) gamma-ray spectrometry to search for near-subsurface ice; iv) ground-penetrating radar surveys for subsurface ice detection and mapping (Desportes 2007).

Singer (1997) reviews classical hypotheses about the origin of Phobos and Deimos, in particular the capture of asteroids hypothesis and the contemporaneous formation with Mars idea. After noting difficulties with both, he argues that the capture and eventual break-up of a large planetesimal early in Mars's history seems consistent with all available data and model predictions (Singer 1997).

2.2 Orbits

Jacobson (2007) fits numerically integrated orbits to a wide range of earlier observations of Phobos and Deimos, including Earth-based astrometry data from the USNO and Table Mountain Observatory, and imaging and ranging data from the MGS, Mars Express and MRO spacecraft. He computes new ephemerii for the Martian moons, and estimates 1σ errors in the radial, in-orbit, and out of plane directions to be 2 km, 5 km, and 2 km for Phobos, and 3 km, 10 km, and 3 km for Deimos, respectively. The new ephemerii is available via the JPL Horizons system (Jacobson 2007).

Nakhodneva and Perov (2007) discuss the "*twice averaged model Hill problem with allowance for the oblateness of the central body*" and apply it to Phobos and Deimos while considering Mars's oblateness. They derive orbital parameters for both Phobos and Deimos (Nakhodneva and Perov 2007).

Perov (2007) investigates potential encounters between comets and Mars.

2.3 Surface

Thomas (1997) examines the "mysteries" and "conundrums" still surrounding the surfaces of Phobos and Deimos, particularly in light of recent spacecraft imaging of other small bodies. He emphasizes the major uncertainties remaining regarding the nature of Phobos's grooves, regolith, and structural properties. Grooves are present only on Phobos where their pattern appears to related to body axes, not radial to the large Stickney Crater (Figs. 6, 7 and 9) (Thomas 1997). Murray et al., however, point out that Phobos's grooves pattern is consistent with a formation by Mars impact ejecta (Ball et al. 2007). Thomas (1997) also notes that spacecraft imaging of Deimos has been minimal since Viking (unlike for Phobos), and little progress has been made in our understanding of the nature of either Phobos or Deimos, or the cause(s) of their striking morphologic differences. The origin of Deimos's remarkable smooth character, in particular, remains poorly understood (Figs. 10 and 11) (Thomas 2007).

Hartmann (2007) shows that the few impact craters on Phobos larger than ~ 90 m are at near-saturation levels (Fig. 8), indicating not only a very old surface for Phobos, but that saturation can be reached in the Martian environment, implying that the present lack of saturation around 1 km crater diameters in even the oldest parts of Mars is due to crater loss processes, not a unique size distribution of early Martian impactors. Thus, the cratering record on Phobos is helping calibrate the cratering record on Mars. Hartmann (2007) also argues that raised rims along crater chains on Phobos suggest blowout of volatiles along fractures (Fig. 9) (cf. Hartmann 1981), consistent with Phobos having originated as a volatile-rich D, P or C-class asteroid. He points out that while their near-surface regolith might be depleted in volatiles from impact processing, their deeper interiors might still be rich in volatiles inherited from their hypothesized origin as outer solar system objects, consistent with Phobos and Deimos's low bulk density. Hartmann also discusses the origin of Phobos and Deimos by capture following an early massive scattering event of primitive asteroids from the outer solar system (Hartmann 1987, 1990, 2007).

Aftabi (2007a) documents the experimental viscous creep of ice and rock mixtures, viewing these as potential analogs for surface materials and processes on Phobos and Deimos. Aftabi (2007b) further interprets a range of surface features on these bodies as water-associated or water-derived formations.

2.4 Dust Rings and Circum Planetary Environment

Espley et al. (2007) review theoretical models of interplanetary micrometeoritic particle impact on Phobos and Deimos predicting the formation of a gossamer torus of dust associated with Deimos's orbit and a gossamer ring of dust associated with that of Phobos, as modeled by Krivov and Hamilton (1997). They describe past and future efforts to directly observe the hypothesized torus and ring using the Hubble Space Telescope (HST), the Spitzer Space Telescope, spacecraft at Mars, and ground based telescopes (Espley et al. 2007). Three recent detection attempts using the HST established upper limits of visual optical depths of $\tau < 3x10^{-8}$ for the Phobos ring, and $\tau < 10^{-7}$ for the Deimos torus (Showalter et al. 2006).

Sauer and Dubinin (2007) review measurements by the Phobos-2 and Mars Global Surveyor spacecraft of dust activity, and plasma and magnetic field disturbances associated with Phobos and Deimos. They interpret the observed phenomena as being likely due to solar wind interactions with these bodies (Sauer and Dubinin 2007).

3. Robotic Reconnaissance

3.1 Ongoing Missions and Recent Observations

Murchie et al. (2007) (presentation by A. Rivkin) present disk-resolved images of Deimos acquired on 7 June 2007 by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) hyperspectral imager on NASA's Mars Reconnaissance Orbiter (MRO) (Fig. 4). They report that Deimos exhibits a featureless red spectrum lacking absorptions due to H_2O or mafic minerals, consistent with earlier results, suggesting that Deimos may have a primitive but anhydrous composition like D-type asteroids. Preliminary data on Phobos acquired on 22 October 2007 are also presented (Fig. 4) (Murchie et al. 2007).

Hoffman et al. (2007) describe ongoing efforts to observe Phobos and Deimos using the HRSC payload on ESA's Mars Express spacecraft. Mars Express is the only orbiter currently operating at Mars that makes sporadic close flybys of Phobos allowing high-resolution remote sensing imaging (Fig. 5). HRSC observations of Phobos aim to achieve complete surface coverage to investigate the inner satellite's geology and surface properties, to validate and improve orbit models, and to refine Phobos's geodetic control net and global shape and terrain models. The HRSC Digital Terrain Model (DTM) of Phobos has an effective resolution of 100 - 200 m (compared to ~ 400 m for the DTM using Viking Orbiter data), and a vertical accuracy of 6 m (12 – 24 m in edge areas). HRSC imaging covers 1/3 of Phobos's surface so far. HRSC objectives at Deimos are to improve the outer satellite's orbit models (Hoffman et al. 2007).

Safaeinili et al. (2007) present radar sounding data on Phobos acquired at 1.3-5.5 MHz with the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) instrument on the Mars Express spacecraft during its flybys of Phobos on 4 November 2005 and 2 October 2007. The radar's sensitivity allowed features to be resolved, but they remain difficult to interpret and showed only weak correlation with high-resolution shape model features (Safaeinili et al. 2007).

3.2 Phobos-Grunt

Zakharov (2007) delivered a keynote talk titled "*Phobos Sample Return Mission*". In this contribution, he provides a summary of the status of the Phobos Sample Return Mission (SRM), *a.k.a.* Phobos-Grunt or Phobos-Soil, currently under development by the Russian Academy of Sciences and the Russian Space Agency (Fig. 12). The main goals of the mission can be summarized as follows: a) investigate the origin, nature, and geologic evolution of Phobos, in particular its internal structure, and the physical and chemical characteristics of its regolith via in situ analysis and sample return (0.2 kg of samples); b) investigate Phobos's orbital and proper motion to understand better its dynamic evolution; c) investigate the martian environment, in particular dust, gas, plasma, particles and fields, and radiation; d) monitor and investigate the dynamics of Mars's atmosphere and surface processes. Zakharov (2007) also indicates how the Phobos-SRM may serve as a precursor for MSR. A launch date c. 7 October 2009 remains targeted for Phobos-Grunt, with an arrival date at Mars of 29 August 2010, a landing on Phobos on 10 May 2011, a sample return stage launch from Phobos five days later, a departure from Mars c. 29 July 2011, and a return to Earth in June or July 2011 (Zakharov 2007).

Approximately fifteen payload elements are currently under consideration for the Phobos-Grunt mission (Zakharov 2007). Three were discussed in more detail during the Conference: AOST (Palomba et al. 2007), MIMOS II (Klingelhofer et al. 2007), and LIFE (Warmflash et al. 2007, Fraze et al. 2007).

Palomba et al. (2007a) discuss the development and status of the AOST Fourier Transform infrared spectrometer on the Phobos SRM. The instrument operates between 2.5 and 25 μm and will investigate the mineralogy and thermo-physical properties of Phobos's surface during both orbital and landed phases. It will also probe the Martian atmosphere and surface (Palomba et al. 2007a).

Klingelhofer et al. (2007) describe the development and status of the Miniaturized Mossbauer Spectrometer (MIMOS) II instrument that will be flown on the Phobos SRM and ESA's ExoMars mission. The arm-mounted instrument will be used to investigate the surface mineralogy of Phobos, in particular in association with Fe-bearing phases. MIMOS II is based on the Mossbauer Spectrometer flown on the MERs, with a few modifications and improvements (Klingelhofer et al. 2007).

Warmflash et al. (2007) describe the motivation and status of the Living Interplanetary Flight Experiment (LIFE) proposed by the Planetary Society for the Phobos SRM. The passive experiment would test the survival of approximately ten species of microorganisms selected from among bacterial, archael, and eukaryotic domains, subjected to a 34 month roundtrip journey to Phobos, an interplanetary travel time relevant to Mars transpermia (Warmflash et al. 2007).

Fraze et al. (2007) describe the design of the proposed lightweight (<100g) LIFE payload with its 31 sample cavities (including one for a permafrost sample), triple-redundant seal integrity, radiation dosimetry strips, and temperature extreme recording paint. LIFE's design is intended to be "*simple, compact, and rugged*", but also responsive to strict COSPAR planetary protection guidelines (Fraze et al. 2007).

3.3 Future Phobos and Deimos Missions

Ball et al. (2007) discuss integrated studies of Phobos and Deimos combining remote, *in situ*, and laboratory investigations. They review past and ongoing Phobos and/or Deimos mission development efforts in Europe. They discuss in particular the Mars Phobos And Deimos Survey (M-PADS) mission proposed in 2004 by QinetiQ and Open University to ESA's Aurora Program as a Mars MicroMission. They also discuss the Deimos Sample Return (DSR) mission proposed in 2007 by Open University to ESA's Aurora Program as a precursor to Mars Sample Return (MSR). They argue that DSR could serve as a valuable precursor to MSR and discuss the possibility that Martian meteoritic materials might be inlcuded among the regolith samples to be retrieved from Deimos (Ball et al. 2007). (But see Gladman (2007) for a potential caveat).

Richards et al. (2007) present the Phobos Reconnaissance and International Mars Exploration (PRIME) mission concept proposed by Optech Inc. in collaboration with the Mars Institute and MDA Space Systems to the Canadian Space Agency. PRIME's central scientific goal is to determine the nature and origin of Phobos. Both a Phobos orbiter and a Phobos lander are examined in the study. The orbiter would perform pseudo-orbits about Phobos, and map and investigate its composition and internal structure. The lander would perform a lidar-guided precision soft touchdown on Phobos to "rock dock" with ejecta blocks and conduct in situ analyses of these boulders viewed as the most likely "outcrops" representative of Phobos's bulk (Richards et al. 2007).

Kremic and Dankanich (2007) present and discuss the potential benefits of using in-space propulsion technologies, in particular electric propulsion, in future robotic reconnaissance missions to Phobos and Deimos and in sample return missions. They discuss the development status and availability of these capabilities within the In-Space Propulsion Technology Project funded by NASA SMD at NASA GRC (Kremic and Dankanich 2007).

3.4 Instruments for Future Missions

Gellert (2007) discusses the suitability of an alpha particle x-ray spectrometer (APXS) instrument on a Phobos or Deimos lander mission. The APXS is a high-heritage, compact contact instrument that can measure elemental abundances and ratios in surface rocks and soils, e.g., Mg/Si, Fe/Si, Fe/Mn, Ni, Al, Ca, P, Ge. Gellert (2007) indicates that a standard APXS like the one on the MERs would be suitable for Phobos and Deimos, allowing a Mars-like composition to be clearly distinguishable from a chondritic composition. The Rutherford backscattering (RBS) mode of the standard MER APXS would also be useful for measuring the abundance of lighter elements, allowing abundances in H_2O and C in the regolith to be measured (Gellert 2007). An APXS is included in the payload of the PRIME mission (Richards et al. 2007).

Blake et al. (2007a) describe progress being made in the development of the spaceflight Microfabricated Scanning Electron Microscope and x-ray Spectrometer (MSEMS), a highly miniaturized Scanning Electron Microscope and electron-induced X-ray fluorescence Spectroscopy (SEM-EDX) instrument under development at NASA ARC with support from the NASA SMD PIDDP program. The MSEMS will enable imaging and compositional analysis of surface materials on Phobos and other solid surface bodies down to submicron/pixel scales (Blake et al. 2007a).

Blake et al. (2007b) discuss how mineralogy analysis by x-ray diffraction (XRD) combined with x-ray fluorescence (XRF) can provide as complete a mineralogical characterization of surface materials as is possible on solid bodies. They describe the design and performance of the CheMin XRD/XRF instrument developed at NASA Ames Research Center and selected for flight on the Mars Science Laboratory (MSL) mission. They indicate that a similar instrument flown on a lander to Phobos or Deimos would provide key compositional and mineralogical data (Blake et al. 2007b).

Palomba et al. (2007b) propose and describe the Mars Tori Investigator (MATI) instrument concept, a dust detector to search for and characterize the hypothesized circum-Mars dust tori associated with Phobos and Deimos (e.g., Espley et al. 2007). The instrument would measure dust particle flux, mass, and velocity distributions around Mars to investigate the 3D structure of the tori (Palomba et al. 2007b).

4. Human Exploration

The Human Exploration Session began with a keynote talk by Stephen J. Hoffman of SAIC and NASA JSC, who presented an overview of "*Recent Human Mars Mission Planning Activities*" at NASA. The presentation served to provide a status on current efforts in the United States to develop integrated approaches and strategies for the future human exploration of Mars.

4.1 Human Exploration Strategies

Landis et al. (2007) report on the recent study undertaken by the Advanced Projects Office (APO) within NASA's Constellation Program (CxP) examining the feasibility of sending a Crew Exploration Vehicle (CEV), the Orion spacecraft, to a NEO (Fig. 13). Such a mission could send two or three astronauts on a 90 to 120 day roundtrip journey to a NEO, including a 7 to 14 day stay at the NEO itself, making it an ideal Apollo 8-style precursor mission to a visit to Phobos and Deimos (Landis et al. 2007).

Stooke (2007) proposes that Mars Sample Return (MSR), a scientifically compelling step in the robotic exploration of Mars but one that has been too costly to implement so far, be a program combining robotic and human elements, to spread and share the cost and risks between robotic and human exploration programs, while allowing ample opportunity for international cooperation. He envisions that Mars samples, and samples from near-Mars objects such as Phobos, Deimos, or Mars Trojans, could be collected by robotic missions first, and delivered to Phobos (or Deimos) over a period of about ten years. The first human mission to Mars, an Apollo 8 or Apollo 10-style rehearsal mission, would then land on Phobos (or Deimos) instead of Mars itself, and collect the samples for return to Earth. By having humans return Mars samples cached on Phobos (or Deimos) rather than landing on Mars itself, Stooke (2007) argues that the huge risk of early human missions to Mars would be mitigated while still allowing such missions (to Mars orbit) to have a major science return.

Singer (2007) advocates a Manned Mission to the Moons of Mars (MMMM), a.k.a. the *Ph-D Project* to establish a base on Deimos, arguing that such a mission would be scientifically compelling, "faster" (could happen sooner than a landing on Mars), "better" (Mars and Phobos would be explored telerobotically in real time from Deimos), "cheaper" (requiring less delta v and less complexity than landing on Mars), and "safer" (than landing on Mars).

West and Lee (2007) review the status of earlier ideas concerning human missions to Phobos and Deimos, and discuss remaining challenges and outstanding opportunities associated with their exploration. They discuss surface exploration operations on the two Martian satellites and advocate the establishment of an infrastructure on Phobos that could play a strategic role in the exploration of Mars (West and Lee 2007).

Lee (2007) discusses in more detail the technical feasibility, scientific merit, programmatic value, and outreach attractiveness of human missions to Phobos and Deimos, to build a case for carrying out their exploration with humans as soon as possible. He argues that a human mission to the moons of Mars will be technically feasible much sooner than a human mission to Mars itself, and that such a mission would be a new, exciting, tangible, and meaningful step beyond the Moon and towards Mars (Lee 2007).

Mistry (2007) discusses in-situ resource utilization (ISRU) on Phobos and Deimos and argues that mining these bodies would likely be most beneficial if applied to supporting infrastructures in space. He also argues that water would be the most useful material to extract (Mistry 2007).

4.2 Space Radiation

Vazquez (2007) (presentation by M. Vasquez and C. Zeitlin) reviews the status of our understanding of space radiation and its potential hazards in the context of a human mission to Mars. He examines in particular data collected in Mars orbit by the energetic Charged Particle Spectrometer on the Phobos-2 spacecraft and by the Martian Radiation Environment Experiment (MARIE) instrument on Mars Odyssey. He emphasizes the need for more *in situ* radiation measurements and research in interplanetary space, on Phobos and Deimos, and on Mars, including radiation measurements through time and at different locations on these bodies, before an adequate picture of radiation hazard and mitigation can be developed for a human mission to Mars orbit and Mars itself (Vasquez 2007).

De Angelis et al. (2007) report on recent efforts to model the radiation environment at and above the surface of Mars, particularly radiation induced by Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE). Characterization of high energy particle fluxes and doses at any location and time on and around Mars is critical for planning human missions to Mars. Preliminary models for the radiation environment at Phobos and Deimos are being developed by extension of those built for Mars (De Angelis et al. 2007).

5. Synthesis

During the final technical session of the Conference, dedicated to synthesis discussions, the following findings received unanimous support from attendees:

1. Phobos and Deimos hold unique keys to a wide range of outstanding questions in planetary science.

Phobos and Deimos are at the crossroads of major issues in planetary science, including: i) the formation and evolution of small bodies, planets, satellites, and rings, ii) the roles of impacts and material exchange in planetary evolution; iii) the history of volatile and organics delivery to planets; iv) processes of small body evolution and disruption; and v) the availability of resources for future human exploration.

2. The single highest priority science question in the study of Phobos and Deimos is that of their origin.

After four decades of spacecraft exploration, the moons of Mars are the only bodies in the inner solar system whose nature and origin remain utterly unknown. Solving these mysteries will open the door to answering a wide range of questions in planetary science.

3. The single highest priority question to be addressed at Phobos and Deimos relating to planning the human exploration of Mars is that of their content in H_2O.

Future human Mars exploration architectures would be profoundly altered from conventional scenarios if H_2O were an exploitable resource on Phobos or Deimos. While the *surfaces* of these moons appear to be devoid in H_2O, their potential primitive nature and low bulk density suggest that their subsurface might be very different from their surface, and possibly rich in H_2O.

4. Russia's Phobos-Grunt mission is an important opportunity for International collaboration.

US and Russian attendees recommend that NASA support an opportunistic Participating Scientist program in the context of the upcoming Phobos-Grunt mission. The Planetary Society suggests that NASA provide $20M in support of US participation in Phobos-Grunt.

5. Phobos and/or Deimos mission proposals in the US need an explicit home within NASA's Discovery Program and/or NASA's Mars Scout Program.

While it is recognized that proposals for missions to Phobos and Deimos might have different emphases (some more on Small Bodies, others more on Mars), there is concern that they are currently deemed too "Mars-related" for NASA's Discovery Program and too "Small Bodies-related" for NASA Mars Scouts, and are cast into a programmatic no-man's land.

6. Phobos and/or Deimos sample return missions are valuable precursors for Mars Sample Return.

Phobos and/or Deimos SRMs offer an opportunity to mitigate the risk (including planetary protection concerns) and spread the development cost of a Mars SRM, while providing a short term opportunity to conduct exciting sample return science and cooperate with international partners.

Prior to the synthesis session, S. Peter Worden, Director of NASA ARC, delivered a keynote talk titled *"Space Exploration and Phobos-Deimos"* which provided additional input into synthesis discussions. He points to NEOs as a key potential direction for the Vision for Space Exploration (VSE) and stresses the importance of characterizing their volatile content (for eventual ISRU), along with the volatile content of Phobos and Deimos as well. He suggests considering an expansion of the Constellation flight envelope to eventually allow reaching Phobos and Deimos, and discusses the potential value of a base on one of the martian moons for conducting tele-robotic Mars surface exploration. He also indicates seeing promise in affordable nano-satellite missions as precursor missions to Phobos and Deimos.

6. Asaph Hall Memorabilia Display

The *First International Conference on the Exploration of Phobos and Deimos* featured an *Asaph Hall Memorabilia Display* in honor of American astronomer Asaph Hall who discovered the two moons of Mars from the United States Naval Observatory (USNO) on 17 August 1877 (Figs. 14 and 15). The exhibit was co-sponsored by the Mars Institute and NASA, and curated and hosted by Steven J. Dick, NASA Chief Historian. The display gathered a collection of unique historical documents relating to the life and achievements of Asaph Hall, and the discovery of Phobos and Deimos.

The technical sessions of the Conference were kicked off with a keynote talk by Steven J. Dick who spoke about *"The Discovery and Exploration of Phobos and Deimos"*. He provided a detailed historical review of the circumstances of the discovery of Mars's moons by American astronomer Asaph Hall (Figs. 15 and 16), and of their exploration by NASA and other efforts to date (Dick 2007).

7. "*Destination: Mars*" Space Art Exhibition

The *First International Conference on the Exploration of Phobos and Deimos* included a space art exhibition on the theme of Mars, Phobos, and Deimos exploration, titled "*Destination: Mars*" (Fig. 16). The exhibit was an initiative of the Mars Institute and was co-sponsored by the International Association of Astronomical Artists (IAAA), the Mars Institute, and NASA. The exhibition was co-hosted by planetary scientist and space artist William K. Hartmann (*Planetary Science Institute*), and by space artist Walter Myers who also designed the Conference's title banner (Title Figure). The exhibit featured artwork by 14 IAAA artists: Joe Bergeron, Richard Bizley, Sean Brady, Michael Carroll, Robin Hart, William K. Hartmann, Garry L. Harwood, Frank Hettick, Steven Hobbs, B. E. Johnson, Julie Jones, Gavin Mundy, Walter Myers, and Pat Rawlings (Fig. 17). "*Destination: Mars*" was open to the public and received an estimated 250 visitors over the course of two days. Appendix C reproduces the exhibition's art catalog.

8. Conclusion and Recommendations

8.1 Conclusion

The *First International Conference on the Exploration of Phobos and Deimos* allowed a timely review of outstanding scientific issues regarding the two moons of Mars, collaborative exchanges on ongoing robotic mission development efforts, and forward-looking discussions on the prospect of future human exploration missions.

Phobos and Deimos present us with both a challenge and an opportunity. The challenge lies in the fact that their nature and origin are still vexing mysteries. They are the only two bodies in the inner solar system still presenting us with such fundamental unknowns. Although observed by robotic spacecraft several times over the past four decades, the number of basic questions associated with the moons of Mars has increased over time, not decreased. The modest size and diminutive status of these satellites are misleading, as Phobos and Deimos are unique places in the solar system where an astonishing number of major problems encountered in planetary science come to a head. Their origin and orbital evolution relate simultaneously to the complex issues of planetary formation, early extended atmospheres, aero-capture dynamics, ring formation and evolution, orbital dynamics and resonances, tidal evolution and disruption, and impacts. Their spectral properties challenge our efforts to understand their composition and potential affiliation with known classes of primitive asteroids, comets, or Mars. The lateral color and albedo variations on Phobos confront us with the common and confounding phenomenon of "space weathering", but also with the possibility of ubiquitous interplanetary dust accretion on both moons. Their implausibly large impact craters raise questions about their internal structure and strength, and have only begun to make sense in light of recent advances in our understanding of the often counter-intuitive process of impact cratering, particularly on small bodies. The crater chains and groove system on Phobos are a puzzle, both figuratively and literally, with uncertain connections to Phobos's initial formation, collisional history, tidal evolution, and/or volatile content. The potential of Phobos and Deimos as repositories of martian meteoritic materials is an intriguing possibility suggested in part by the recognition that we have Martian meteorites on Earth, but dynamical calculations presented at this Conference by Gladman (2007) suggest that Martian impact ejecta cannot be present in significant absolute amounts, and in any case, are likely secondary to asteroidal dust as an accreted component in the regoliths of Phobos and Deimos.

In a true sense, the moons of Mars represent an epitome of solar system challenges. To explore these objects means addressing simultaneously several central issues in planetary science. Therein lies the very unique opportunity that Phobos and Deimos present. Their exploration is about far more than the study of two obscure secondary bodies, but instead, that of two mysterious worlds with possibly very complex histories and exciting potentials in the future. Phobos and Deimos merit focus and priority.

8.2 Recommendations

The following recommendations from the *First International Conference on the Exploration of Phobos and Deimos* summarize the wide range of input received or shared during the Conference concerning future next steps. The recommendations listed below, titled with a keyword, are based principally on the findings of the synthesis session (see Synthesis section above), which represented the unanimous view of attendees, with additional important input provided to the author through individual technical contributions and open communication which may or may not represent a unanimous opinion. A summary of these recommendations was presented by the author to NASA HQ SMD on 10 April 2008.

a) Priority
The scientific exploration of Phobos and Deimos should be made *an* explicit scientific priority in the exploration of Small Bodies and Mars given the important solar system science goals they allow us to address.

b) Origin
Determining the origin of Phobos and Deimos should be considered the highest priority in the scientific exploration of these bodies.

c) Cloak
Because Phobos and Deimos may have accreted asteroidal dust over time (more than Martian meteoritic ejecta), and their regolith materials may be impact-shocked and heavily irradiated following time spent in dust belts, investigations of their surface spectral properties may not allow reliable determinations of their true nature and origin. *In situ* surface investigations and future sample return efforts should focus on impact ejecta blocks on Phobos and Deimos, because these boulders are likely derived from the interiors of the moons and offer the best prospect and most reliable strategy for obtaining the bulk composition of Phobos and Deimos from compositional studies of surface materials.

d) H_2O
While no H_2O has been reliably detected on either Phobos or Deimos, their possible origin as primitive (C, D or P-type) asteroids from the outer regions of the main belt (some of which may be comet nuclei), and their very low bulk density (and implied high porosity), mean that an H_2O-rich deeper interior remains a possibility. The measurement of the potential H_2O content of Phobos and Deimos should be considered a high priority investigation given its scientific importance and potential impact on the development of future human Mars exploration architectures. More refined density measurements (in particular via improved volume determinations), subsurface radar sounding, and penetrator missions are among proposed approaches to address subsurface H_2O content. More modeling of subsurface H_2O sublimation and loss through time could also help.

e) Craters and Grooves
The distribution and morphology of craters (including crater chains) and grooves on Phobos should be reexamined in detail in light of recent, more refined DTMs, to better understand the origin of the moon's surface features and their potential connection with its subsurface structure.

f) Ejecta Emplacement
The emplacement of impact ejecta on Phobos and Deimos should be modeled in detail to help interpret material distribution and observed lateral variations in surface textures.

g) Dust Belts
Efforts to detect and observe gossamer dust belts associated with the orbits of Phobos and Deimos should be continued given their consistent prediction by modeling and their potential impact on future exploration operations, manned and unmanned, near Mars.

h) Radiation
Space radiation measurements should be made over a range of energies and through time at the surface of both Phobos and Deimos to understand their radiation environments well enough for planning future human Mars exploration missions.

i) Phobos-Grunt
NASA should consider supporting a Participating Scientist program in the context and opportunity presented by Russia's Phobos-Grunt mission.

j) NASA Missions
NASA should consider identifying explicitly programmatic homes for Phobos and/or Deimos exploration (payloads or missions) within its Discovery, Mars Scout, and New Frontiers Programs.

k) Anchors & Drills
To help detect and characterize possible subsurface H_2O inside NEOs, Phobos and/or Deimos, techniques to anchor on small bodies and drill into their interior should continue to be developed.

l) Sample Return
Phobos and/or Deimos sample return should precede direct Mars sample return to help reduce the risk and spread the cost of MSR, while still addressing high priority solar system science.

m) Meeting Outreach
The inclusion of public exhibits on astronomy history and space art as part of the *First International Conference on the Exploration of Phobos and Deimos* generated considerable interest and was deemed a success. Such public outreach events should be considered again in the organization of future conferences and workshops

n) Future Meetings
Holding further conferences or workshops on the science, robotic reconnaissance, and human exploration of Phobos and Deimos is recommended, particularly as spacecraft currently in orbit about Mars and more that are due to arrive, acquire new data on the martian satellites.

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Abbreviations and Acronyms

APL	Applied Physics Laboratory
APO	Advanced Projects Office
APXS	Alpha Particle X-ray Spectrometer
ARC	Ames Research Center
CRISM	Compact Reconnaissance Imaging Spectrometer for Mars
CSA	Canadian Space Agency
CxP	Constellation Program
DSR	Deimos Sample Return
DTM	Digital Terrain Model
ESA	European Space Agency
ESMD	Exploration Systems Mission Directorate
EVA	Extravehicular Activity
GCR	Galactic Cosmic Rays
GRC	Glenn Research Center
HQ	Headquarters
IAAA	International Association of Astronomical Artists
IKI	Institute for Space Research (Russia)
ISRU	In Situ Resource Utilization
JAXA	Japan Aerospace Exploration Agency
JHU	Johns Hopkins University
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
LIFE	Living Interplanetary Flight Experiment
LMO	Low Mars Orbit
LPSC	Lunar and Planetary Science Conference
MARSIS	Mars Advanced Radar for Subsurface and Ionospheric Sounding
MEPAG	Mars Exploration Program Analysis Group
MER	Mars Exploration Rover
MGS	Mars Global Surveyor
MI	Mars Institute
MIMOS	Miniaturized Mossbauer Spectrometer
M-PADS	Mars Phobos And Deimos Survey
MRO	Mars Reconnaissance Orbiter
MSEMS	Microfabricated Scanning Electron Microscope and x-ray Spectrometer
MSL	Mars Science Laboratory
MSR	Mars Sample Return
NASA	National Aeronautics and Space Administration
NEA	Near-Earth Asteroid
NEAR	Near-Earth Asteroid Rendezvous
NEO	Near-Earth Object
NRP	NASA Research Park
PIDDP	Planetary Instrument Design and Development Program
PRIME	Phobos Reconnaissance and International Mars Exploration
RBS	Rutherford Backscattering
SAIC	Space Applications International Corporation
SEM	Scanning Electron Microscope
SETI	Search for Extraterrestrial Intelligence
SMD	Science Mission Directorate
SPE	Solar Particle Event
SRM	Sample Return Mission
TPS	The Planetary Society
USNO	United States Naval Observatory
XRD	X-Ray Diffraction
XRF	X-ray Fluorescence

Figures

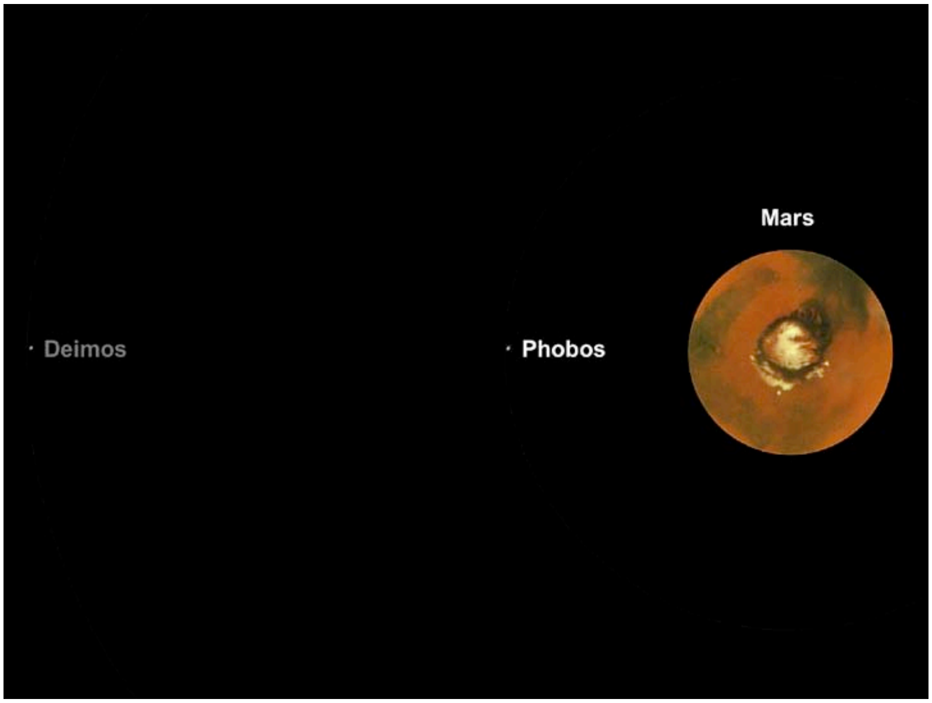


Figure 1: Diagram of Mars and its satellite system viewed from above Mars's North pole. The orbital distances of Phobos and Deimos, are shown to scale. *(MI / P.Lee).*

Figure 2: Orbital distance of Phobos to scale. *(MI / P.Lee / HST image: NASA / STI).*

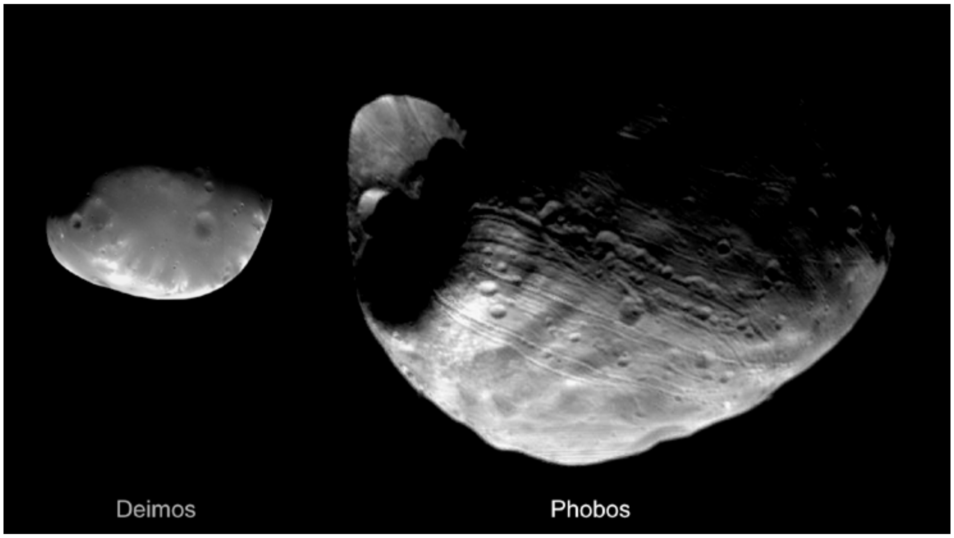
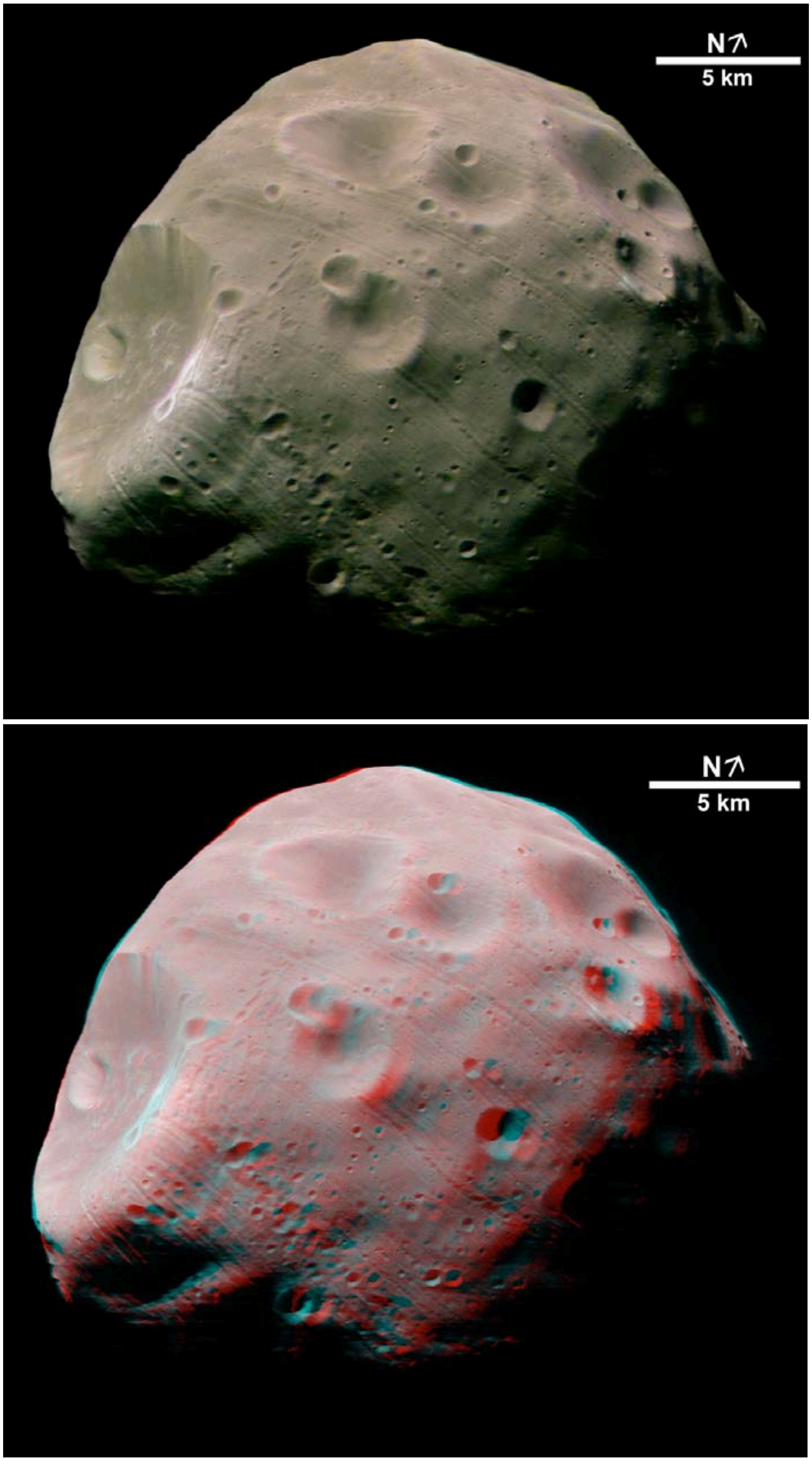


Figure 3: Phobos and Deimos to scale. *(NASA / Viking Orbiter).*

Figure 4: MRO CRISM color composite images of Phobos (top) and Deimos, acquired on 23 Oct and 7 Jun 2007, respectively. The Deimos data are the first spectral measurements to resolve Deimos's disk. *(NASA / JPL / JHU-APL).*



A

B

Figure 5: Phobos imaged on 22 Aug 2004 by the HRSC on ESA's Mars Express. Spatial resolution: 7 m/pxl. A: "True" color; B: Stereo. *(ESA / DLR / FU Berlin / G.Neukum).*

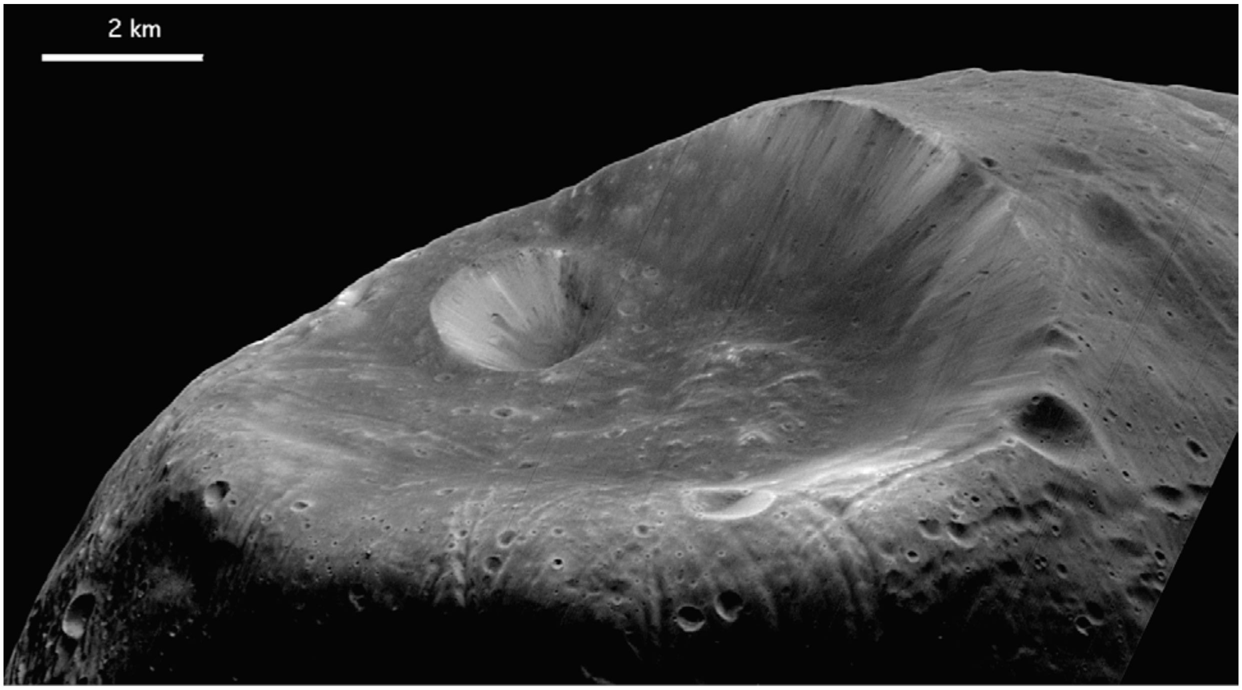


Figure 6: Stickney Crater on Phobos imaged by Mars Global Surveyor. *(NASA / JPL / MSSS)*

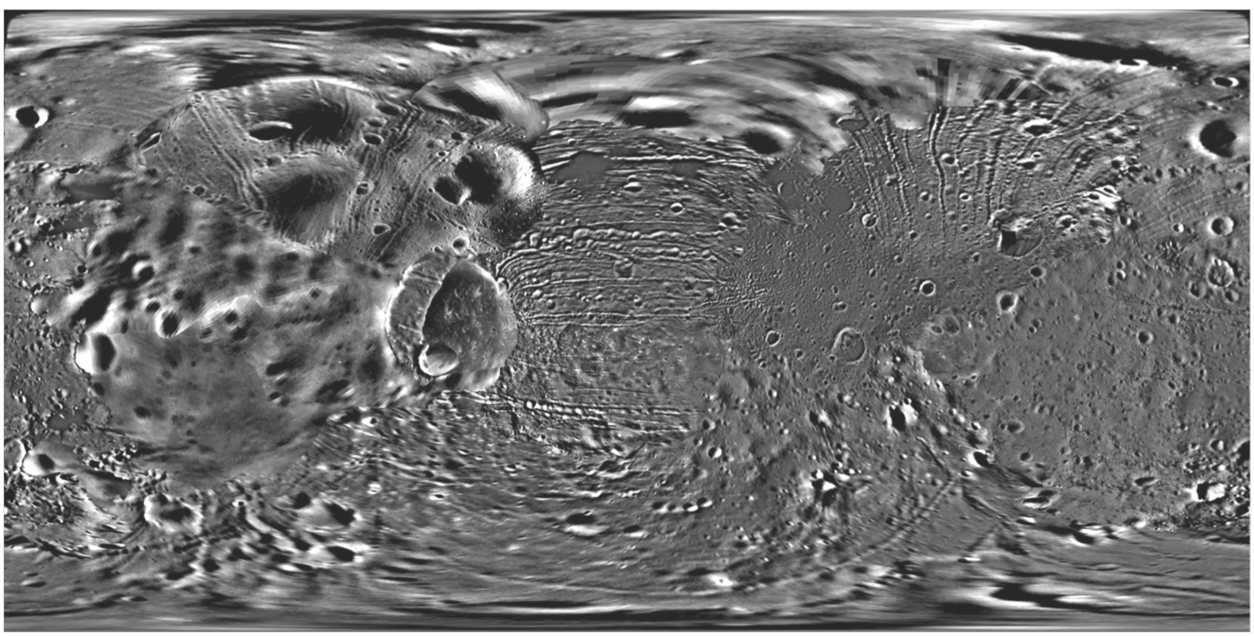


Figure 7: Photomosaic map of Phobos constructed from NASA Viking Orbiter imaging data. The pattern of grooves is related to body axes, not radial to Stickney (Thomas 2007). *(Cornell U. / P. Thomas).*

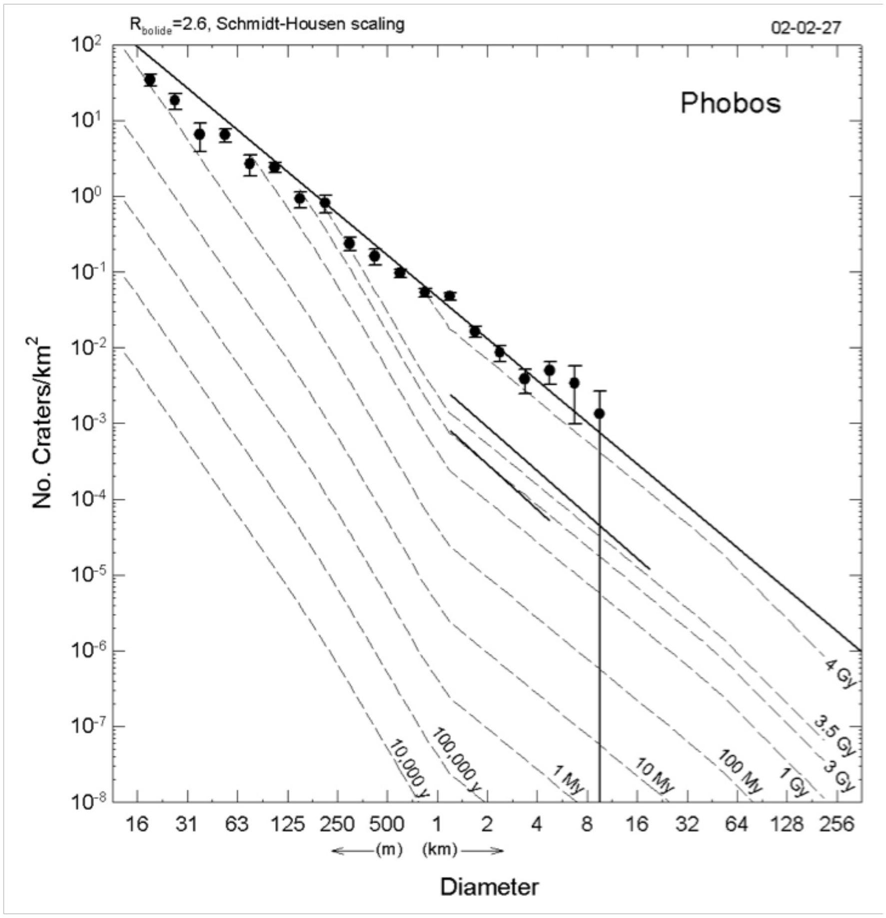


Figure 8: Cratering on Phobos follows saturation (Hartmann 2007).

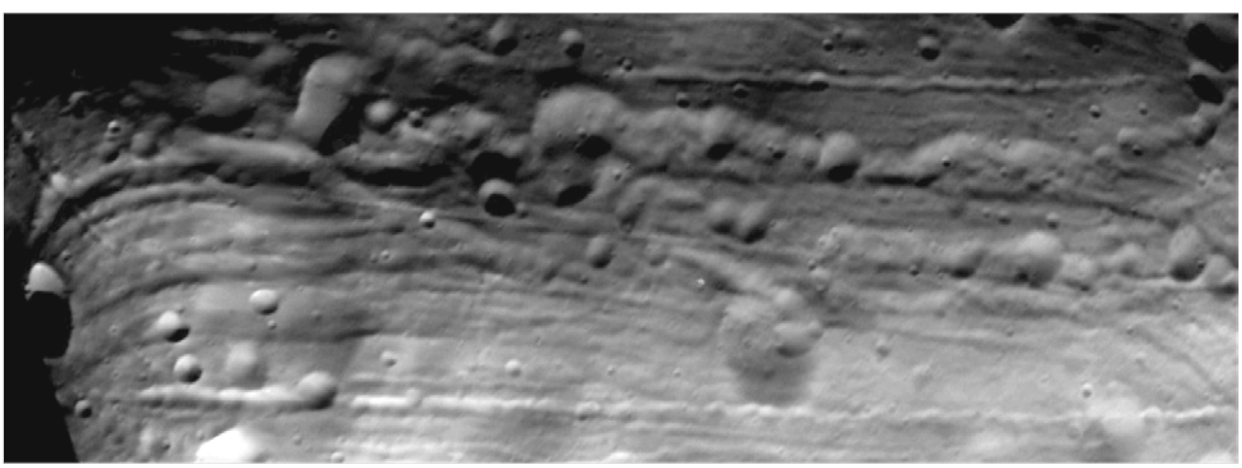


Figure 9: Grooves and crater chains on Phobos. Hartmann (2007) suggests raised rims might be due to eruptions of volatile-rich subsurface materials. *(NASA / Viking Orbiter).*

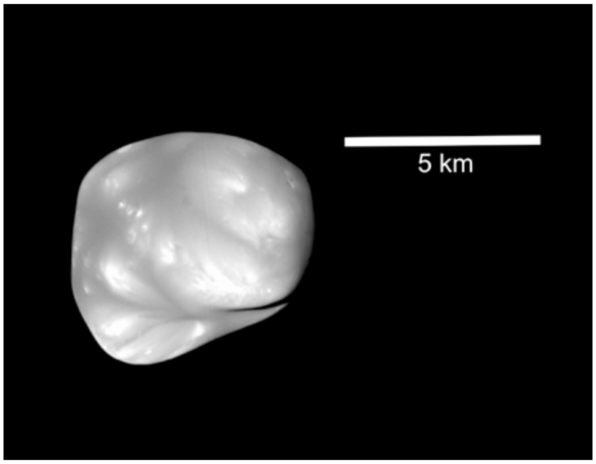


Figure 10: Deimos and its smooth surface. *(NASA / Viking Orbiter).*

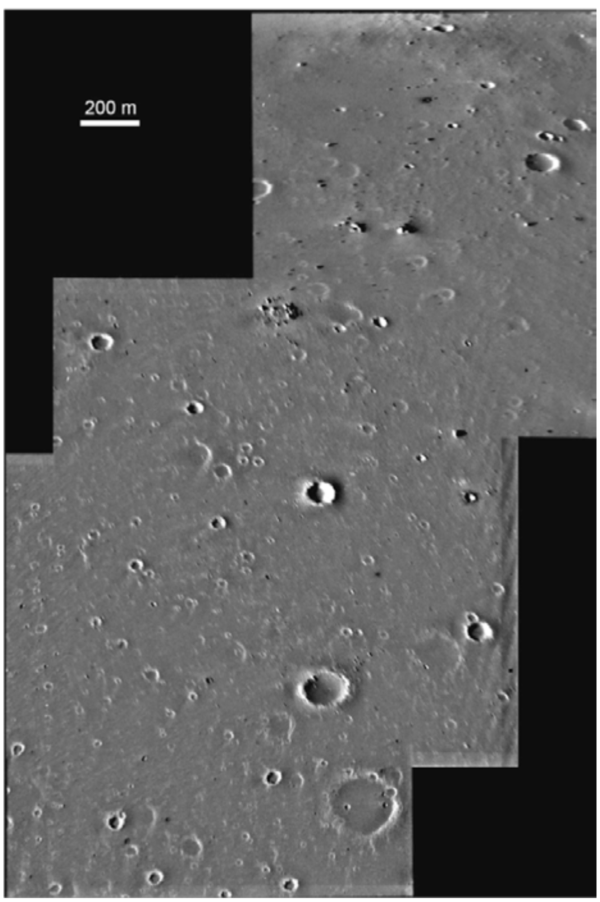


Figure 11: Photomosaic of NASA Viking Orbiter images showing details of Deimos's surface. Note the substantial infilling of craters. Many craters appear as just rims. *(NASA / Viking Orbiter).*

Figure 12: The Phobos-Grunt spacecraft. The dome-shaped element at the top of the spacecraft is the Phobos Earth Return Descent Module (or capsule) housing the LIFE experiment. *(The Planetary Society).*

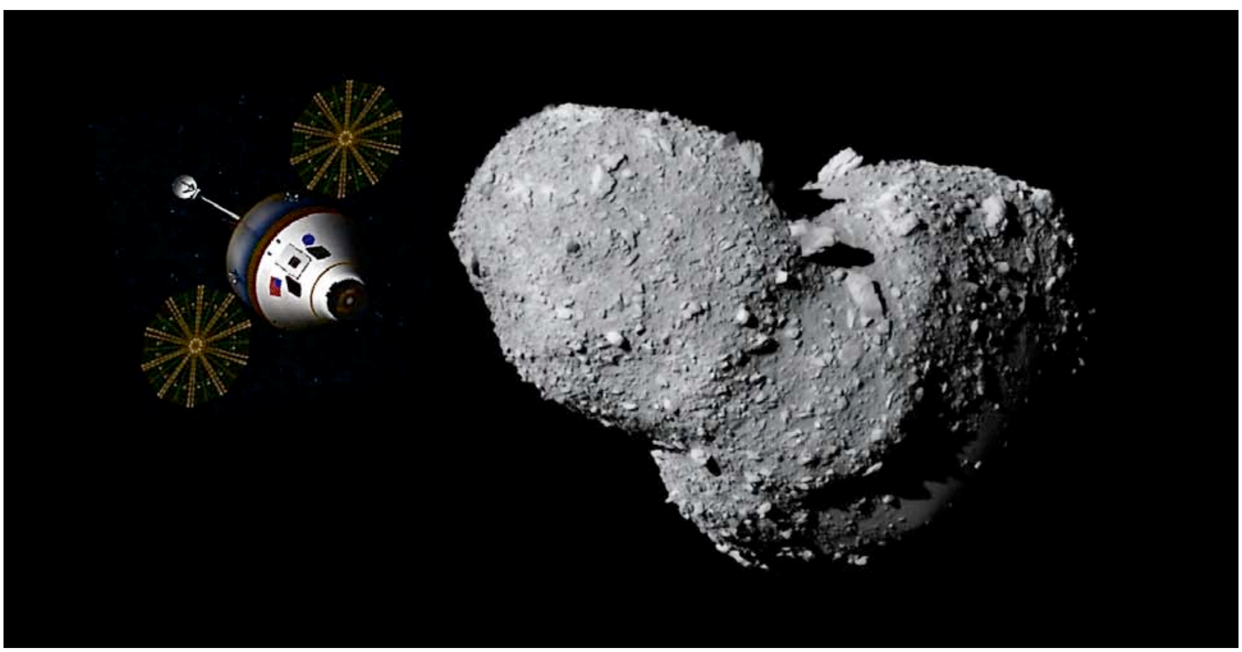


Figure 13: NASA CEV spacecraft on a human mission to a NEO. Asteroid Itokawa is shown. *(NASA / JAXA/ MI / P.Lee).*

Figure 14: Asaph Hall, discoverer of Phobos and Deimos. *(U.S. Naval Observatory).*

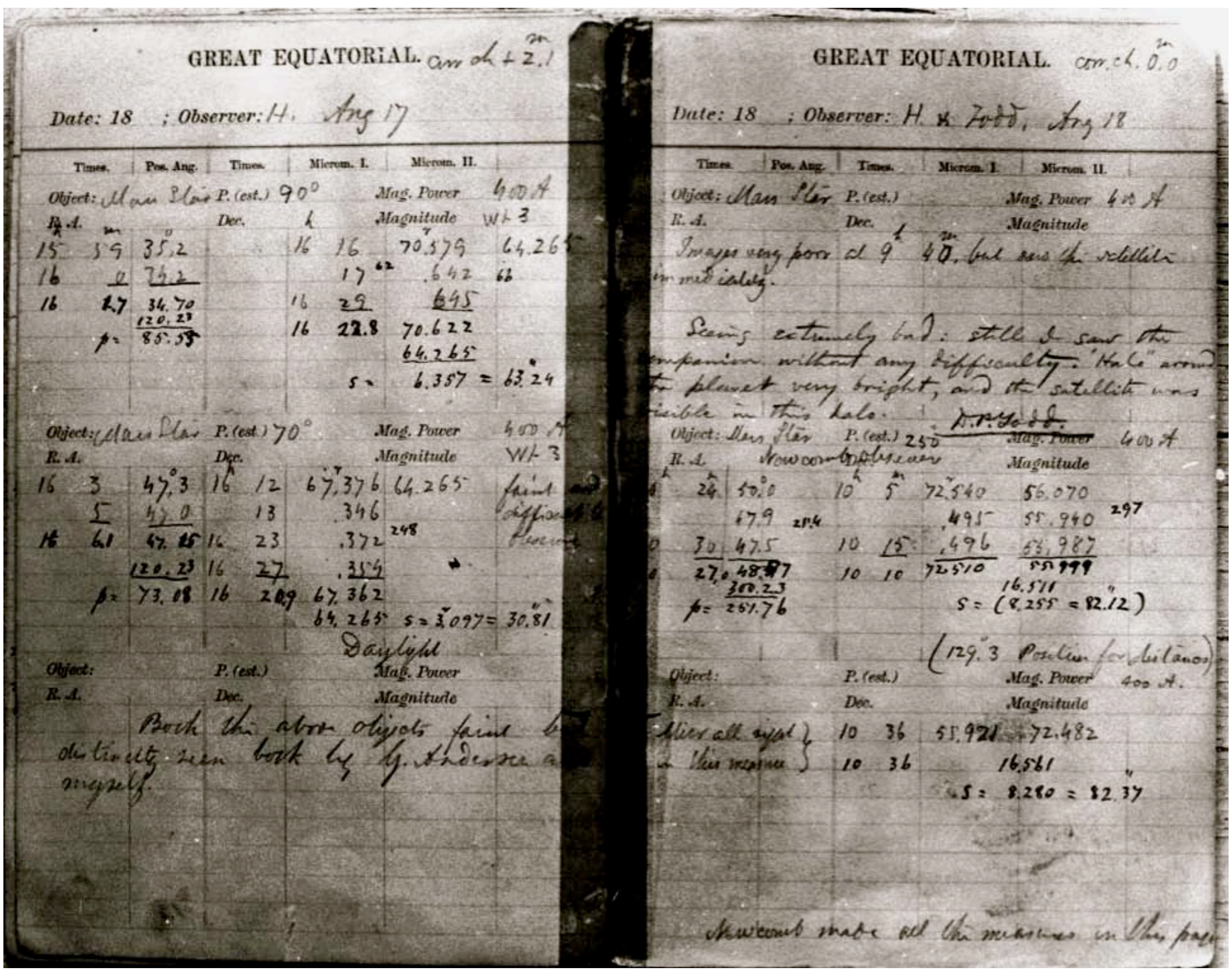


Figure 15: Asaph Hall's observation book with the record of Phobos and Deimos's discovery on 17 August 1877. *(U.S. Naval Observatory / NASA)*

Figure 16: The "*Destination: Mars*" space art exhibition at the NASA Ames Conference Center, the venue of the *First International Conference on the Exploration of Phobos and Deimos*. The exhibition was co-sponsored by the International Association of Astronomical Artists (IAAA), the Mars Institute, and NASA Ames Research Center. *(MI / M. West).*

Figure 15: "The Island", an oil painting by Pat Rawlings, depicts the human exploration of Phobos. The painting was among the artwork exposed in the "*Destination: Mars*" space art exhibition. *(Pat Rawlings).*

Tables

Table 1: Physical and Geologic Characteristics of Phobos and Deimos.

	Phobos	**Deimos**
Radii (Irregular-shaped)	13.5 x 10.8 x 9.4 km	7.5 x 6.1 x 5.5 km
Mass	~13.0 10^{15} kg	~1.9 x 10^{15} kg
Volume	5766 km^3	1017 km^3
Mean density	~1.86+/-0.06 $g.cm^{-3}$	~1.54+/-0.22 $g.cm^{-3}$
Composition	Rock (but porous)	Rock (but porous)
Geometric albedo	0.06	0.07
Surface gravity (range due to shape)	0.32 - 0.64 $cm.s^{-2}$	0.20 – 0.27 $cm.s^{-2}$
Escape velocity	3 - 16 $m.s^{-1}$	4 – 7.5 $m.s^{-1}$
Orbital semi-major axis	9378 km	23460 km
Orbital eccentricity	0.015	0.0005
Orbital inclination	1.02^o	1.82^o
Orbital period	7 hr 39 min Slowly spiraling inward	30 hr 18 min Slowly spiraling outward
Rotation (spin) period	7 hr 39 min Synchronous rotation	30 hr 18 min Synchronous rotation
Impact craters	Heavily cratered. Normal depth/diameter ratios.	Substantial infilling. Many just rims.
Largest crater	0.85 R_m	1.4 R_m
Regolith downslope transport	Local	Global
Grooves presence and dimensions	Yes 10 km x 0.1 km x 0.01 km	No

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Appendix A: Conference Conveners and Organizers

The Conveners of the *First International Conference on the Exploration of Phobos and Deimos: The Science, Robotic Reconnaissance, and Human Exploration of the Two Moons of Mars* were:

Pascal Lee (Mars Institute, SETI Institute, and NASA Ames Research Center),
David Beaty (NASA Mars Program Office),
Alain Berinstain (Canadian Space Agency),
Marcello Coradini, (European Space Agency),
Christopher P. McKay (NASA Ames Research Center),
Yvonne Pendleton (NASA Headquarters),
Joseph Veverka (Cornell University), and
Alexander Zakharov (Space Research Institute, Russian Academy of Sciences).

The Conference's Technical Organizing Committee comprised:

Pascal Lee (Chair) (Mars Institute, SETI Institute, and NASA Ames Research Center)
Dale Cruikshank (Co-Chair) (NASA Ames Research Center)
Brian Glass (NASA Ames Research Center),
Don Pettit (NASA Johnson Space Center).

The Technical Organizing Committee for the *Science Session* comprised:

Peter C. Thomas (Chair) (Cornell University)
Jean-Pierre Bibring (Co-Chair) (Institut d'Astrophysique Spatiale)
Erik Asphaug (University of California, Santa Cruz)
Bruce Betts (The Planetary Society)
Joseph A. Burns (Cornell University)
Jeff Cuzzi (NASA Ames Research Center)
Brett Gladman (University of British Columbia)
Penelope King (University of New Mexico)
Andrew Rivkin (Applied Physics Laboratory, Johns Hopkins University)
Seiji Sugita (University of Tokyo).

The Technical Organizing Committee for the *Robotic Reconnaissance Session* comprised:

Alexander Zakharov (Chair) (Space Research Institute)
Robert Richards (Co-Chair) (Optech)
Andrew J. Ball (Open University)
Christopher Dreyer (Colorado School of mines)
Lou Friedman (The Planetary Society)
Alan Hildebrand (University of Calgary)
Butler Hine (NASA Ames Research Center)
Greg Mungas (Jet Propulsion Laboratory)
Carle Pieters (Brown University)
Konrad Sauer (Max Planck Institut fur Extraterrestrische Physik)

The Technical Organizing Committee for the *Human Exploration Session* comprised:

Pascal Lee (Chair) (Mars Institute, SETI Institute, and NASA Ames Research Center)
Stephen J. Hoffman (Co-Chair) (SAIC and NASA Johnson Space Center)
Buzz Aldrin (Sharespace)
William K. Hartmann (Planetary Science Institute)
Ed Hodgson (Hamilton Sundstrand)
Jeffrey A. Jones (NASA Johnson Space Center)
Geoffrey Landis (NASA Glenn Research Center)
Larry Lemke (NASA Ames Research Center)
Fred Singer (Science and Environmental Policy Project)
Dennis Wingo (SkyCorp, Inc.)

The Technical Organizing Committee for the Student Program comprised:
Nicholas Wilkinson (Chair) (Mars Institute - Canada)
Michael West (Co-Chair) (Mars Institute - Australia)

The Asaph Hall Exhibit was organized by:
Steven J. Dick (Chair) (NASA Headquarters)
Pascal Lee (Co-Chair) (Mars Institute, SETI Institute, and NASA Ames Research Center)

The "*Destination: Mars*" Space Art Exhibition Committee comprised:
William K. Hartmann (Chair) (Planetary Science Institute and IAAA)
Walter Myers (Co-Chair) (IAAA)
Bettina Forget (IAAA)
Julie Jones (IAAA)
Pascal Lee (Mars Institute, SETI Institute, and NASA Ames Research Center)
Kara Szathmary (IAAA)

Appendix B: Conference Program

This appendix reproduces the program of the *First International Conference on the Exploration of Phobos and Deimos* published by the Lunar and Planetary Institute.

Program

First International Workshop on the Exploration of Phobos and Deimos

November 5–7, 2007 • Moffett Field, California

Monday, November 5, 2007

2:30 p.m.		Registration, Exhibits, and Welcome Reception
2:30 – 4:30 p.m.		Meeting Registration
3:00 – 3:30 p.m.		Asaph Hall Memorabilia and Mars Space Art Exhibit Inaugural
3:30 – 4:30 p.m.		Welcome Reception

Tuesday, November 6, 2007

8:00 a.m.	Main Ballroom	Science Session
1:00 p.m.	Main Ballroom	Robotic Reconnaissance Session

Wednesday, November 7, 2007

8:00 a.m.	Main Ballroom	Human Exploraton Session
12:15 p.m.	Main Foyer	Poster Session
1:00 p.m.	Main Ballroom	Synthesis Session
2:00 p.m.		Meeting Adjourns

PRINT ONLY

Tuesday, November 6, 2007
SCIENCE SESSION
8:00 a.m. Main Ballroom

Chairs: **P. Thomas**
J. -P. Bibring

8:00 a.m.	WELCOME AND LOGISTICS; CONFERENCE OBJECTIVES (P. Lee and C. McKay)
8:30 a.m.	Dick S. J. * [KEYNOTE] *The Discovery and Exploration of Phobos and Deimos* **[#7013]**
9:00 a.m.	Thomas P. C. * [INVITED] *The Surfaces of the Martian Satellites: Mysteries, Conundrums, and Relations to Other Small Objects* **[#7009]**
9:15 a.m.	Rivkin A. S. * [INVITED] *The Composition of Phobos and Deimos: Constraints and Questions* **[#7022]**
9:30 a.m.	BREAK
9:45 a.m.	Gladman B. * [INVITED] *Origin and Evolution of Phobos and Deimos* **[#7049]**
10:00 a.m.	Hartmann W. K. * [INVITED] *Phobos: Nature of Crater Populations and Possible Evidence for Interior Volatiles* **[#7048]**
10:15 a.m.	Espley J. R. * Knez C. Hamilton D. P. Connerney J. E. P. *Dust Rings from Phobos and Deimos?* **[#7041]**
10:30 a.m.	Sauer K. * Dubinin E. *Phobos/Deimos Effects in the Solar Wind* **[#7017]**
10:45 a.m.	Singer S. F. * *Origin of the Martian Satellites Phobos and Deimos* **[#7020]**
11:00 a.m.	BREAK
11:15 a.m.	DISCUSSION; SCIENCE (P. Thomas, Chair)
11:45 a.m.	LUNCH
12:15 p.m.	Worden P. * [KEYNOTE] *Phobos, Deimos, and the Vision for Space Exploration*
12:45 p.m.	BREAK

Workshop on the Exploration of Phobos and Deimos (2007) **sess02.pdf**

Tuesday, November 6, 2007
ROBOTIC RECONNAISSANCE SESSION
1:00 p.m. Main Ballroom

Chairs:	**A. Zakharov** **R. Richards**
1:00 p.m.	Hoffmann H. * Willner K. Oberst J. Giese B. Gwinner K. Matz K.-D. Roatsch T. Jaumann R. Duxbury T. Neukum G. *Ongoing Observations of Phobos and Deimos by the HRSC Experiment on Mars Express* **[#7023]**
1:15 p.m.	Murchie S. * Choo T. Humm D. Rivkin A. Bibring J.-P. Langevin Y. Gondet B. Roush T. Duxbury T. CRISM Team *MRO/CRISM Observations of Phobos and Deimos* **[#7005]**
1:30 p.m.	Safaeinili A. * Cicchetti A. Nenna C. Calabrese D. Jordan R. Duxbury T. Plaut J. Picardi G. Flamini E. Plettemeier D. *Radar Sounder Observation of Phobos* **[#7046]**
1:45 p.m.	Zakharov A. * Project Science-Design Team [KEYNOTE] *Phobos Sample Return Mission* **[#7037]**
2:15 p.m.	Warmflash D. * Ciftcioglu N. Fox G. E. McKay D. S. Friedman L. Betts B. Kirschvink J. *Living Interplanetary Flight Experiment (LIFE): An Experiment on the Survivability of Microorganisms During Interplanetary Transfer* **[#7043]**
2:30 p.m.	BREAK
2:45 p.m.	Fraze R. * Svitek T. Betts B. Friedman L. D. *Phobos-LIFE: Preliminary Experiment Design* **[#7040]**
3:00 p.m.	Blake D. F. * Nguyen C. V. Ribaya B. P. Niemann D. Rahman M. Dholakia G. R. Aalam A. Ngo V. McKenzie C. Joy D. Espinosa B. *Spaceflight Microfabricated Scanning Electron Microscope and X-Ray Spectrometer (MSEMS)* **[#7002]**
3:15 p.m.	Ball A. J. * Franchi I. A. Murray J. B. *Integrated Studies of Phobos and Deimos — Remote, In Situ and Laboratory Investigations* **[#7018]**
3:30 p.m.	Richards R. * Lee P. Hildebrand A. PRIME Team *PRIME (Phobos Reconnaissance and International Mars Exploration): A Phobos Lander Mission to Explore the Origin of Mars's Inner Moon* **[#7045]**
3:45 p.m.	Gellert R. * *Suitability of an APXS for Phobos and Deimos Missions* **[#7028]**
4:00 p.m.	BREAK
4:15 p.m.	DISCUSSION; ROBOTIC RECONNAISSANCE (R. Richards, chair)
4:45 p.m.	ADJOURN FOR THE DAY

Workshop on the Exploration of Phobos and Deimos (2007) **sess03.pdf**

Wednesday, November 7, 2007
HUMAN EXPLORATON SESSION
8:00 a.m. Main Ballroom

Chairs:	**S. Hoffman** **P. Lee**
8:00 a.m.	LOGISTICS; SUMMARY OF DAY ONE (P. Lee and C. McKay)
8:30 a.m.	TBA [KEYNOTE]
9:00 a.m.	Singer S. F. * [INVITED] *To Mars Via Its Moons Phobos and Deimos (Ph-D Project)* **[#7021]**
9:15 a.m.	Landis R. R. * Korsmeyer D. J. Abell P. A. Adamo D. R. Jones T. D. Lu E. T. Lemke L. Gonzales A. Gershman R. Morrison D. Sweetser T. Johnson L. *Prelude to Human Exploration of Phobos and Deimos: The NEO Factor* **[#7031]**
9:30 a.m.	BREAK
9:45 a.m.	Stooke P. J. * *Mars Sample Return Via Phobos Cache and Human Retrieval* **[#7001]**
10:00 a.m.	De Angelis G. * Badavi F. F. Blattnig S. R. Clowdsley M. S. Singleterry R. C. Jr. Wilson J. W. *Time-dependent Models for the Radiation Environment of Planet Mars* **[#7007]**
10:15 a.m.	Vazquez M. E. * [INVITED] *Human Exploration of Phobos and Deimos: Radioprotection Issues* **[#7050]**
10:30 a.m.	West M. D. * Lee P. *Human Exploration of Phobos and Deimos: Engineering Challenges and Unique Opportunities* **[#7032]**
10:45 a.m.	Lee P. * *Phobos-Deimos ASAP: A Case for the Human Exploration of the Moons of Mars* **[#7044]**
11:00 a.m.	BREAK
11:15 a.m.	DISCUSSION; HUMAN EXPLORATION (S. Hoffman, chair)
11:45 a.m.	LUNCH

Workshop on the Exploration of Phobos and Deimos (2007) **sess04.pdf**

Wednesday, November 7, 2007
12:15 p.m. Main Foyer

POSTER SESSION

Blake D. F. Sarrazin P. Bish D. L. Chipera S. J. Vaniman D. T. Ming D. Morris D. Yen A.
Remote Mineralogical Analysis as a Window into the Origin and Processing of Solar System Objects **[#7003]**

Desportes C.
Phobos Spectral Overview: Suggestions for Future Orbital Measurements **[#7004]**

Jacobson R. A.
The Orbits of the Martian Satellites **[#7039]**

Kremic T. Dankanich J. W.
In-Space Propulsion Technologies for the Exploration of Phobos and Deimos **[#7042]**

Mistry A. H.
Mining on Phobos and Deimos **[#7015]**

Nakhodneva A. A. Perov N. I.
On a Problem of Evolution of Orbits of Phobos and Deimos **[#7011]**

Palomba E. Longobardo A. D'Amore M. Battaglia R. Della Corte V. Ferrini G.
MATI: An Instrument for the Detection of the Martian Tori **[#7033]**

Palomba E. Korablev O. Grigoriev A. AOST International Team
AOST: An Infrared Spectrometer for the Phobos-Soil Mission **[#7035]**

Workshop on the Exploration of Phobos and Deimos (2007) **sess05.pdf**

Wednesday, November 7, 2007
SYNTHESIS SESSION
1:00 p.m. Main Ballroom

Chairs: **P. Lee**
J. Veverka

1:00 p.m. SYNTHESIS SESSION (P. Lee, Moderator)

2:00 p.m. MEETING ADJOURNS

PRINT ONLY

Aftabi P.
The Water Traces and Structural Lineaments on Martian Moons **[#7030]**

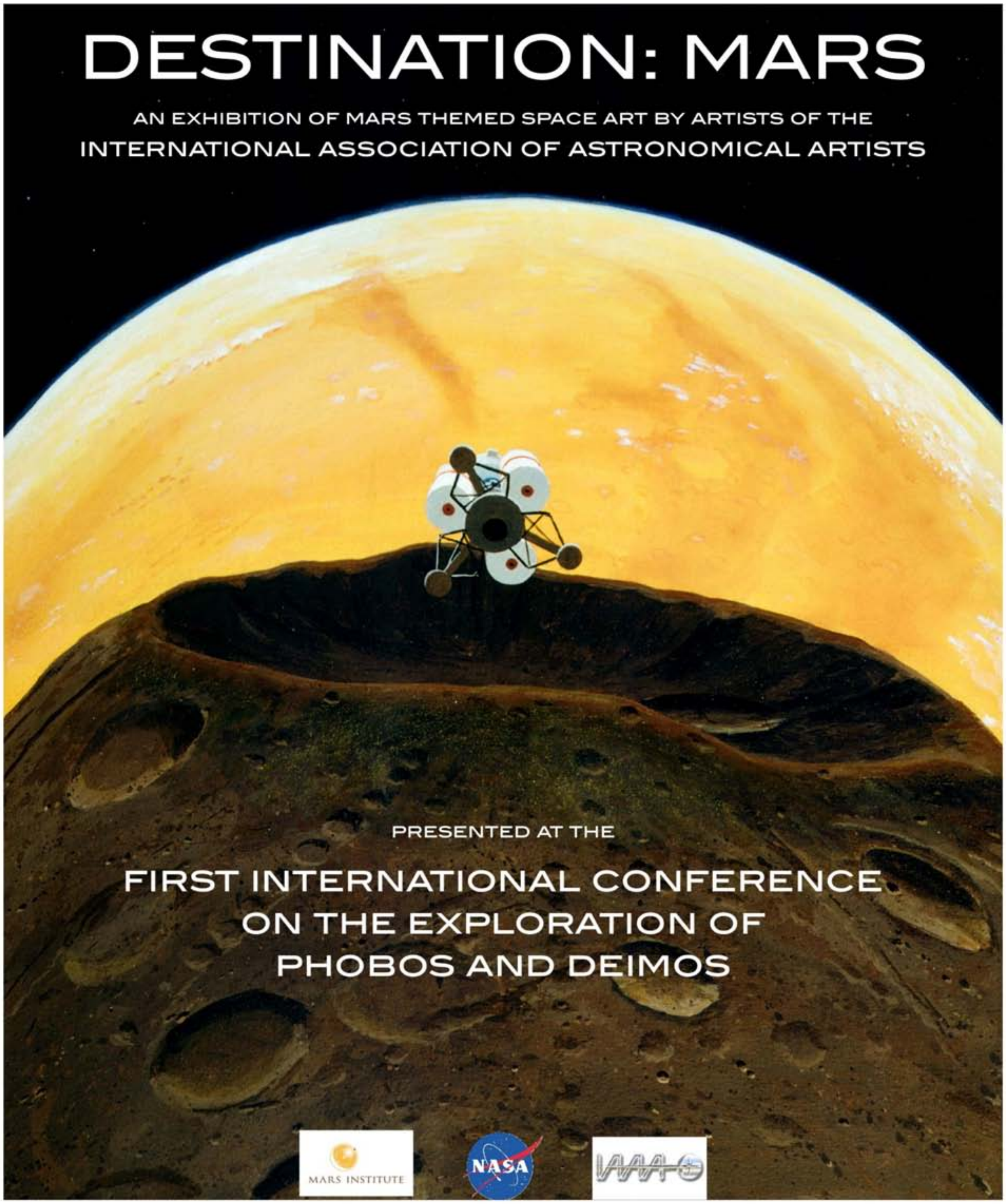
Aftabi P.
The Dirty Ice Flow on Martian Moons, Analogue and Prototype Models **[#7047]**

Klingelhöfer G. Rodionov D. Blumers M. Bernhardt B. Fleischer I. Schröder C.
Morris R. V. Girones Lopez J.
The Miniaturised Moessbauer Spectrometer MIMOS II: Application for the "Phobos-Grunt" Mission **[#7038]**

Perov N. I.
On a Problem of Existence of Martian Cometary Family **[#7012]**

Appendix C: "*Destination: Mars*" Space Art Exhibition Catalog

This appendix reproduces the Art Catalog of "*Destination: Mars*", an exhibition of Mars themed space art created by artists of the International Association of Astronomical Artists (IAAA), presented at the *First International Conference on the Exploration of Phobos and Deimos.* The original Art Catalog is copyright of the IAAA. The individual artists listed in the catalog hold the copyright to the respective artwork presented.


DESTINATION: MARS
AN EXHIBITION OF MARS THEMED SPACE ART BY ARTISTS OF THE
INTERNATIONAL ASSOCIATION OF ASTRONOMICAL ARTISTS
PRESENTED AT THE
FIRST INTERNATIONAL CONFERENCE
ON THE EXPLORATION OF
PHOBOS AND DEIMOS
MARS INSTITUTE
NASA

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Richard Bizley, *FIAAA*
Sean Brady
Michael Carrol, *FIAAA*
Robin Hart
William Hartmann, *FIAAA*
Gary Harwood, *FIAAA*
Frank Hettick
Steven Hobbs
B. E. Johnson, *FIAAA*
Julie Jones
Gavin Mundy
Walter Myers
Pat Rawlings, *FIAAA*

Curator
Bettina Forget
Director of Exhibitions
IAAA

front cover art::
William K. Hartmann
Phobos Rounding the Bend

THE CONFERENCE

NASA Ames Research Centre
Moffet Field, CA, USA
5 - 7 November, 2007

The First International Conference on the Exploration of Phobos and Deimos: The Science, Robotic Reconnaissance, and Human Exploration of the Two Moons of Mars is the first international meeting focused on Phobos and Deimos, and on how their exploration relates to that of the Moon, Mars, and the solar system beyond. The conference is an open international forum bringing together scientists, engineers, space exploration professionals, and students interested in discussing the status and advancement of the exploration of Mars' satellites, and the exploration of Mars itself and other near-Earth objects (NEOs) through them.

THE EXHIBITION

The exhibition "Destination: Mars" was curated specifically for the First International Conference on the Exploration of Phobos and Deimos. It features 26 Mars-themed artworks from 14 artists of the International Association of Astronomical Artists (IAAA).

In this exhibition the visitor is invited to explore past, present, and future vistas of Mars and its moons, imagine scenarios of living and working on the red planet, and observe Mars, Phobos and Deimos both from an orbital perspective and in extreme close-up.

Every painting has a story, and in this catalogue you'll find background information for all artworks in the "Destination: Mars" exhibit written by each IAAA artist.

We hope to inspire those who inspired us.

Bettina Forget
Director of Exhibitions, IAAA

A WORD FROM THE ORGANIZERS

As the National Aeronautics and Space Administration (NASA) and other space agencies around the world take concrete steps to return humans to the Moon and plan their future journeys to Mars and beyond, the First International Conference on the Exploration of Phobos and Deimos represents a timely opportunity to collectively pause and think about the scientific significance of the two moons of Mars and the key roles their exploration could play in the future.

To remind us of earlier ideas, expand on current thinking, and inspire new visions for the future, we are delighted to include in this conference an exhibition of original space art by members of the International Association of Astronomical Artists (IAAA) titled "Destination: Mars". Space art is a powerful engine of space exploration. We hope that this exhibition, hosted by NASA Ames Research Center and co-sponsored by the IAAA and the Mars Institute, will give its visitors a taste of the wonderful journeys ahead.

Pascal Lee
Mars Institute, SETI Institute,
and NASA Ames Research Center

MARS INSTITUTE

The International Association of Astronomical Artists (IAAA) is the world's premier organization dedicated to the advancement of the genre of space art. Its diverse, global membership participates in mankind's scientific exploration of the universe, visualizing and sharing scientific discoveries via a variety of forms of artistic expressionincluding painting, sculpture, music and dance.

Our "Destination: Mars"exhibition, is but a small snippet of a much larger body of work which is spread far and wide across the globe in exhibition halls, corrector galleries, private homes and artists studios. We hope this window of space art inspires wonder and awe which the heavens have provided since mankind first gazed into the starry canopy of night.

Kara Szathmary
Persident, IAAA

QUICK REFERENCE LIST

p3	Joe Bergeron	joe@joebergeron.com
p4	Richard Bizley	richard@bizleyart.com
p5	Sean Brady	seanbrady2@blueyonder.co.uk
p6	Michael Carroll	cosmicart@stock-space-images.com
p7	Robin Hart	rhstarbird@earthlink.net
p8	William K. Hartmann	hartmann@psi.edu
p9	Garry L. Harwood	glh@nataraja.demon.co.uk
p10	Frank Hettick	fhettick@hotmail.com
p11	Steven Hobbs	swhobbs2000@hotmail.com
p12	B. E. Johnson	bj@spaceart.org
p13	Julie Jones	JulieJones@ArtFromTheSoul.com
p14	Gavin Mundy	artist@mundyart.co.uk
p15	Walter Myers	spaceart@arcadiastreet.com
p16	Pat Rawlings	roy.p.rawlings@saic.com

Most works in the "Destination: Mars" exhibit are for sale by the artist. For more information, please contact the artist directly via the e-mail addresses provided above.

Sean Brady

ABOUT THE ARTIST

I'm a recently retired A/V technician who lives in Scotland with my wife and way too many cats. I've painted stars and planets for most of my life. I migrated a few years ago from the more traditional oils and acrylics to a variety of digital programs and now do most of my work in that medium. For inspiration I look to the fantastic photographs taken by H.S.T. and the other great telescopes we take so much for granted these days. But most of all I'm inspired by going out of my back door on a crisp winter's night, looking up and out, and just letting my mind wander.

ABOUT THE ARTWORK

I also enjoy transposing local landscapes offplanet. The landscapes in both the Mars paintings are based on local scenery.

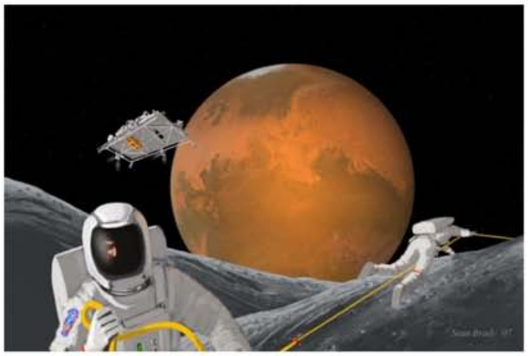
"Olympos Station" shows a group of astronauts setting up an automatic weather station on the lower slopes of Mons Olympos. Rather than the usual heavy tracked vehicle I considered that a series of two wheeled "boxcars" with a semirigid but flexible membrane between them might be more suitable for the terrain, each wheel having it`s own driving mechanism, each "box" capable of being isolated from the others.

"North Wall" depicts an astronaut taking ground readings on the floor of Valles Marineris. I thought I'd try my hand at doing a more fanciful, science fictiony, environmental suit. There is, however, no local scenery in "Rope Walk". Because of the low gravity on Phobos, I imagine it might be quite difficult to take a step never mind walk about on that moon, so in this painting I assume that among all their other accomplishments astronauts will also have to learn the use of pitons and carabiners.

ARTIST CONTACT

seanbrady2@blueyonder.co.uk

Rope Walk, digital print, 2007
Olympos Station, digital print, 2007
North Wall, digital print, 2007



MICHAEL CARROLL

Argyre, digital print, 2006
Mars, digital print, 2006
Polar Impact, digital print, 2006

ABOUT THE ARTIST

Michael Carroll has been doing astronomical art for 25 years. His work has appeared in a host of books and magazines including National Geographic, TIME, OMNI, Astronomy and Sky & Telescope. He has done commissioned paintings and murals for NASA, JPL, Lockheed/Martin and many science museums. He lives in Littleton, Colorado,

ABOUT THE ARTWORK

Argyre Sea

Some research suggests that the Argyre impact basin was once ringed with glaciers feeding into a shallow sea. This painting depicts such a Martian past, with a more dense atmosphere scattering light across a much-bluer sky. Phobos and Deimos are both visible above.

Mars Volcano

Most volcanoes on Mars are either shields or small cones. Still others are eroded, steep-sided strato-volcanoes. Here, a volcanic eruption triggers outgassing as lava comes into contact with subsurface ices.

Polar Impact

An asteroid impacts the Martian northern polar cap. In the foreground we see layered terrain, based on similar morphology of Icelandic glaciers. Some terraforming scenarios suggest directing carbonaceous chondritic asteroids into the poles to darken the surface. The sunlight would then heat the darkened ice, releasing CO2 and water vapor.

ARTIST CONTACT

cosmicart@stock-space-images.com
http://stock-space-images.com

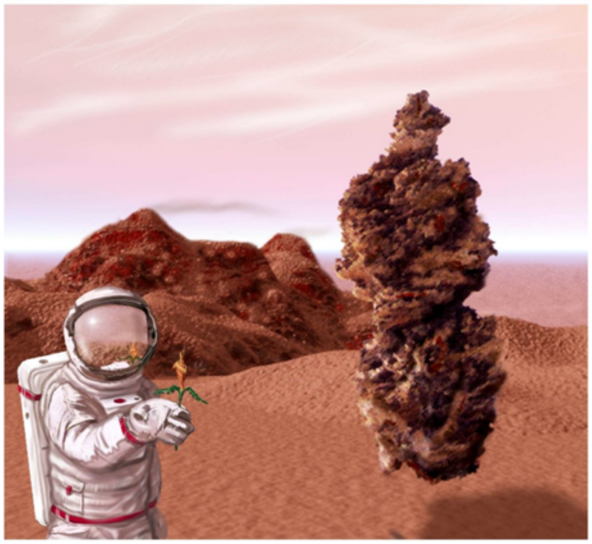
ROBIN HART

ABOUT THE ARTIST

Art has always been at the center of Robin Hart's life. Along with it, almost entwined like a double helix, is her love of space and the cosmos. Born into that generation of boomers that grew up with the space age, from the launch of the first satellites, through the manned space program and beyond to the outer reaches of the solar system; she has followed these events with great enthusiasm. During her college years, Robin was encouraged by one of her professors to incorporate something she was passionate about into her art. Her love of space was that passion. When she began to integrate that subject matter into her work, there was an explosion of creativity that has continued over the years. Robin counts herself among the interpretive space artists. She often realistically renders a space environment, but adds something terrestrial to it to it or has something terrestrial that seems to be morphing into space. She uses these themes to illustrate her passion, emotion and wonderment of the extraterrestrial environments she envisions. Sometimes she likes to add a touch of humor as well. Robin Hart has had 2 one woman art shows at the Griffith Observatory, been in many space art exhibits, exhibited her work internationally and has been a member of the IAAA for many years.

ABOUT THE ARTWORK

This surreal painting ponders the age old question about the chances of life on Mars. The flower and the helix shaped floating rock suggest the potential for life yet to be discovered on the red planet.

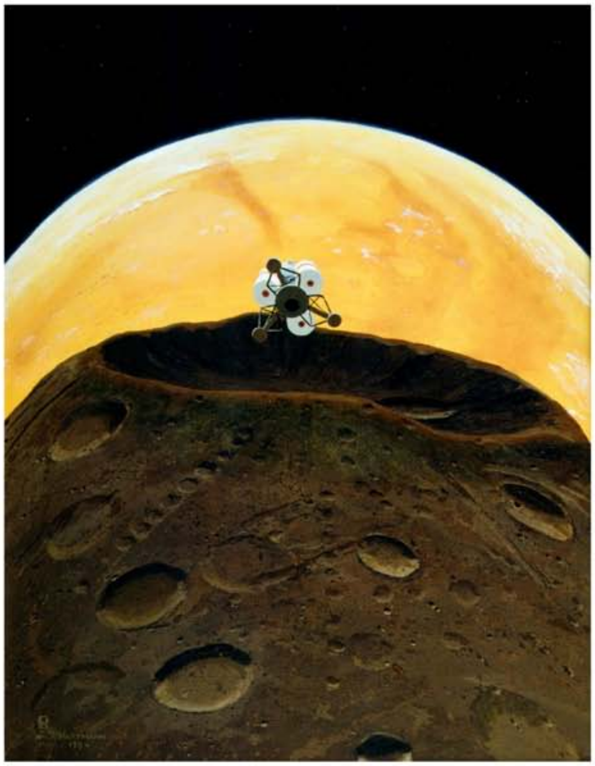


Is There Really Life on Mars
digital painting
2000

ARTIST CONTACT

rhstarbird@earthlink.net

WILLIAM K. HARTMANN



Phobos Rounding the Bend
acrylic on canvas
1984

ABOUT THE ARTIST

William K. Hartmann is recognized internationally as a painter, scientist, and writer. He is especially known for paintings of astronomical subjects based on recent discoveries. These paintings have been published in magazines including Natural History, Smithsonian, Science and the Economist and other magazines in Japan, Russia, France, Germany, England, and Italy. In 1997, Hartmann was named first winner of the Carl Sagan Medal of the American Astronomical Society, in recognition of his communication of science to the public, in part through his artwork. Asteroid 3341 is named after him in recognition of his planetary research, and he was given the Lucien Rudaux Lifetime Achievement Award of the International Association of Astronomical Artists. A 2007 profile in the leading U.S. scientific journal, "Science," was titled "Renaissance Man of the Solar System."

Hartmann holds a Ph.D. in Astronomy and M.S. in Geology, both from the University of Arizona, and a B.S. in Physics from Pennsylvania State University. Although his paternal grandfather was a painter, he is primarily self-taught and has been painting since the early 1970s.

ABOUT THE ARTWORK

This painting was done for the1984 book "Out of the Cradle" by William Hartmann, Ron Miller, and Pamela Lee. The book described goals of human space exploration in the 21st century, in a context of discovery and possible energy and material shortages on Earth. The painting shows a future spacecraft moving past Phobos toward Mars. The painting depicts large craters and crater chains on Phobos, and the striking difference in color between Phobos and Mars.

ARTIST CONTACT

hartmann@psi.edu
www.psi.edu/hartmann/index.html

Garry L. Harwood

ARTIST CONTACT
glh@nataraja.demon.co.uk

The Long Fall
oil on canvas board, 24" x 20"
2007

ABOUT THE ARTIST

Garry L. Harwood was born in 1959 in London, England and studied for a career as a marine biologist and physical oceanographer. After two decades in the jewelery industry he decided to return to his roots and make painting his chosen profession. His interest in the natural and physical sciences occasionally influences his artwork and in this guise his astronomical paintings are an attempt to visualize and communicate scientific data to the public. His work has been widely exhibited and is in private collections world wide. When not getting lost in some remote corner of the globe, he divides his time between London and the far west of Cornwall where he can often be found painting on the cliff tops a short distance from his studio. He is a lifetime member and Fellow of the International Association of Astronomical Artists.

ABOUT THE ARTWORK

Despite much number crunching and head scratching the origin of Mars' two moons Phobos and Deimos presents an outstanding problem for planetary scientists. One attractive possibility is that both moons are asteroids which became gravitationally bound to Mars sometime in the early history of the solar system.

In this painting, Phobos and proto-Mars are backlit against sunlight scattered by dust grains in the inner solar system. Mars casts a shadow through an extended envelope of material left over from its formation and sports an atmosphere temporarily choked with impact generated dust. Disturbed from its original location in the main asteroid belt Phobos makes another close encounter with Mars but this time will not escape from that planets gravitational embrace. As a new satellite of Mars subsequent passages will modify Phobos' position until it occupies the decaying orbit we see today. On Phobos the large impact crater Stickney is deep in shadow while the night-side is briefly illuminated as a small piece of high-speed debris from the outer solar system slams into the surface to make yet another crater.

Frank Hettick

View of Home II, mixed media canvas print, 2006

About the Artist

The entire universe is the subject for Frank Hettick's photo-realistic depictions of distant planets, moons and alien landscapes. The artist's home-base and studio are now located in the high desert of Central Oregon although he travels extensively to exotic locations studying the geology and gaining inspiration for his unusual art pieces. His attention to lighting and use of detail in his works cause many viewers to believe his "other-worldly" paintings are fine photographs! However - the subjects Frank renders have never been seen or photographed by any human before. His goals include encouraging today's youth towards the same enthusiasm for space and other worlds as he had in those early days before the Apollo missions - when he was growing up. Hettick is a member of the International Association of Astronomical Artists; The National Space Society; The Mars Society; The Planetary Society; sits on the Space Art Committee of Federation of Galaxy Explorers; and a Honorary Member conferred by Star- Ships of the Third Fleet writer's group.

About the Artwork

'View Of Home' won First Place in The Mars Society' international competition in August 2004. Hettick explains "the piece was something I just had to paint - it pictures very simply the huge vastness of space, the loneliness of exploration, the potential danger of being in a strange, unknown land and utterly alone in both time and distance from other human assistance – and that single astronaut just has to be concerned about every decision he will be called upon to make." 'View Of Home' was also selected to be the backdrop piece for the on-stage guest speaker at the 25th Anniversary Celebration of The Planetary Society. Ray Bradbury was the speaker and we exchanged letters regarding how the piece had just seemed so appropriate and fitting for the occasion.

Artist Contact

fhettick@hotmail.com
www.skyhighgallery.com

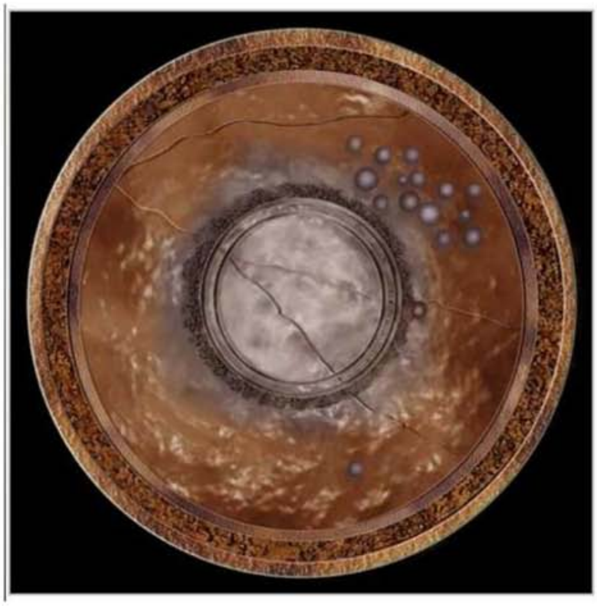
JULIE JONES

ABOUT THE ARTIST

After a 33 year career at the Lawrence Berkeley National Lab writing research and development contracts, Julie Rodriguez Jones left corporate America to pursue her art full time in 2003. Her interests in space and space art began at an early age but she did not seriously pursue her art until late in her career. After college and while at LBNL she studied art with Arngunner Yr, Lien Truong and Gwyneth Welch. Julie's art incorporates that initial training but now she primarily uses a digital airbrush. Julie's art includes a wide variety of award winning pieces from her space art and flowers to her liturgical art. She has been published both nationally and internationally including book covers, corporate art, magazines and more.

ABOUT THE ARTWORK

When the Mars Exploration rovers, Spirit and Opportunity, began transmitting images of the rock surfaces after having been ground by the rock abrasion tool, Julie found them to be quite unusual and equally beautiful. This is an abstract/ representational piece of the many images sent to Earth. Joel Hagen, Fellow IAAA, says about this piece, "For my money, it ranks high in the top 10 paintings ever produced by IAAA artists. Really a remarkably fine work." This is a limited edition of only 99 pieces.



Abraded Surface
archival giclee
limited edition of 99

ARTIST CONTACT

JulieJones@ArtFromTheSoul.com
www.ArtFromTheSoul.com

GAVIN MUNDY

MER, oil on board, 2005
Mars Explorers, acrylic on board, 2007

ABOUT THE ARTIST

Gavin's lifelong interests in art and space converge on regular occasions. He views space as the extension of nature beyond Earth but enjoys depicting natural wonders down here too. Human endeavour is also a source of inspiration.
Light, texture and form he finds intriguing and recreating this in paint brings with it a closer understanding of the subject.

ABOUT THE ARTWORK

MER

A depiction of a Mars Exploration Rover cresting a hill. Looking towards a Martian sunset. Its solar panels will shortly be deprived of the starlight that also powers an inquisitive neighbouring planet. A foreground rock bears the scar of its grinding tool.

Phobos Landing

After some robotic explorations to lay the groundwork humans arrive to fine-tune studies and construction. Here a large spacecraft, a mixture of space station and Lander rests idly on the surface of Phobos while a geologist studies some interesting detail in a boulder. Behind them Mars dominates the heavens.

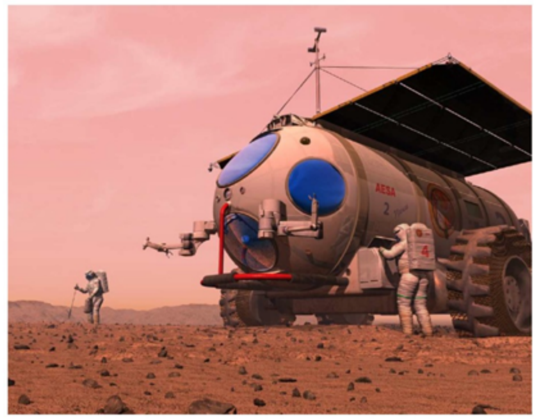
ARTIST CONTACT

artist@mundyart.co.uk
www.mundyart.co.uk

Walter Myers

ABOUT THE ARTIST

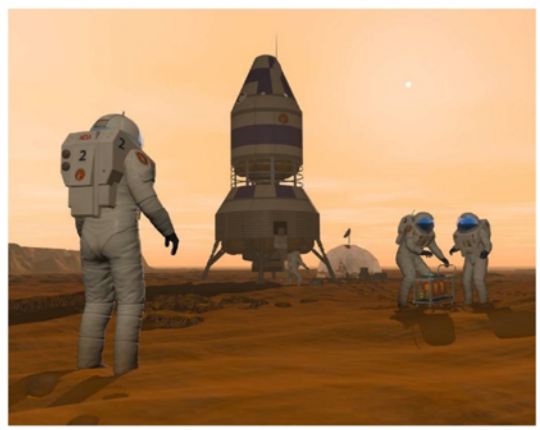
I was born in Indiana in the USA just a few months after Sputnik I made world history. I now live near Chicago and am a freelance computer graphics artist, in addition to whatever other gigs I can drum up. I've been a space enthusiast and interested in astronomy for as long as I can remember. Professionally, I've worked as a graphic artist, photographer, computer programmer, web designer, instructional designer, and projected media designer. My space art strives toward photorealism, hopefully with the resultant image being more interesting and informative than anything a still camera can produce. My work has been described as "sober," and that I take as a complement.



ABOUT THE ARTWORK

In these computer graphic images I indulge in two of my interests: the worlds beyond Earth as the ultimate expression of nature's wilderness, and the many and varied details of manned space exploration and technology. I've rendered each of Mars' exotic moons with an attention to their orientation to, and distance from, the martian surface. I've also attempted to contrast the stark barren surfaces of Phobos and Deimos with Mars' dynamic environment.

The manned exploration images suggest how missions to Mars may be realized within the next 30 to 60 years. Obviously, these missions will be all about the logistics and details of getting there, living and working effectively in a very hostile environment, and getting home. The technologies represented are drawn primarily from my imagination, based upon a (amateur) sense of what will be required to achieve the dual goals of exploring exotic worlds while meeting the moment-by-moment needs of the human explorers.



ARTIST CONTACT

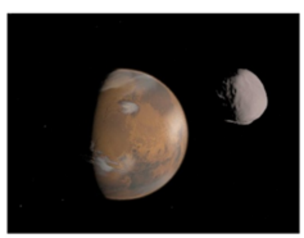
spaceart@arcadiastreet.com
http://www.arcadiastreet.com

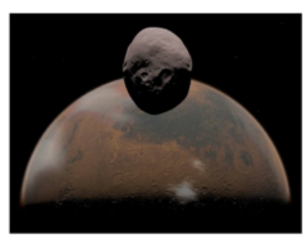
Martian Motor Home
digital print
2007

Martian Pioneers
digital print
2007

Mars and Deimos
digital print
2006

Mars and Phobos
digital print
2006





PAT RAWLINGS

The Island
acrylic on board
2006

ABOUT THE ARTIST

For over two decades, internationally recognized space illustrator and designer, Pat Rawlings has visually documented the future of space exploration. His highly realistic views of both human and robotic exploration provide a chronology of the plans, hopes and desires of the planet's best space visionaries.

Rawlings' paintings, digital images and designs have been reproduced in and on hundreds of magazines, books, television programs and films in both in the U.S. and abroad. His artwork for all of the NASA Centers reflects more than 2 decades of space exploration plans, ranging from robotic planetary missions to the human exploration of Mars and beyond.

To ensure scientific and technical accuracy in his compositions, Mr. Rawlings consults with astronauts and experts in spacecraft design, mission design, mission operations, planetary geology, meteorology, and other related fields. The resulting photorealistic images give the viewer a sense of "being there."

ABOUT THE ARTWORK

Two astronauts explore the rugged surface near the North Pole of Phobos with Mars looming on the horizon. The mother ship, powered by solar energy, orbits Mars while astronauts inside remotely operate rovers on the Martian surface. The explorers have landed on Phobos in a small excursion vehicle that fires a line into the soil to anchor the unit. The astronaut on the right is examining a one thousand pound boulder (Earth pounds) which weighs a mere pound in the low gravity of Phobos.

NASA Office of Exploration Artwork by Pat Rawlings/SAIC
Collection of the Artist

ARTIST CONTACT

www.patrawlings.com

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Please visit our website at
www.iaaa.org

back cover art::
Michael Carroll
Argyre

DESTINATION: MARS

AN EXHIBITION OF MARS THEMED SPACE ART BY ARTISTS OF THE
INTERNATIONAL ASSOCIATION OF ASTRONOMICAL ARTISTS

PRESENTED AT THE

FIRST INTERNATIONAL CONFERENCE
ON THE EXPLORATION OF
PHOBOS AND DEIMOS