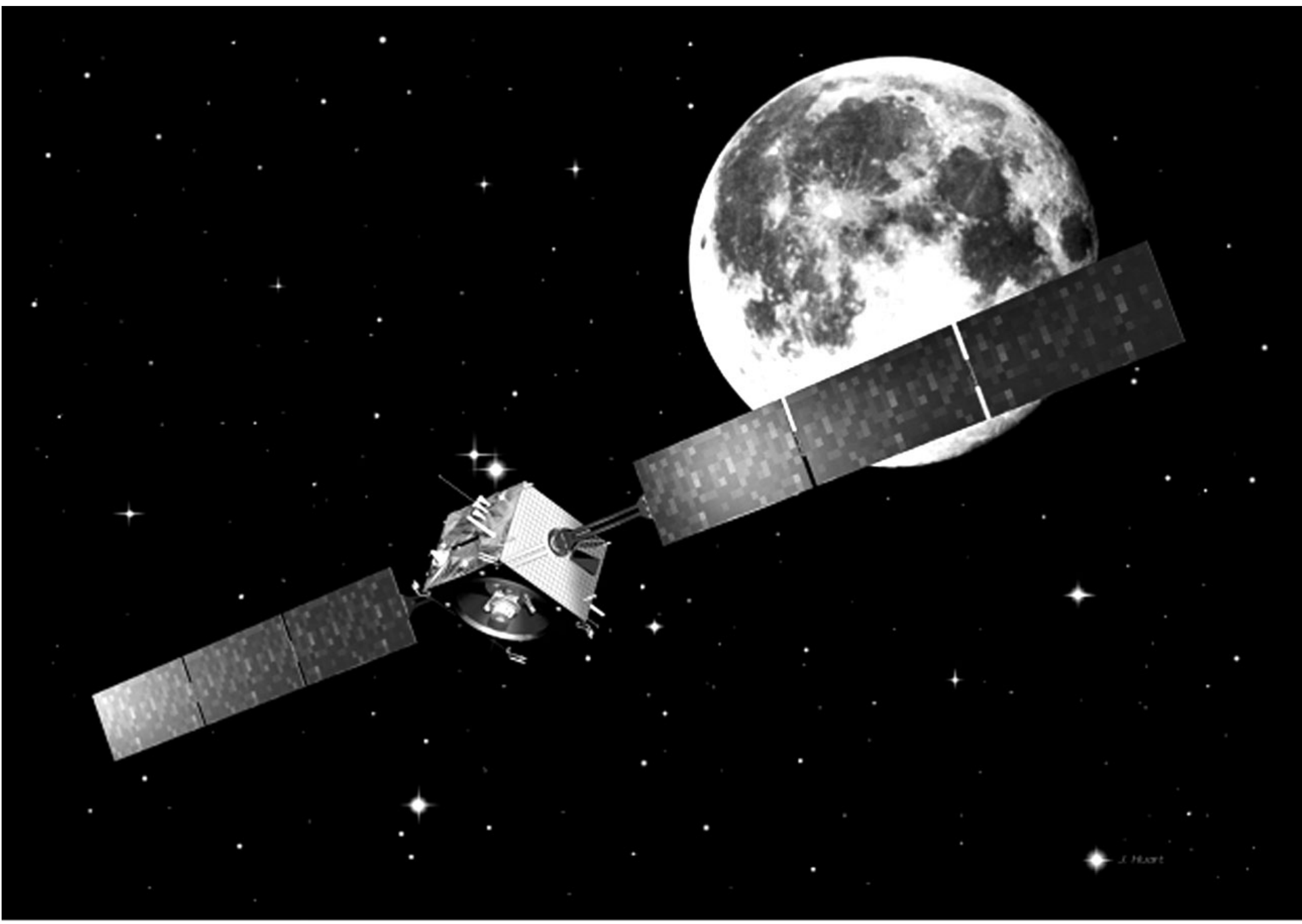
DEVOTED TO THE STUDY OF EARTH'S MOON

VOL. 24 NO. 4 WINTER 2005

SELENOLOGY

The Journal of
The American Lunar Society



Selenology

Vol. 24 No. 4 - Winter 2005

The official journal of the American Lunar Society, an organization devoted to the observation and discovery of the earth's moon

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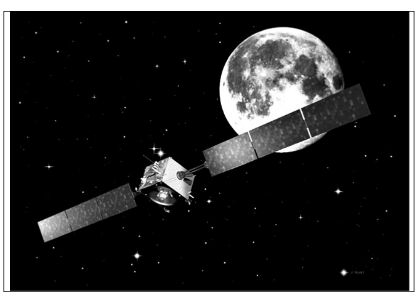

COVER:

Artist's impression of the SMART-1 mission. ESA.
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Selenology, Vol. 24 No. 4, Winter 2005. Publication of the American Lunar Society.
President: Eric Douglass; Vice President: Steve Boint; Editor: Francis G. Graham.

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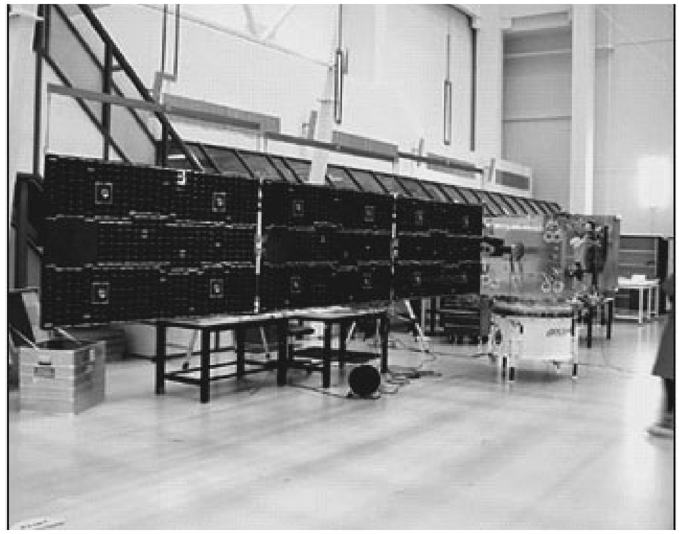
Send manuscripts, general observations, and other correspondence to:
Francis G. Graham, Kent State University East Liverpool Campus, 400 E. 4th St., East Liverpool, OH 43920
Phone: 330-382-7466 — E-mail: fgraham@eliv.kent.edu.
Send photographs and drawings that do not accompany a manuscript to:
Steve Boint – E-mail: sboint0362@msn.com
Send changes of address to Eric Douglass at ejdftd@mindspring.com

THE AMAZING SMART-1 LUNAR PROBE

By Francis G. Graham

In December, 1972, the United States left the moon. A foray into Mare Crisium by the Russians with an automatic sample return probe occurred in 1975. Then, for two decades the moon was ignored. Clementine did explore the moon's poles, but almost as an afterthought-its original purpose was to test military "Star Wars" sensors. The Galileo probe also photographed the moon as a sort-of on-the-way test en route to Jupiter.

The Japanese were the first to start a new wave of lunar exploration with the Hagamoro/Hiten probe and now everyone is going to the moon. The USA has several new lunar missions planned, one of them manned. Its Lunar Prospector probe was very successful in 1998. Suddenly the moon is back in style. The Chinese plan to get there with the Chang'E 1 lunar probe and the Japanese have more probes, such as Luna A, demonstrating to the world their already superlative prowess in robotics. India is planning a lunar probe too, the Chandrayaan-1.



Solar panels arrive for SMART-1

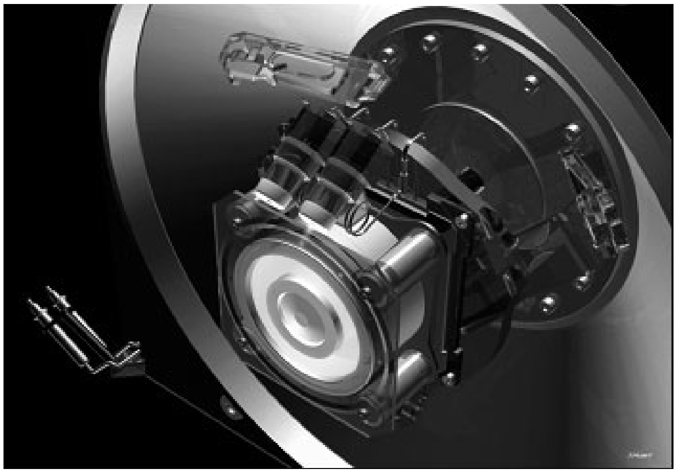
Not to be left behind are the Europeans, whose cooperative ventures to Mars, Titan, Venus and Comet Halley are of legend. History has always shown that the Europeans can do great stuff when they cooperate on an equal footing, but that has been a problem historically. Some of the most horrific wars of all times involved rivalries between Britain, France, Spain and Germany. America soared ahead while those nations, in one combination or another, devastated each others' cities, infrastructure and economy. It is no accident that peace and prosperity go together.

But times change. Except for the horror of Serbia and Bosnia, by and large, the Europeans have been at peace since 1945. While Northern Ireland and Basque-speaking Spain have also sometimes seen shooting, and there was the Hungarian revolt of 1956, nothing of the nature of previous European wars has happened for 60 years. The Euro is now the world's most stable currency. World War II set Europe back a half-century; but they are on track again!

Blastoff of SMART-1, Insat, and eBird 1 on the Ariane 5 rocket, September 27, 2003
All images in this article courtesy ESA

The European Space Agency is the cooperative group of European countries, many of which have previously been blood rivals for world hegemony: Great Britain, the Netherlands, Belgium, France, Germany, Switzerland, Finland, Sweden, Denmark, Italy, Spain, Austria, Portugal, and Luxembourg. It is the model for international cooperation that could create starships in the 22nd century.

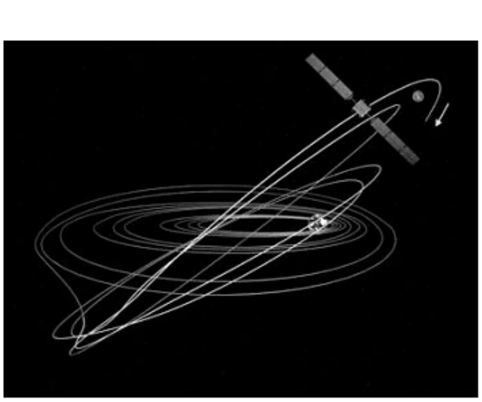
The SMART-1 (Small Missions for Advanced Research in Technology) lunar probe is precisely this sort of achievement. It is not only a lunar probe, but also a spacecraft of unusual achievement. SMART-1 is an extremely lightweight and advanced craft. It uses a xenon-gas ion engine,



SNECMA PPS-1350 Hall Ion Engine, SMART1

which operates on 1.4 kw from solar panels. Weighing only 367 kg (287 kg without propellant), it uses the solar-panels to operate the SNECMA PPS-1350 xenon ion engine to produce only 70 millinewtons of thrust. This is about the weight of a postcard. The engine makes use of an effect discovered by the American physicist E.H. Hall in 1879 whereby a current flowing across a magnetic field creates an electric field directed sideways to the current. This electric field is used to accelerate massive xenon atoms. The only inert gas heavier than xenon (radon) is radioactive, so that xenon, 131 times as dense as hydrogen, provides the largest safe reaction mass per coulomb of charge.

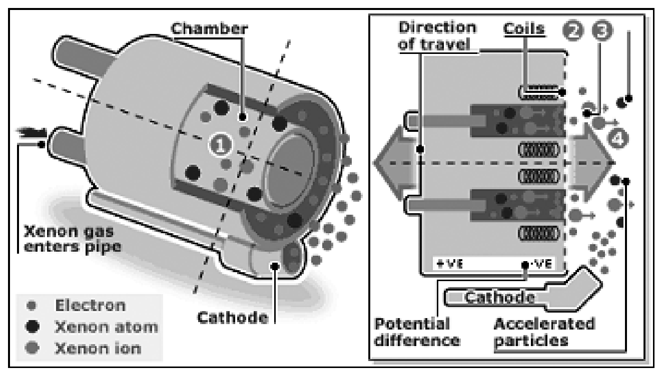
4.45 newtons equals a pound of force, so 70 millinewtons may seem like a miniscule amount- and it is. Acting on a probe between 367 kg and 287 kg, it results in an acceleration of about 2 meters per second faster every 10,000 seconds. So, once placed in orbit, the SMART-1 slowly gained velocity moving in an elliptical spiral until it finally was able to pass the L1 (Lagrangian 1) point, where the Earth's gravity was matched by the moon's. Then, it slowly spiraled into the moon.



SMART-1's 16-month circuitous Lunar voyage

The 80 kilograms of xenon occupied 60 liters at standard temperature and pressure. Each kilogram of propellant resulted in a change of velocity of 45 meters per second. This is a total impulse of 1.5 meganewton-seconds, a substantial amount for its mass.

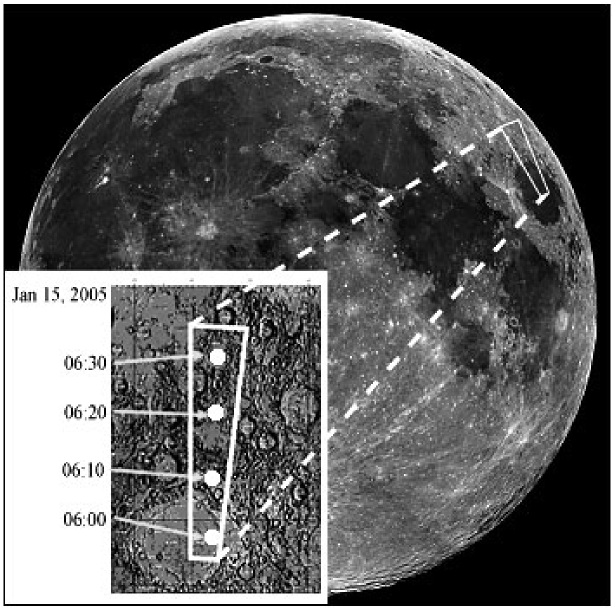
One measure of this achievement is that if one takes the total impulse and divides it by the weight of the spacecraft at the Earth's surface, one gets the specific impulse of the rocket motor. This is a measure of the engine's efficiency. For SMART-1 this was 1,640 seconds-or 16.1 kilonewton-seconds per kilogram. This is over three times the specific impulse of the most efficient practical chemical rocket engines. It is the highest specific impulse of any spacecraft to date.



Operation of Hall-Effect Ion Engine, SMART-1

The SMART-1 spacecraft was only a 1 meter cube when its solar panels were folded up. Unfolded, the solar panels stretch 14 meters. And it was cheap as lunar spacecraft go–the entire spacecraft and operation cost only 110,000,000 Euros. Further, it was a hitch-hiker, since the probe was piggybacked on a Ariane-5 launched from Kourou in French Guiana, which also launched Insat 3E and eBird1, two commercial communications satellites. The launch occurred on September 27, 2003.

The spacecraft took a long and circuitous route to the moon. 42 minutes after launch, the craft was released to a geostationary tranfer orbit of 7,035 x 42,223 km at 7 degrees inclination. The xenon ion engine was engaged and the craft began its slow



Calcium abundance in Mare Crisium by DCIXS

acceleration. It took 13 months just to get beyond the Earth's orbit.

SMART-1 had reached its last perigee on November 2, 2004. On its next apogee, November 11, it passed through the L1 point and was in the moon's gravitational influence, past a balancing point which is 90% of the distance from the Earth to the moon. It came to its first periselene (closest point to the moon) on Nov. 15 and began an ionic thrusting that would reduce its orbit so that it could comfortably orbit and image the moon.

SMART-1 carries the following instruments and experiments:

Electric Propulsion Diagnostic Package– EPDP is fed by a selection of sensors mounted on the outside of the spacecraft. It is designed to monitor the ion engine's effects on the spacecraft. Ion-engine technology can cause surface temperatures to rise and create unwanted electrical currents on the spacecraft.

Principal Investigator: Giovanni Noci, Laben Proel, Italy gnoci@webmail.laben.it; Scientific co-ordinator: José Gonzales, ESA Electric Propulsion Unit, ESTEC, Noordwijk, The Netherlands Jose.Gonzalez@esa.int

Spacecraft Potential, Electron and Dust Experiment–SPEDE consists of two electrical sensors mounted on the ends of 60-centimetre booms fixed to the outside of the spacecraft. They, too, monitor the effects of the solar-electric propulsion on the spacecraft. During SMART-1's cruise phase, the experiment mapped the plasma-density distribution around Earth and, when SMART-1 is in lunar orbit, it will study how the solar wind affects the moon.

Principal Investigator: Anssi Malkki, Finnish Meteorological Institute Helsinki, Finland Anssi.Malkki@ fmi.fi.

The experiment was built jointly by FMI (Helsinki, Finland), ESA/SSD (Noordwijk, The Netherlands), IRFU (Uppsala, Sweden), and KTH (Stockholm, Sweden).

X/Ka-band Telemetry and Telecommand Experiment–Using very sensitive receivers onboard the spacecraft, KaTE tests new digital radio communications technology. It demonstrates, for the first time on a science mission, the performance of a new higher range of communication frequencies in the X-


The Alpine Valley

Glushko crater

band (8 GHz) and Ka-band (32/34 GHz). It also tests new data encoding techniques (Turbo code) used to validate the corresponding ground-based infrastructure needed to receive these signals.

Principal investigator: Detlef Heuer, Astrium GmbH, Germany, in association with TTC and Radio Navigation Section, Electrical Department, ESTEC, Noordwijk, The Netherlands Detlef.Heuer@astrium-space.com

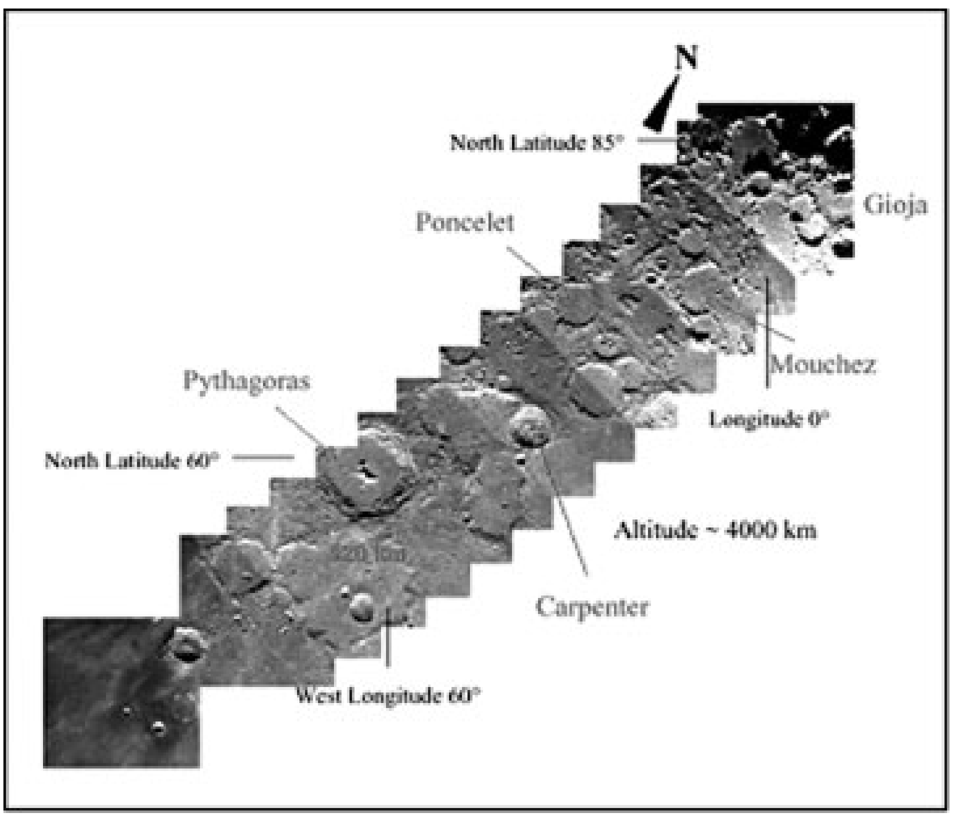
Radio Science Investigation with SMART-1 –RSIS uses KaTE and AMIE to perform a painstaking investigation into the way the moon wobbles. This is the first time a spacecraft in orbit has performed such an experiment. It is therefore an essential test for future missions, such as BepiColombo, that will investigate Einstein's Theory of Relativity.

Principal Investigator: Luciano Iess and Giovani Palmerini, University of Rome, Italy in association with TTC and Radio Navigation Section, Electrical Department, ESTEC, Noordwijk, The Netherlands iess@hermes.ing.uniroma1.it, g.palmerini@caspur.it

Laser Link Experiment–Demonstrating the use of a continuous laser beam to point a spacecraft from Earth for future communication purposes, it is the first European test of a laser connection between Earth and a spacecraft traveling at deep space distances. SMART-1 used the AMIE camera to spot the laser beam emitted by the ground station at Tenerife (Canaries Islands, Spain).

Principal Investigator: Zoran Sodnik, Senior Optical Engineer, Optics Section, Mechanical Systems Department, ESTEC, Noordwijk, The Netherlands Zoran.sodnik@esa.int

On-board Autonomous Navigation–OBAN uses AMIE (below) to gather images of celestial objects such as Earth, the moon, and asteroids, to work out exactly where SMART-1 is in space. This



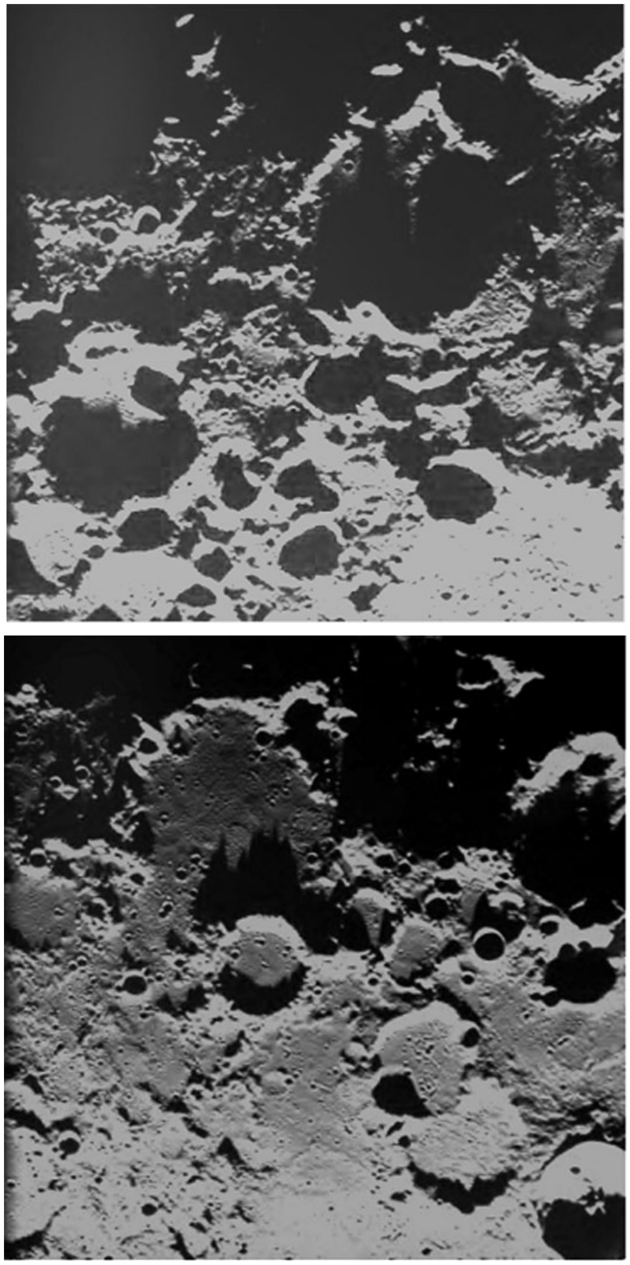
Typical pushbroom swath

is the first step towards a spacecraft that will be able to self-navigate.

Principal Investigator: Finn Ankersen, guidance, navigation and control analyst at ESTEC, Noordwijk, The Netherlands, in cooperation with the European Space Operations Centre (J. Fertig), ESOC in Darmstadt, Germany Finn.Ankersen@esa.int

Asteroid-Moon Micro-Imager Experiment–AMIE is a miniature camera capable of taking color images and storing them in memory. It can perform some automatic image processing. As well as imaging the moon, AMIE supports the Laser-Link experiment and OBAN and it will assist with RSIS.

AMIE's lunar images are used for educational and science communication as well.



Lunar South Pole (top) and Lunar North Pole (bottom) compared; the relief is much lower at the Lunar North Pole, so it is less likely lunar ices will be located there.

Principal Investigator: Jean-Luc Josset, Space-X, Centre Suisse d'Electronique et de Microtechnique (CSEM) in Neuchatel, Switzerland, leading a team from seven other European industrial or academic establishments. jean-luc.josset@space-x.ch

Infrared Exploration of the Lunar Surface–SIR will perform a detailed analysis of the moon's surface composition. It will provide greater insight into the processes of crater and maria formation and the phenomenon of "space weathering" on the moon's surface.

Principal Investigator: Uwe Keller, Max Planck Institute für Aeronomie, Germany. He is leading a consortium including Carl Zeiss, Jena and tec5, Frankfurt, Germany. Keller@linmpi.mpg.de

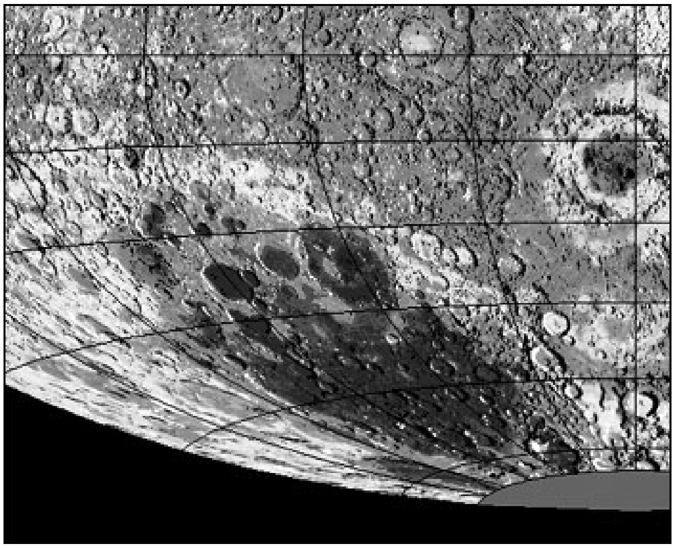
Demonstration of a Compact Imaging X-ray Spectrometer–D-CIXS will provide the first global map of the lunar surface's composition. Its observations will allow scientists to confirm theories on the evolution of lunar terrains and will provide clues to the origin of the moon. This is a test instrument for a similar investigation of Mercury using ESA's BepiColombo mission.

Principal Investigator: Manuel Grande, Rutherford Appleton Laboratory, United Kingdom m.grande@rl.ac.uk

X-ray Solar Monitor–XSM will monitor the Sun's output of X-rays so that solar storms do not confuse the results from D-CIXS and it will observe the Sun as an X-ray star during the cruise.

Principal Investigator: Juhani Huovelin, University of Helsinki Observatory, Finland huovelin@astro.helsinki.fi

The SMART-1 probe was tested long before it entered the moon's gravitational influence. On May 21, 2004 the 450 gram AIME camera was tested in the space environment by imaging Earth. A very good image was obtained near perigee June 17, 2004, and during a total lunar eclipse October 27, 2004. The probe then continued to its November,



Chemical Structure of Aiken Basin near S. Moon as determined by D-CIXS

2004 transfer to lunar gravity and began push-broom imaging of the lunar surface on January 26, 2005. It imaged the moon, also, as it approached in early and mid-November, 2004. Push-broom imaging is when the camera captures an area, like a push-broom captures an area on a floor to be swept, and then moves forward. This push broom imaging has been used by a number of space probes in the past and was the chosen mode for SMART-1.

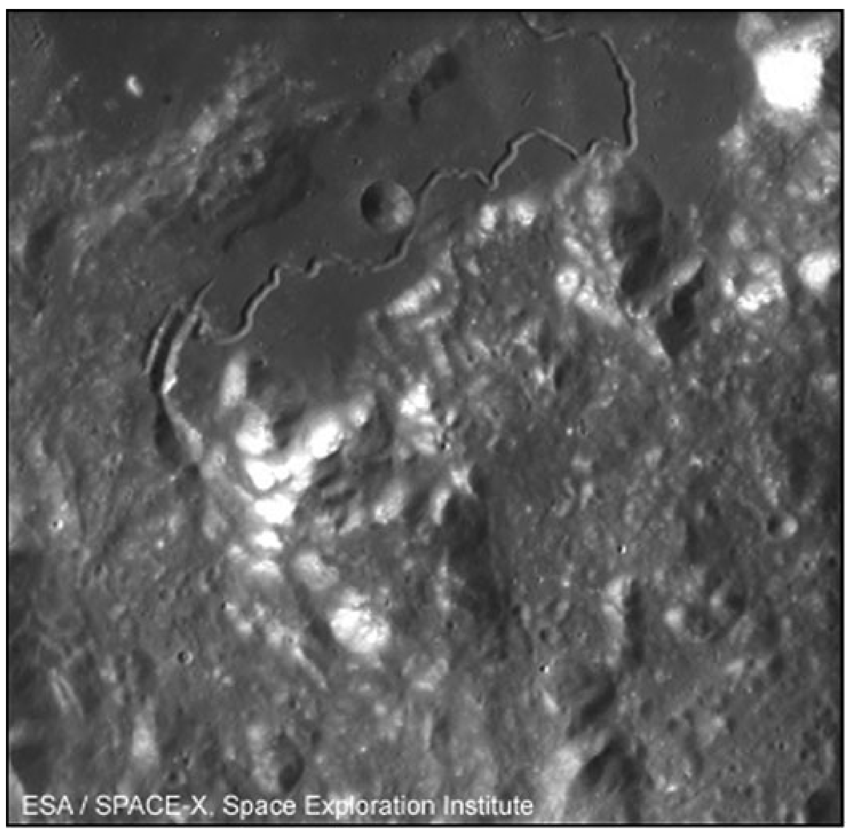
The X-Ray monitor, an auxilliary calibration device to D-CIXS, also began to return data on the solar environment. To prevent damage that might result from increased particle emission during a solar flare, the electronics of SMART-1 were "hardened" against radiation exposure and ionization.

D-CIXS also began imaging the moon in quest of its mineralogy. On January 15, 2005, calcium was detected in Mare Crisium and a map of calcium emission was obtained. One April 15, SMART-1 began its investigation of perpetually illuminated areas at the lunar poles (PELs: "Peaks of Eternal Light"). Such terrain can exist on moons and planets with low obliquity.

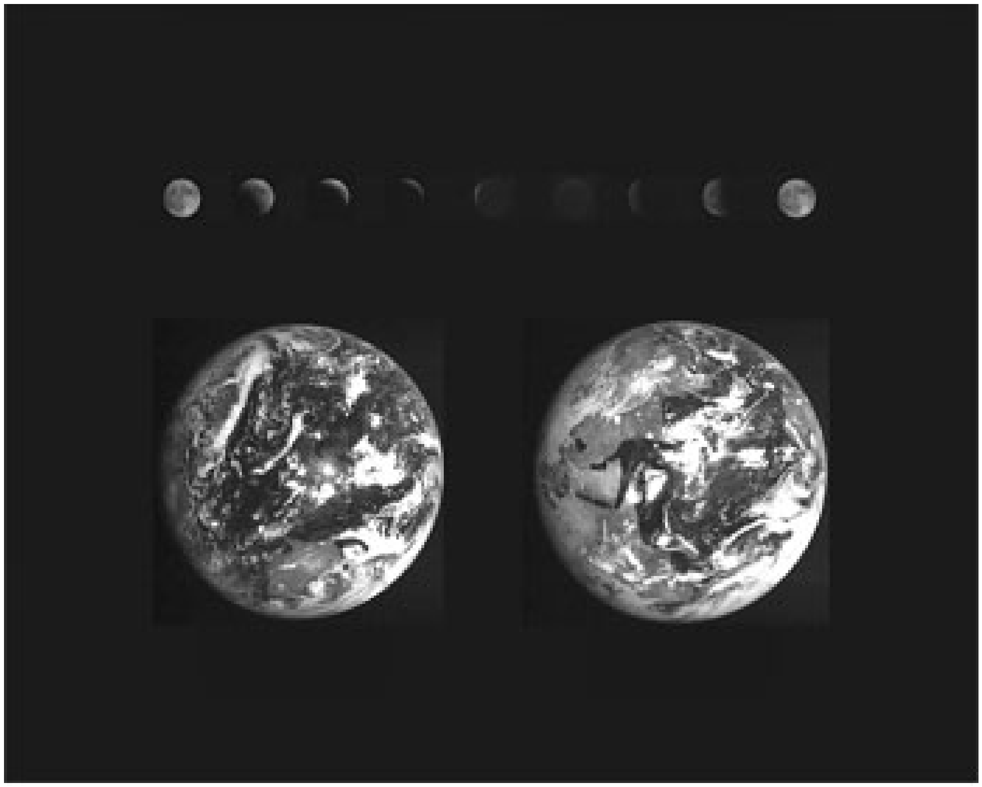
By the time it began a search for PELs, SMART-1 had settled into a final lunar orbit of apocenter distance 4471 km (Moon radius = 1738 km, so apolune is 2,733 km) pericenter distance = 2361.5 km (so the perilune is 623.5 km). Inclination of orbit: 90.4 degrees; Right ascension of ascending node: 238.2°; argument of perilune, 270.1°. 6.5 kilograms of hydrazine remained in the chemical boost fuel tank, and 260 grams of Xenon, of which 60 grams were useable.

Incredible images were obtained of many features on the moon: Glushko crater, the Alpine Valley, lunar crater chains, peaks of eternal light (More of them exist in the moon's south, where the so-called "Doerfel Mountains" meet the southern pole; the lunar north pole has much less topographical relief.), Pythagoras crater, Hadley Rille, and many other features.

By December, 2005, the SMART-1 probe slowly began changing its lunar orbit due to the gravitational effects of the Sun and Earth. By December, the craft had a perilune of 628 kilometers and an apolune of 2,728 km. The orbit henceforth would



Hadley Rille, last visited by Apollo 15 in 1971



Lunar eclipse as seen by SMART-1

decay, and the perilune would reduce, until about June 10, 2006 the perilune would be as low as 300 km with an inclination of 91°. The perilune would then be further reduced by gravitational forces until about August 17, 2006, when lunar impact would occur, if no further boosts are made. This impact would occur at latitude 37° south, and longitude 174°, on the lunar farside.

However as a final scientific experiment the European Space Agency, under the principal investigation of Bernard H. Foing, will make a final course correction and boost the spacecraft so that impact will occur on the lunar nearside, in view of Earth, on or about September 1. The 290-kg, empty SMART-1 spacecraft will impact he moon at about 2 km/s at a grazing angle of about 37 degrees south latitude. A large number of astronomers are preparing to observe it.

This will reduce much of the accompanying hydrazine fuel but the impact will still produce a considerable flash. The aluminum alloy that the spacecraft is made of will vaporize in the explosion and produce an aluminum emission line at 3961 Angstroms, within the broad Fraunhofer H line feature. Thus it should have no interference from Earthshine and be easily visible though modest telescopes/spectrometer configurations.

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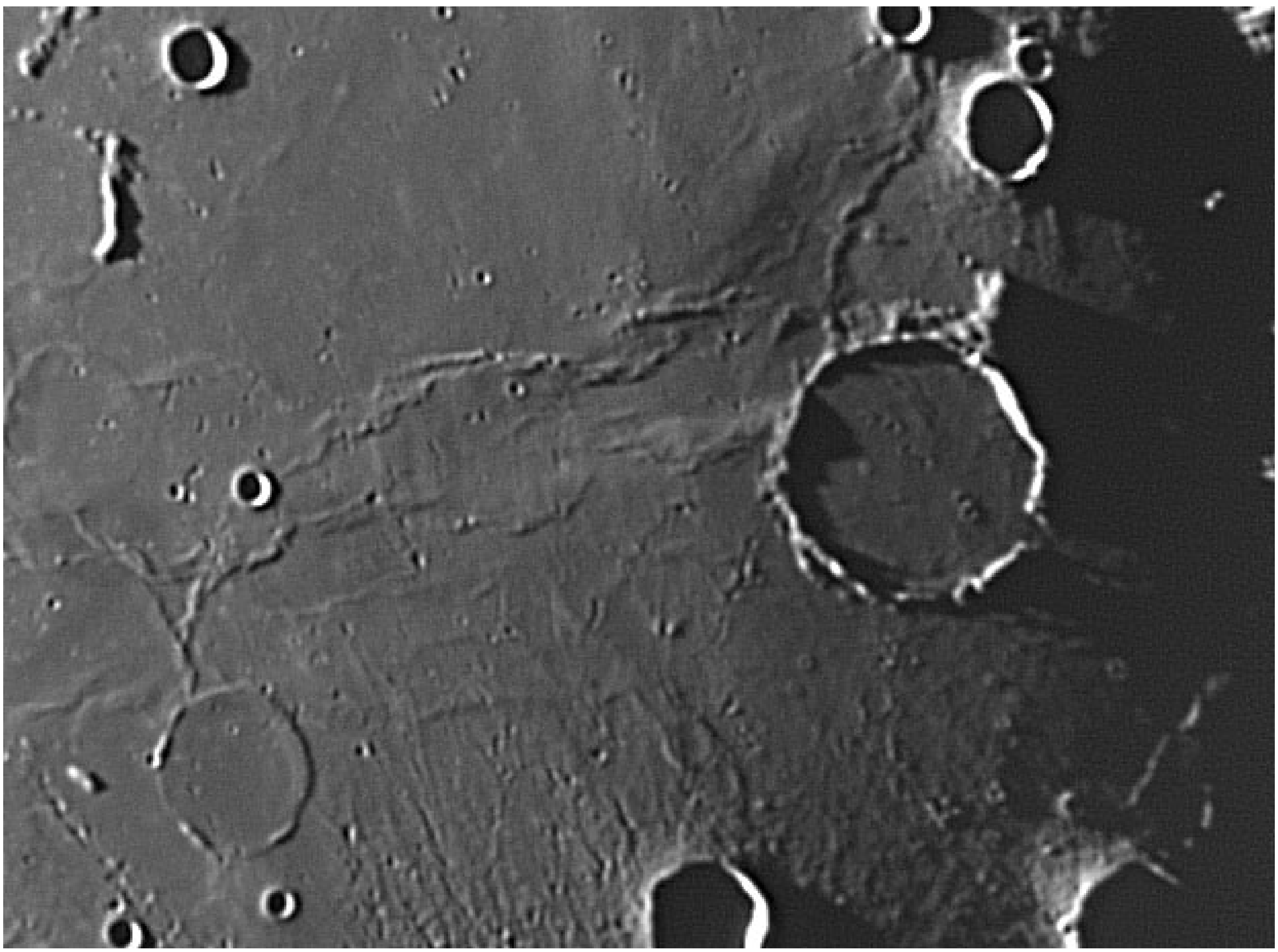
What fascinates you about the moon?

Have you examined the Clementine maps for the mineralogy and perused the scholarly literature for more clues about your favorite lunar feature? Share your information with *Selenology's* readers! Or maybe you have multiple photos or drawings of the feature as the shadows alternately reveal and hide its different facets. Let your series grace the pages of *Selenology!* Give your fellow readers the opportunity to wonder! While *Selenology* can't publish every submission it receives, we remain eager to publish the work of the American Lunar Society's members—**This Is Your Journal!**

Send article submissions to: fgraham@eliv.kent.edu.

Send drawings and photographs to: sboint0362@msn.com

Photograph By KC Pau
Hong Kong



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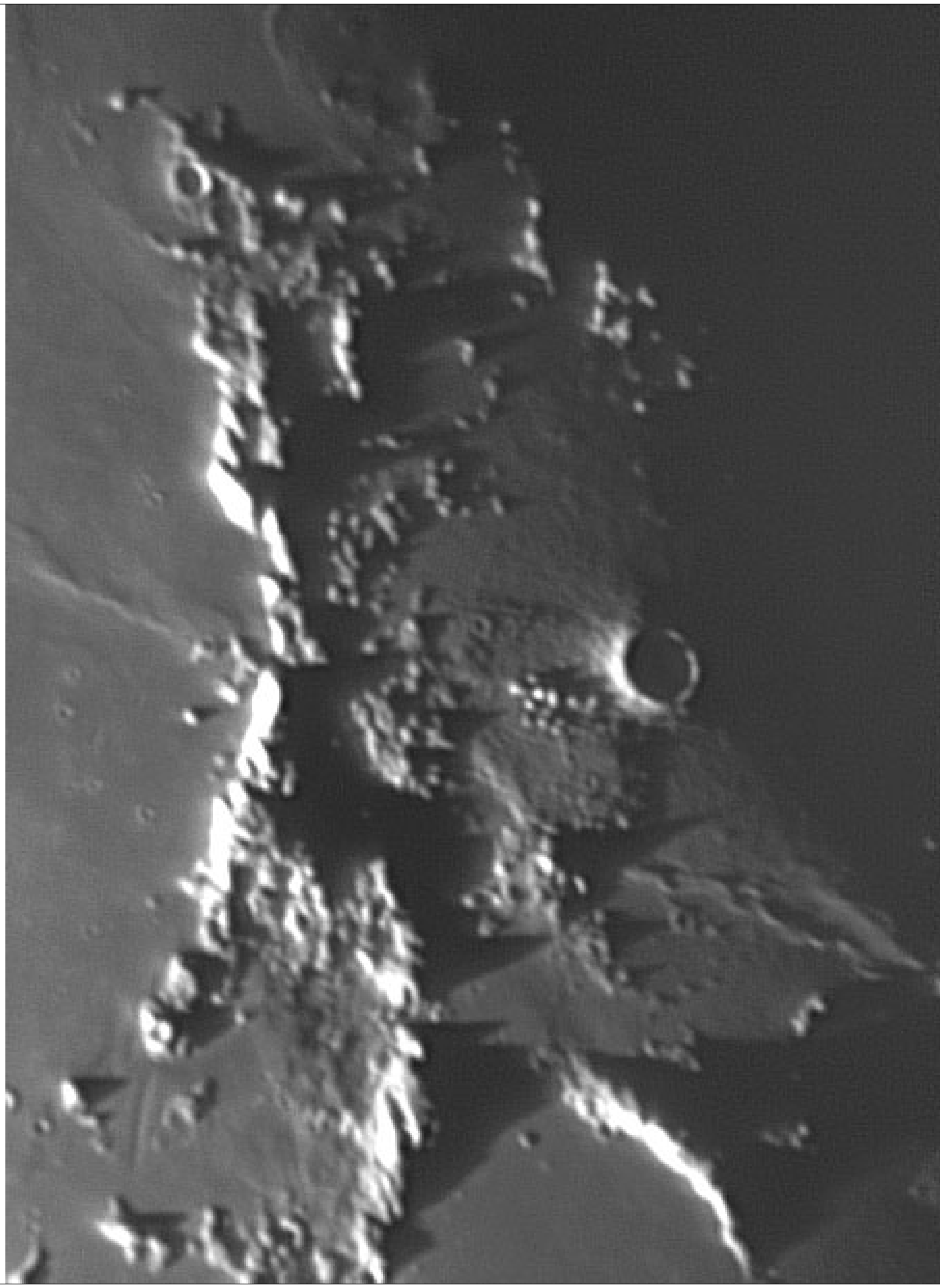
More Photographs By KC Pau

Hong Kong



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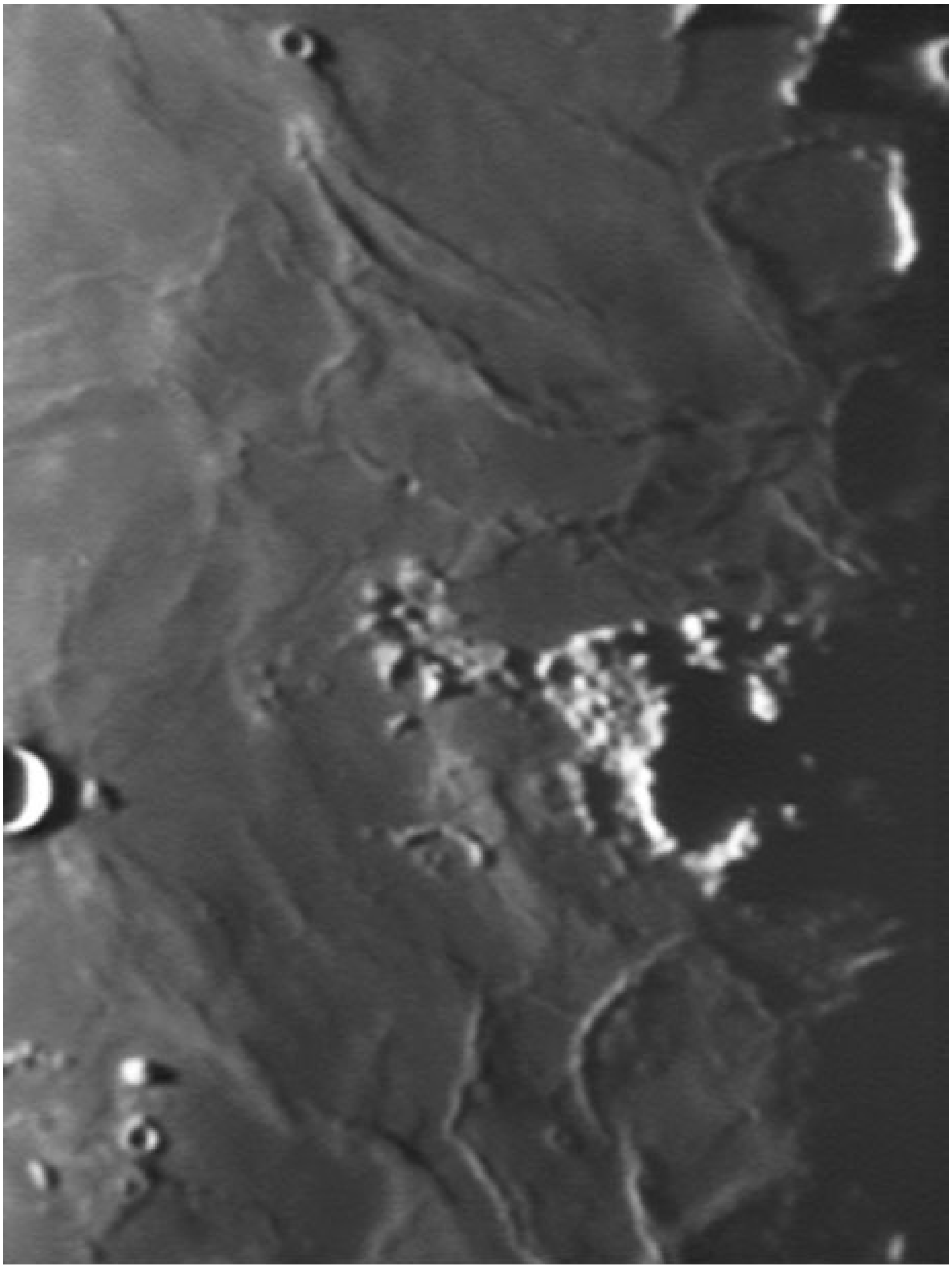

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ANNIVERSARY OF DISNEY'S MAN IN THE MOON

The year 2005 marks the fiftieth anniversary of an important milestone in space exploration: the production of Walt Disney's "Man in Space" series and the 1955 release of "Man in the Moon". These old films, televised on "Walt Disney Presents" on ABC at that time, were recently re-released on DVD as "Walt Disney Treasures: Tomorrowland, Disney in Space and Beyond."

Since California was not convenient for Pittsburghers in the 1950s, I never did visit Tomorrowland but I remember with great happiness watching these episodes on a black and white television with my grandfather in the 1950s. They excited me beyond all reason with the possibilities–indeed the promise-of the future to come. Coupled with the New York World's Fair of 1965-66, I eagerly anticipated the year 2000 where I would be in my prime years.

Vietnam and a host of economic, political and mismanagement disasters trashed that once glowing vision of a future. It is now 2005 and there is nobody on the Moon, nor have people visited Mars. It was difficult to imagine then that this would be the case. However, the technological revolution of the 1980's (the microchip) has, in many ways, redefined the direction of technological progress. Some futurists wrote of a post-nuclear war world that was straight back to the stone ages, but few imagined the world of today, a world where there is neither apocalyptic destruction nor a progress onward into outer space.

Dell Comics made an illustrated story of the Disney movie series "Man in Space" Copyright Dell Comics 1956.

I recommend watching these DVDs again, especially if you, like me, are of age enough to remember them. A promised future was not delivered; a check given was bounced. Was it all a circus act to begin with, just a promotional stunt for Disney's theme park? Or was there once a real promise and possibility for a much wider future than we now have? Watching these again will make you mad. Or make you sad. Or make you, paradoxically, wonder.

Stombecker's plastic assembly kit for the moon rocket RM-1 was based on the Disney Man to the Moon serial. Dr Werner von Braun was a technical advisor and appeared on the series, and, also, the RM-1 was to be the size of a V-2 (50 ft. long).

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BOOK REVIEWS:

FIRST MAN : THE LIFE OF NEIL A. ARMSTRONG

By James R. Hansen.
Simon and Schuster, 2005.

A biography of Neil Armstrong is due, now that all of the Apollo astronauts are retired or deceased, and the biography must go farther than the standard NASA public relations office blurbs. We had, with great compassion, followed Buzz Aldrin's Return to Earth and Jim Lovell's Lost Moon. But Armstrong has, of his own volition, remained enigmatic, almost hermitic; his autographs have soared in price. With the deftness of Greta Garbo, Armstrong's life has remained extremely private. Thus, with such a person, the mettle of the biography lies in how well the biographer has penetrated the seals of the vault of the soul of the unique first man on the moon.

Verdict: as a biography, it's pretty good. The author consulted all of the appropriate archives, private papers, and interviewed Neil and his family. It is a robust biographical sketch and a deserving book.

No biography should be a hagiography; it should reveal the faults as well as the glories of the man. This book presents the disorganized confusion that marked some of Armstrong's life and which resulted in his wife's suit for divorce. It does mention his association with RMI Titanium Corp. (he is a member of the board of directors) but does not mention RMI's shameful lockout of its long-time unionized employees. All in all, Hansen has done an excellent job.

WHO BUILT THE MOON?

By Christopher Knight and Alan Butler
Watkins Publishing, 2005

Don Wilson's *Our Mysterious Spaceship Moon* (1975) put out the absurd hypothesis (for 1975) that the Moon was a constructed spaceship. The hypothesis is repeated in *Who Built the Moon?* by Knight and Butler, showing that old pseudosciences never die. Mix neolithic monuments, extraterrestrials, out-of-context quotes from famous scientists, creationism, pyramid numerology and Daniken's god-astronauts and you have the incomprehensible melange that is this book. It omitted Raymond Bernard's *Hollow Earth* in the mix, and it is just as well(at least Bernard was comprehensible). This is a book which it seems the authors pained to finish writing. Imagine the agony that awaits to finish reading it.

EPPINGER CRATER DIS-NAMED

The lunar crater Eppinger has been de-named due to the discovery that its namesake was a Nazi war criminal. The International Astronomical Union's Working Group on Planetary System Nomenclature took this highly unusual step in view of the egregious nature of the Nazi war crimes and Eppinger's willing participation in them. There is no prior case of removal of an official designation due to the reputation of the person involved; the removal of the designation of "Soviet Mountains" was due to the understanding that the topographical feature, originally identified on grainy Luna 3 probe photos, did not exist when these areas were examined with more resolution.

Hans Eppinger was born in Prague in the Austro-Hungarian Empire in 1879. A cultural German, he obtained his medical degree and began an academic and professional career which was initially quite promising. After the first world war, when Prague became Czech, he emigrated to Germany, becoming a professor of anatomy and medicine at the Universities of Frieburg, Cologne and Vienna. He also, for a while, became a personal physician to Soviet premier Josef Stalin.

At the start of the Second World War, Eppinger returned to Germany and obtained work doing research for the Nazis. The Luftwaffe was urgently interested in survival limitations for its pilots shot down over the North Sea and the Kreigsmarine was interested in survival of sailors on the open sea. A number of scientific projects were hatched by the Luftwaffe which involved use of concentration camp inmates as nonconsenting subjects.

For example, Dr. Sigmund Rascher took Jewish concentration camp victims and placed them in freezing water in Dachau to see how long they would survive and what physiological changes would occur as they died. He used about 300 prisoners in these experiments. Rascher also placed Jewish prisoners in decompression chambers and simulated high altitude conditions without oxygen; he would often dissect subjects' brains while they were still alive.

Eppinger was concerned with downed pilots drinking salt water. He used about 90 Gypsy (Roma) prisoners at Dachau in 1942-44 and permitted them to drink only salt water. They became so utterly dehydrated they often licked the floor after it was mopped. Most died and those that did not were later executed.

Eppinger may have also participated in the experiments testing sulfa drugs as anti-infection agents for wounded soldiers. Jews were deliberately wounded to test the drugs.

Hans Eppinger survived the war but not for long. His devotion to the Nazi regime was too profound. On September 25, 1946, after learning that he would have to testify in Nuremberg against his former Nazi masters, Eppinger committed suicide by taking poison.

Not knowing of his background, on the basis of his earlier academic accomplishments, Eppinger was rewarded in 1976, on the 30th anniversary of his death, by the naming of a six-kilometer wide crater at lunar longitude 25.7 west, lunar latitude 9.4 south, in Mare Cognitum.

Eppinger's experiments came to light as cold war documents were declassified. Nazi experiments, with their military medicine application, were classified in the cold war to deny the data to the Soviets, who likely had them anyway. When the experiments came out, there was a controversy as to whether the Nazi data could be used and cited in scholarly research. For example, Robert Pozo of the Hypethermia Laboratory of the School of Medicine of the Unniversity of Minnesota in Duluth needed data from situations (beyond which he could expect informed consenting volunteers to survive) for the purpose of devising new methods of treatment for hypothermia victims. For example, was rapid warming or slow warming the best option, and under what conditions? A careful review of the whole controversy concluded that while some medical scholarship using Nazi data would save lives, the entire field of medical scholarship would be compromised in the long run if data from nonconsenting prisoners was admitted. In other words, data obtained inhumanely, if used, would taint medical scholarship itself as inhumane.

This is entirely in accord with recognizing what the Hadasic Jewish philosopher Martin Buber , in his book *I, Thou*, identified as the fountain of all evil: the willingness to use other people as mere objects stripped of their humanity. Medical science must have informed consent to use human test subjects and these standards are rigorously applied. Although there are grey areas (Does a poor person, who needs money to buy food for their baby and has no alternative, really make a free decision when they elect to become a medical test subject for money? Can a 16-year old give informed consent?) The principle is now firmly established that something like substantial informed consent must be given for human medical test subjects. This also applies to space medical experiments as well and many advances in space medicine must be made before lunar colonies become commonplace.

It was an American lunar interest group headquartered in New York, The Lunar Republic, which brought the Eppinger case to the attention of the IAU. The de-naming of Eppinger crater was championed by Vladislav Shevchenko of the IAU Lunar Task Group.

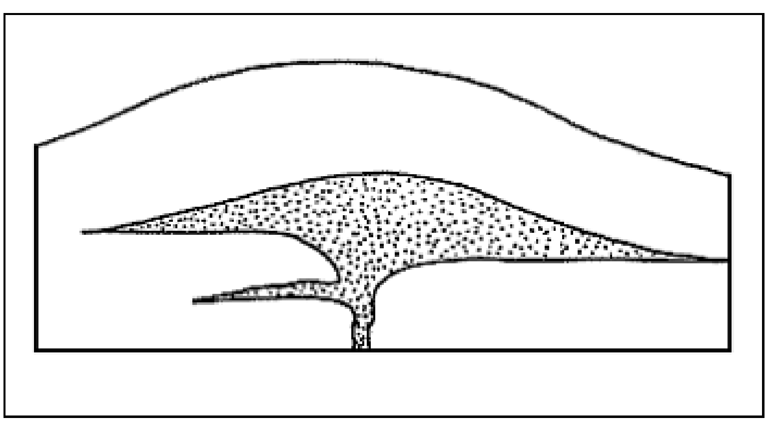
A Brief Overview of Lunar Domes: What They Are, How They Originate

By Zachary Brown

I: History of Lunar Domes

Most features on the moon are collectively a result of impact from debris in space, some form of geological activity, or a combination of the two. Lunar domes, though, are believed to be a result of volcanic activity many years ago. J. Westfall in his article "A generic classification of lunar domes", gives the following definition of these lunar formations: "A discrete, regular swelling whose ratio of major axis:minor axis, when corrected for foreshortening, does not exceed 2:1, and whose maximum slope, not including secondary features, does not exceed 5°. Under high illumination, domes are indistinguishable from their surroundings. Domes may exhibit secondary features, such as pits, clefts, ridges, and hills, as long as any single such feature does not occupy more than a quarter of the area of the dome."[1] This excerpt from Westfall's literature has been accepted by most lunar societies as the official definition of a lunar dome. However, it should be noted that some domes do not meet the aforementioned criteria for the second feature. These can be found particularly in the Mare Orientale-Lacus Veris region.

Although lunar domes have more than likely been around for centuries, they were not observed until the 1900's. Even though the moon was once the most observed object in the night sky (since it is the largest, closest, and most visible), astronomers were so fascinated by more obvious features of the moon that they overlooked miniscule features like the lunar domes. Astronomers often mistook them for clouds because their shadow simply vanished as the night went on.



Magma forcing the surface into a dome-like shape

Once observers started to take notice of lunar domes, they automatically assumed them to be very rare features; they were rather easy to miss. Because they are so small, they lack large enough shadows to readily reveal details equivalent to those of other formations on the moon. Therefore, the domes must be viewed when near the terminator (boundary between the sunlit and dark parts of the moon) to give an optimal shadow and useful observation.

As more thorough observations were performed throughout the 1960s and 1970s, it became very clear that these domes were much more common than once believed. The lunar orbiter photographs of today actually show that lunar domes are among the most bountiful features of the moon. Hundreds have been catalogued to date.

II: Formation, Physical Origin, and Geology of Lunar Domes

Although it's not stated in actual definitions of lunar domes, they are formations with a volcanic origin. They are generally a result of a flow of lava to a central point, pushing up the surface of the moon, as shown.

The idea that domes are volcanically formed is supported by their distribution and location. They are most prominent in areas surrounding the Maria and on floors of large craters. The Maria, themselves, were formed by eruptions of basaltic lava at the site of meteoroid impacts.

The domes are composed of basaltic material which is very fluid, giving very low-profile "shield-like" features. A basaltic magma should not accumulate and build pressure but instead should flow for long distances. The only plausible explanation, in the absence of geological samples of the domes, is that the domes were erupted at lower temperatures, or had a higher volume fraction of crystals, or a combination of the two, which would cause much higher viscosities than usual. Different effusion rates and magmatic differentiation may also have contributed to an increase of viscosity in the lava that formed the lunar domes

III: Categorization of Lunar Domes

Although the word "shield" in volcanology would more appropriately define these objects, the word "dome" has been used in their classification and widely accepted by lunar groups because the formation of domes differs greatly from that of the Earth-bound shields, as does their geological composition.

Lunar domes can be generically placed into two categories. The first category deals with low, relatively flat-topped, smooth, circular domes with some summit craters and slopes of no more than one to three degrees and having smaller craterlets. The second category deals with high standing islands of terrain. These appear more "hill-like", showing more detail. Some within this second group do not have summit crater pits, leading to the idea their creation is of a different origin.

Lunar domes are also more specifically categorized into seven classes. These classes have been defined by James Head and Ann Gifford, who studied and categorized nearly 200 pre-existing, individual lunar domes, in their publications on the moon and other planets. The categories are as follows:

Classes 1, 2, 3 refer to volcanic features resembling terrestrial shields.

Class 4 refers to dome-like features associated with ridges and mare arches. Because of the complex topography of ridge/arch, it is not certain if this class represents a dome type.

Class 5 includes domes that originated from lava mantling of pre-existing highland topography.

Class 6 includes domes with higher albedo than mare material and steeper slopes compared with ordinary domes.

Class 7 are complex maria domes with irregular outline and topography (i.e. Marius Hills).

Classes 1, 2, 3 and 7 are in most cases the direct result of volcanic activity. Classes 5 and 6 are the result of the draping of pre-existing topography (secondary volcanic effects such as flooding of highland material and draping of lavas to produce irregular dome-like topography). Class 4 structures are mainly associated with mare ridges. [2]

Nearly 700 domes have been found, verified, and catalogued in the short time since they were first deemed important in the mid 1900s and more are discovered regularly. Keep in mind, this is only on the side of the moon visible to us! It is a mystery how many may lie on the farside of the moon.

IV: Lunar Domes And The Farside

The International Farside Lunar Domes Survey (FLDS) is a combined project effort of the American Lunar Society (ALS) and the Geologic Lunar Research group (GLR) . With the United States Geological Survey digitalizing all the images of the farside of the moon at a high resolution, it will become possible to document and categorize domes on the opposite side of the moon. [3] This will be a project of extended duration. FLDS has two main goals:

1. To classify structures according to their morphologic characteristics.

2. To gather data on associated features in order to provide information on their origin and to understand the geologic setting of domes. [3]

Already this project has led to the interesting discovery of several domes on the farside. In addition, the ALS and GLR groups have identified several dome volcanic features. The characteristics identified in the survey were originally published in Selenology as the following:

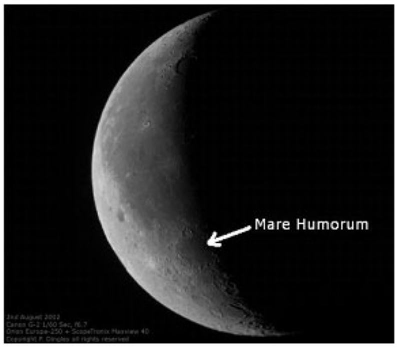
A) They have a flat summit and a generally irregular outline.

B) The flat summit and irregular outline are more abundant in the Orientale-Lacus Veris region than elsewhere on the nearside;

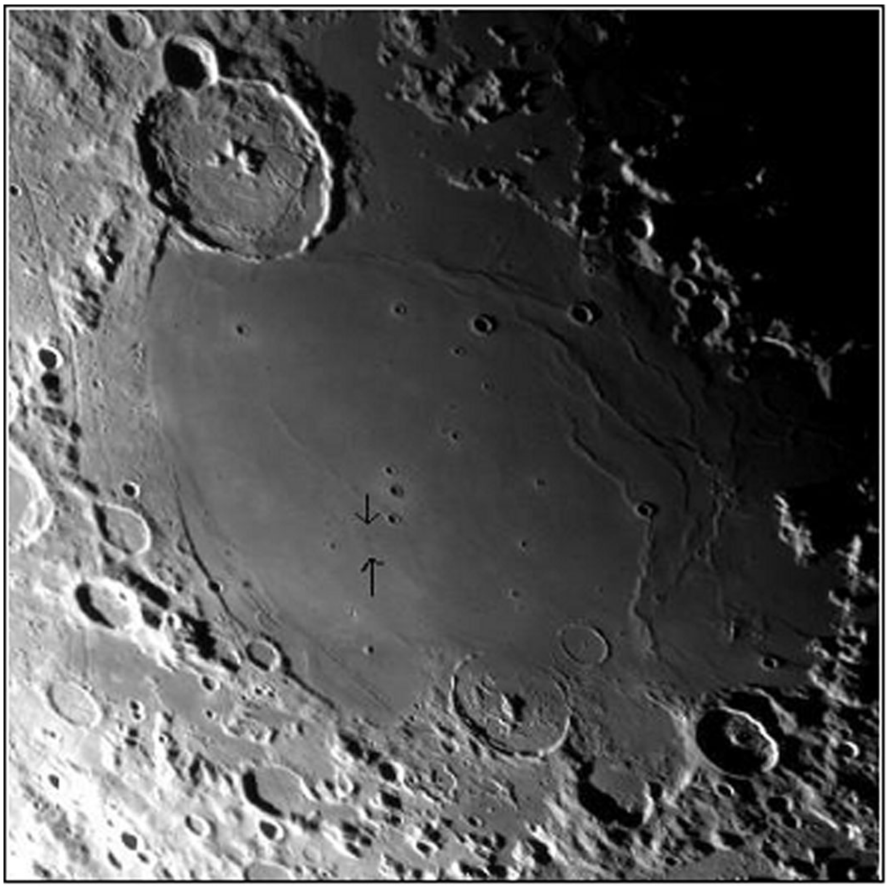
C) Most of them represent examples of swelling or may be non-swelling high-lava remnants.

D) The described domes (Table 1) [sic] refer to Class 2 in the Head classification system. Domes of Class 2 are similar to Class 1 but with a pancake-like cross-sectional outline, having a penchant toward flat tops and steeper sides. They range from 6.0 to 16.0 km in diameter. 73% of these domes have summit craters. [3]

Over time, this study hopes to show the lunar



Dome in Mare Humorum near Gassendi crater



community that it is possible to find more domes or similar objects on the farside of the moon. Also, it has found that lunar domes on the farside are much lower features than those on the nearside. More data will help determine whether or not this is a characteristic of all lunar domes on the farside of the moon.

V: Amateur Observing, How-To, and Personal Observations

Anyone with the drive, determination and equipment can contribute to the discovery and morphological categorization of lunar domes. It is possible to acquire digital images of the moon through NASA or other research groups. With these, you may carefully study the moon and its features for longer periods of time. Live study of lunar domes is also possible for individuals with telescopes having an aperture of at least 4 inches. Although resolution is limited for earth-bound telescopes, the largest catalogues of lunar domes to date have been done by amateur organizations like the Association of Lunar and Planetary Observers. Although these catalogues may be lacking in precise measurement and location of the domes, they are sufficient and are constantly being revised for accuracy.

Observational data such as location, size, details, sketches, and photographs are some of the most valuable contributions that anyone, particularly amateurs, can give to the astronomical community. With a relatively decent sized scope, one can see some impressive domes. Drawings can be useful, but are subjective as each persons perspective may differ. Photographs, on the other hand, provide a more detailed view, although even under ideal conditions, the pictures are not of as high a resolution as the eye itself.

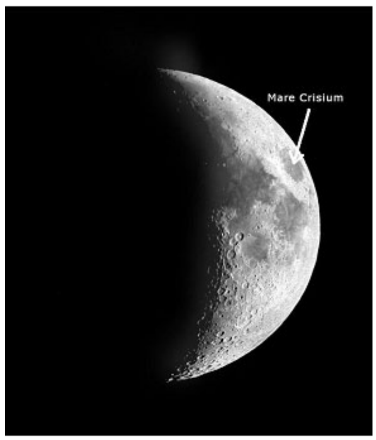
Personally, I own a Meade LX90 Ultra High Transmission 8" Schmidt-Cassegrain telescope. During my first observation, on the early morning of November 28th, 2005, with a 9mm eyepiece and poor seeing conditions, on the waning crescent I could see a group of domes, specifically visible in the southernmost portion of the moon, near Mare Humorum, where multitudes of craters are condensed . The domes most visible were those that appeared near the floors of the Maria. The terminator helped in casting shadows of the miniscule domes. They were very low in profile and nearly invisible without extended lengths of observation (and particularly difficult if your scope is not tracking them mechanically). As the terminator moved in on them with the waning crescent, they became easier to spot, but only briefly as the shadow overtook them. Although personal photographs of these could not be taken, due to technical conditions, here are similar observations:

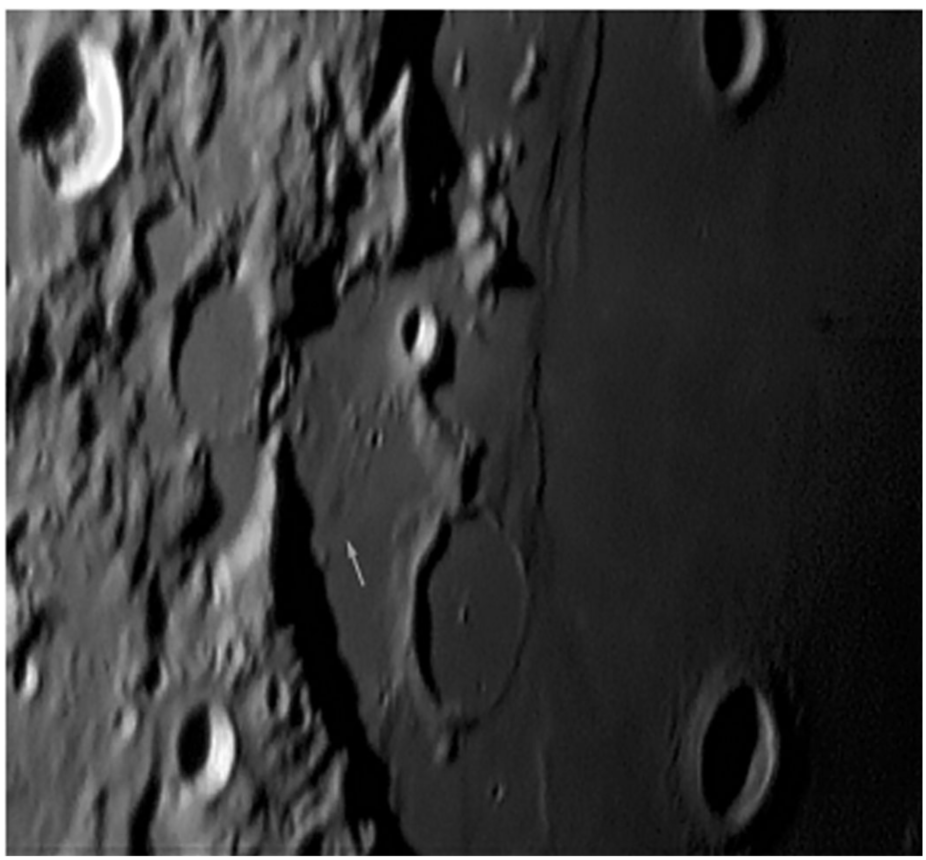
"The dome, itself, is located northwest of theYerkes crater and is inconspicuous when looked at briefly. The dome is very difficult to spot, even with the naked eye. Since the terminator was days past it and this was the first clear night my area had received in weeks, simply finding the dome proved difficult. Yerkes is a very apparent crater, though, and with very high resolution pictures and some patience I saw the dome several times and managed to snap a photograph of the area in which it lies with my new Lunar and Planetary Imager. Because the image is not magnified as much as it could be, nor as clear because the camera wouldn't focus correctly, I could only get the magnification of about a 6mm eyepiece to result in a clear image."

VI: Conclusion

Lunar domes, compared to other lunar features and astronomical objects, are only in the earliest stages of research. They are an interesting, overlooked feature of the moon's surface. The domes catalogued, and those yet to be discovered, could mean very important things to the lunar community. They are of volcanic origin which suggests these structures could hold our moon's deepest and most ancient geological secrets. How and when they were formed remains uncertain and, to my knowledge, there is no physical sample of one to date. With patience, hard work, and a little research, we could unlock the mystery of these domes and discover even more about them and the moon as a whole. Like astronomers of the past, the telescope was not just a tool to see through, but something else: a key to unlocking the secrets of our own planet, moon, and so much more. So, if you or someone else you know has the time and the equipment, dust off that scope, grab something to write with and get ready to look at the fascinating structure that is the lunar dome.

Dome, located above and left of the crater Yerkes.
Photo from Selenology





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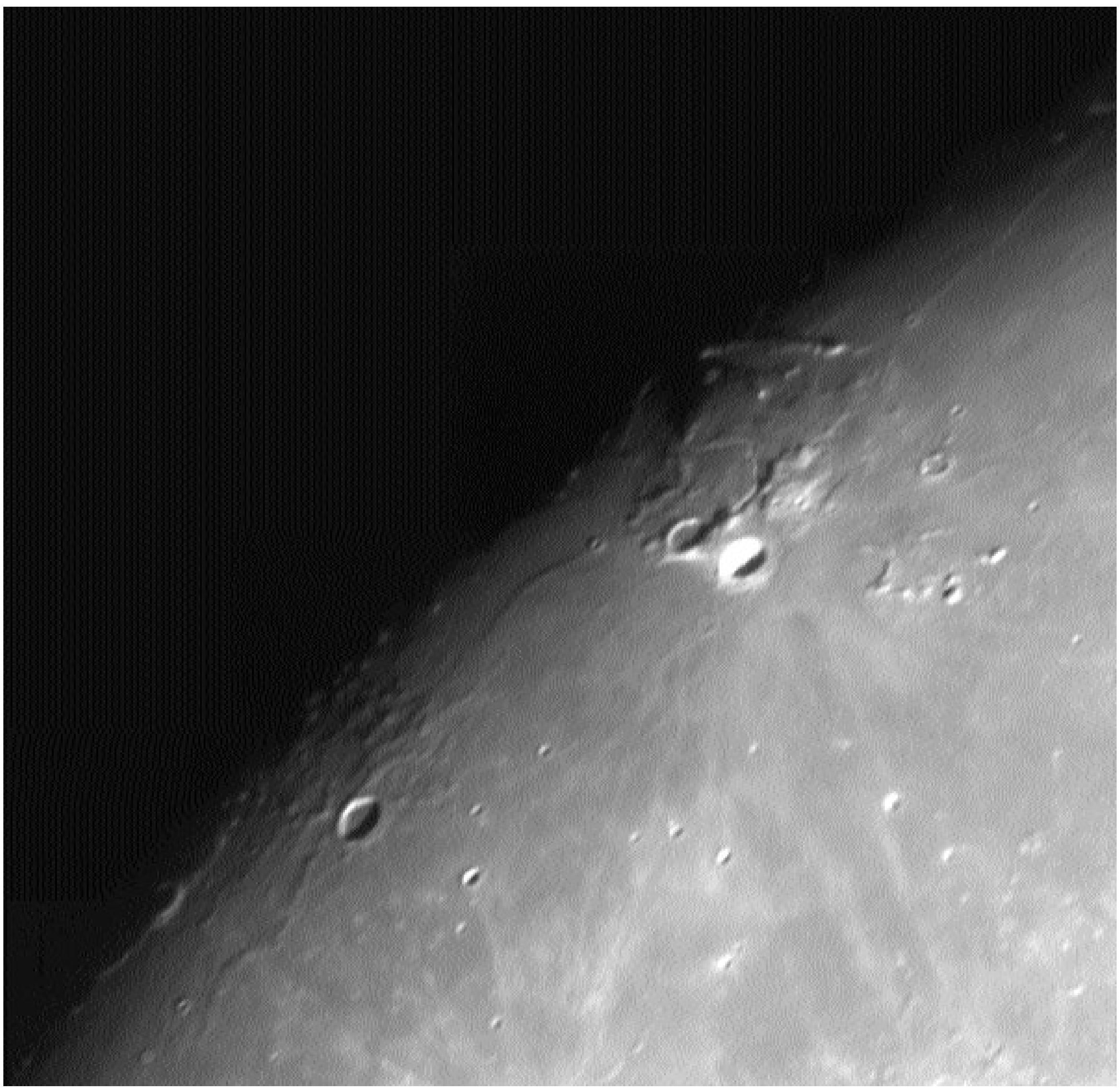
Aristarchus Plateau

By Steve Boint, Sioux Falls



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