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The 44th Lunar and Planetary Science Conference (LPSC)

Dr. Larry Jay Friesen, Wes Kelly and Shen Ge

Also, Continuing in this Issue! Part 5 of 8

Man Will Conquer Space Soon!

(Collier's 1952-54)

Near the top of every page is an invisible link to return to this page.
The link is in located here (the blue bar), but not all pages display this bar.

March / April 2013
Horizons, Newsletter of AIAA Houston Section

TABLE OF CONTENTS

From the Chair 3

From the Editor 4

The 44th Lunar and Planetary Science Conference 5

Near-Earth Objects in Earth-Like Orbits, by Daniel R. Adamo 17

The “Horseshoe” Orbit of Near-Earth Object 2013 BS$_{45}$, by Adamo 20

Cranium Cruncher, by Douglas Yazell 26

A 3AF MP Editorial First Published in La Gazette #26, by Philippe Mairet 27

Chelyabinsk Bolide Trajectory Reconstruction, by Daniel R. Adamo 28

Clear Creek High School and NASA’s HUNCH, with Mr. Robin Merritt 30

Current Events including NASA Curiosity Update, by Dr. Dorothy Oehler 32

Times are Tough!, by Philippe Mairet, 3AF MP 33

The 1940 Air Terminal Museum, An AIAA Historic Aerospace Site 34

The Experimental Aviation Association (EAA) Chapter 12 (Houston) 35

Climate Change and Local Responses, by Douglas Yazell 36

The Johnson Space Center (JSC) Astronomical Society (JSCAS) 37

Calendar 38

Section News 39

Section News: Wayne Hale dinner meeting & Guy Thibodaux 1969 Address 44

Our History Technical Committee’s Audiobook Project, by Ted Kenny 49

Student Section News: Rice University 50

Student Section News: Texas A&M University 51

The Collier’s Series, Man Will Conquer Space Soon! (1952-1954) 52

San Antonio and the Genesis of the Collier’s Series, by Colin Davey 54

The 1957 Encounter: Robert A. Heinlein & Albert A. Jackson IV 56

March 7, 1953, Man’s Survival in Space, Testing the Men (Collier’s) 60

The Back Cover: Photographs of the late James C. McLane, Jr. 74

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Cover: Two photographs of speakers at the 44th Lunar and Planetary Science Conference of March 18-22, 2013, at the Woodlands near Houston, Texas. Left: Dr. Lindy Elkins-Tanton delivering the Masursky lecture. Right: R. Aileen Yingst. Image credits: Douglas Yazell. Table of contents page: part of Vincent van Gogh’s 1889 painting The Starry Night.

The 44th Lunar & Planetary Science Conference

Cover Story

DR. LARRY JAY FRIESEN, WES KELLY AND SHEN GE

Where should one begin discussion of a multi-world trade fair, the 44th Lunar and Planetary Science Conference (LPSC), held in the Houston-area Woodlands Marriott Convention Center 18-22 March 2013? Let's start with the first day plenary session featuring the Masursky memorial lecture, "On Building an Earth-Like Planet," by Dr. Lindy Elkins-Tanton, Director of the Department of Terrestrial Magnetism at the Carnegie Institute for Science.

The conference guide to oral and poster presentations provides one or two sentences for each of 2,000 papers. All are available online as two-page abstracts (www.lpi.usra.edu/meetings/lpsc2013).

Elkins-Tanton's new paper **[#1408]** says, "Magma ocean processes on planetesimals and planets control the earliest compositional and volatile content of the terrestrial planets." Listening to Elkins-Tanton at this year's plenary session, we observe the timeline of events close to the Earth's formation are noted to three decimal point precision in the period from 4 to 4.6 billion years ago. Yet, the role of cometary collisions with Earth in the Late Heavy Bombardment period (LHB – see Glossary) is greatly reduced or revised to explain the supply of "volatile" materials such as water and carbon compounds. Hydrogen and carbon within the earth's interior and magma ocean, it is reasoned, were eventually released as the early heated atmosphere; this, in part, precipitated into early oceans and lakes.

This thesis could mean giving up a popular idea for supplying water to early Earth, the idea of late addition of water to Earth by comets, because comets are not a good match for Earth's deuterium-to-hydrogen isotopic abundance ratio, nor do comets match Earth's ratio of nitrogen isotopes. For this late addition argument to hold, we need asteroids made of rocky materials, plus retention of enough water and other volatiles during accretion impacts. In principle, a water ocean could have been produced with very little initial water (Compare the depth of Earth's oceans with the thickness of the mantle.), but there is not full understanding of what happens to water in a magma ocean (a layer of molten rock thought to have covered early Earth). The take-home message is that any terrestrial planet should start with a water ocean early in its formation.

Whether this is a majority consensus, we hesitate to say, except that evidence or argument for this scenario appears throughout papers presented in LPSC 44, some in collaboration with Elkins-Tanton. But there are arguments and data sets causing one to wonder where the matter will finally rest. Also, there are findings in sessions about planetary formation processes in other star systems. These findings place the formation of Earth and our other solar system's planets in a larger context with other possible outcomes. Thus, an increasingly clear picture of planetary formation processes emerges. That picture is based on

- Field findings from planets, meteorites and asteroids,
- Better instrumentation in labs, and
- Data from and modeling of solar system and extrasolar planets.

This picture is made even clearer by exhaustive debate that frequently revises much of this never-to-be-finished mosaic.

Magma (from Greek word for "mixture") is a mixture of molten or semi-molten rock, volatiles and solids found beneath the surface of the Earth. Clearly, its presence and composition across space and time beneath planetary, lunar and asteroid surfaces are features of much debate, as session paper abstracts show. Separation of the magma into layers of rock rich in silicates, metals, carbonates or water is discussed in detail by geologists.

After decades of conferences since the lunar landings, there is now increased concern with volatiles: compositions of atmospheres and fluid reservoirs, and origins of water.

We identified lakes, oceans and glaciers on several planets and moons in our solar system, and we find traces and inferred histories of lakes, oceans and glaciers on planets and moons beyond our solar system. All lakes, oceans and glaciers disappeared on Mars and Venus. Current research interests are often

- The origins of life on this world,
- Habitability (perhaps for astronauts) earlier or now on other solar system bod-

(Continued on page 6)

Above: The help desk on Sunday, March 17, 2013. Image credit: LPSC royalty-free images.

Cover Story

(Continued from page 5)

ies, and

- The prospect that extrasolar planets could provide parallel-Earth examples (such as Thursday's session, **Planetary Atmospheres: Exoplanets [R452]**).

This is not to say that the conference is unconcerned with many other aerospace issues. Descriptions of planetary and lunar environments affect the design of future spacecraft. The conference is also a treasure trough of data on existing spacecraft performance, operations, payload sets and proposals for new spacecraft missions. Whether proposals are presented in oral or poster format, it is clear that the submissions were already connected to a legacy of previous conferences. It is also clear that future proposals will be shaped by this year's scientific and operational reports.

Historical Notes

The March 18, 2013, afternoon lecture **[M151]** is named for pioneer space geologist and astronomer Dr. Harold Masursky (1922-1990). In the NASA Apollo program years, Masursky led lunar and planetary surface survey teams and landing site selection groups. He helped monitor and guide the 1969 Moon landing and analyzed the data afterwards. Looking to Mars, he led the1971 Mariner 9 Mars observing team and the selection of the 1976 Mars Viking lander sites. Masursky regularly visited Houston during his career. Many here remember him from work, conferences, or his sharing of scientific findings with television audiences. One of us (Wes Kelly) last saw him with students and coworkers at a Houston Clear Lake area Indian restaurant on Upper Bay Road during a late 1980s LPSC.

The first of these conferences took place in 1970. It was called the Lunar Science Conference (LSC). The eighth conference was the first to use the new name, the Lunar and Planetary Science Conference (LPSC). The 1970 LSC took place at NASA Johnson Space Center (JSC) and the newly formed Lunar Science Institute (LSI) in the former James Marion West plantation house east of JSC on the NASA Parkway. Some of those earliest conferences (1971 and others) took place in a downtown Houston convention center which no longer exists.

As scope of lunar and planetary science studies increased, with more varied missions and international participation, the gatherings grew from hundreds to thousands of presenters and participants. New and larger venues near JSC subsequently served as hosts, including a hotel in South Shore Harbor.

LPSC proceedings were once three-volume sets resembling Houston's yellow pages. A compact disk (CD) version arrived in 2005. The memory stick issued to 2013 attendees contains 2,087 abstracts and 750 megabytes of data. Abstracts are also available online at the Houston Clear Lake area Lunar and Planetary Science Institute (LPI) web site. This report will mention and link to some of those abstracts. The author list, though not all were in attendance, exceeds 7,000 names. Among "non-attendees," as Table 1 indicates, is the extensive fleet of robotic spacecraft exploring planets, moons, comets and asteroids. These spacecraft made this flurry of Woodlands activities possible.

Early Sessions and Papers

To illustrate the structure and depth of LPSC 44, Monday morning's first-day (March 18, 2013) sessions began with four simultaneous sessions of oral presentations prior to Dr. Elkins-Tanton's talk:

- **Planetary Differentiation across the Solar System [M101]**; the first of several special sessions devoted to

(Continued on page 7)

Table-1 Lunar and Planetary Science Mission Sources for 44th LPSC Papers

Spacecraft	Target(s)	Activity Period
Cassini	Saturn, Titan, Enceladus & other satellites	Current
Curiosity / Mars Science Lab	Mars	Current
Messenger	Mercury	Ongoing
Bepi-Columbo	Mercury	Preparation
Dawn	Asteroid Vesta (en route to Ceres)	Current
LRO (Lunar Reconnaissance Orbiter)	Moon	Complete*
GRAIL (Gravity Recovery and Interior Laboratory)	Moon	Complete**
Selene	Moon	Complete
Chang'e 1	Moon	Complete
Chane'e 2	Moon, Asteroid 4172 Toutatis***	Current
Selene / Kaguya	Moon	Complete
Hayabusa-1	Asteroid Itokawa	Complete
Phoenix	Mars	Complete
Mars Exploration Rover (Opportunity)	Mars	Current (at Endeavour Crater)
Stardust	Comet Wild	Complete
Genesis	Solar wind	Complete

* Apollo mission data contributed to many reports.
** Vehicles guided to crash on lunar surface
*** Earth-Sun L2 Lagrangian point, also

(Continued from page 6)

the Mars Science Laboratory (MSL) Curiosity rover results,

- **Geology and Environment [M102]**,
- **Lunar Remote Sensing [M103]**, devoted to results from several recent lunar orbiters, and
- **Early Solar System Chronology [M104]**, derived from isotopic ratios obtained from geological field sites and meteorites. The afternoon sessions were devoted to planetary characterization:
- **Cartography [M152]**,
- **Volcanism in the Solar System [M154]**,
- **Dynamics and Tectonics [M155]**,
- **From Dust to Planetary Disks [M156]** (early formation stages) and
- **Soils and Rocks [M153]**, more about the MSL results.

The evening included a NASA briefing on future plans. Press briefings highlighted particular discoveries or reports.

Starting with the Monday morning MSL session Project Scientist Dr. John Grotzinger presented a broad survey of Curiosity's activities with instruments for the first 100 Martian days, or sols (about 24.5 hours per sol), since the landing of August 5, 2012. The vehicle has an expected drive capability of 20 kilometers with a payload of 11 cameras, spectrometers, and digging tools as chemical analyzers. The names of the principal instruments are listed below. Session papers providing more detailed discussions of their 100-sol findings are indicated by catalog number.

- SAM: a gas chromatograph -mass spectrometer to search for carbon in rock
- CheMin: an X-ray diffraction meter to identify mineral type (#1365, #2781)
- Mastcam & MAHLI cameras (#1617)
- APXS: an alpha particle X-ray spectrometer for in situ soil chemical analysis
- ChemCam: a laser breakdown spectrometer (#1267) for rock and mineral chemical composition
- DAN: an active neutron spectrometer
- REMS: the Mars "weather station" (#1548, #1625)
- RAD: background solar radiation monitor

Amid this summary of 100-sol findings Grotzinger declared that geological evidence of ancient water (clays) indicated relatively neutral pH levels, low salinity and some carbon, present in crystalline forms.

Contemporary Martian surface features are the main concern of the session described above. Elsewhere, at the **Differentiation session [M101]**, planetary theoretical models dig deeper, searching sometimes for "magma." Work of the morning's first presenter William Bottke (#1672) was reported in Horizons last year. This and subsequent papers concentrate on

- The asteroid belt as observed,
- The asteroid belt's composition inferred from meteorites, and
- Models of interior processes, such as convection and differentiation into different mineral layers.

Here there is a close link between

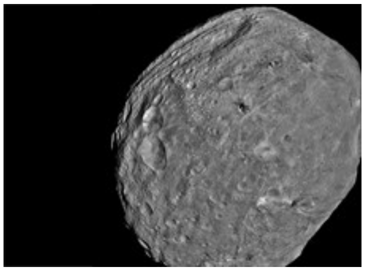
- What Elkins-Tanton presents about planetesimals coalescing into Earth-like planets in a sequence of collisions and mergers, and
- What can be determined from examining asteroid remains of such a process.

Differentiation session papers **[M101]**, at the very least, show that the asteroid belt composition is not uniform and that formation processes were influenced by initial distance from the Sun (as in "Asteroid Partial Melting at the Solar System's Snow Line," #2481), and then by the sizes of the bodies after surfaces and interiors cooled. Subsequent collisions scattered remains into the heterogeneous asteroid belt composition we observe today, and scattered remains into meteorites collected here on Earth, where we attempt to trace them back to their parent bodies.

The solar-electric powered NASA Dawn mission to asteroids Vesta and Ceres is another spacecraft star of the LPSC 44 show. Wednesday's special session, **Dawn: Vesta from the Inside Out [W301]**, naturally links with **Differentiation session** papers **[M101]**, and links with results discussed later in the conference, **Dawn at Vesta [Session 802]**, with its one paper, **[#1136]**. T. H. Burbine's paper **[#2637]** begins by stating, "The asteroid class best linked to a meteor type are the V-types." In this case, V indicates Vesta or similar asteroids that have one-micron bands similar to the spectra of howardite, eucrite and diogenite (HED) meteorites. For decades prior to the Dawn mission, Vesta had already been identified as a source for meteorites with volcanic features not attributed to Mars or the Moon. This led to speculation that Vesta would be rich in volatiles or a differentiated surface, perhaps even

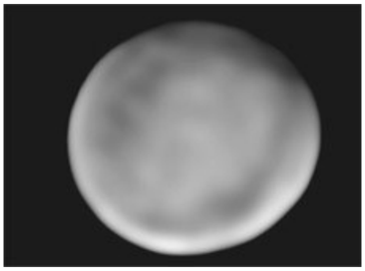
(Continued on page 8)

Cover Story



Above: Vesta image by NASA's Dawn spacecraft. Vesta is the second largest asteroid in the main asteroid belt. Image credit: NASA.

Above: Vesta image by the Hubble Space Telescope. Image credit: NASA.



Above: Image of Ceres, the largest asteroid in the main asteroid belt, taken by the Keck Telescope. Image credit: Keck Observatory by C. Dumas.

Above: An artist's version of the NASA Dawn spacecraft leaving Earth. Dawn completed the Vesta portion of its mission and is now on its way to Ceres. Image credit: NASA/JPL-Caltech/UCLA/McTech

Cover Story

Above: An image from the NASA Mars Science Lander (MSL) press briefing. Image credit: LPSC royalty-free images.

(Continued from page 7)

carbonates and water. From remote sensing it certainly appeared to differ from other larger asteroids such as Ceres. It now appears that Vesta has a deep basaltic crust about ten kilometers thick. Other V type asteroids are perhaps crustal remains with diameters of that order. As for large quantities of volatiles, as paper **[#2767]** argues, if not at Vesta, there is still good prospects for their presence at Ceres, the largest asteroid and a body connected with carbonaceous chondritic meteorites. Ceres is the next stop on Dawn's excursion.

It was Monday afternoon (Session **From Dust to Planets in the Protoplanetary Disk [M156]**) that the authors of paper **[#1403]** ("Effects of Refractory Carbon Grains on Exoplanet Planetesimal Composition") addressed variations of magma composition on the interstellar vs. interplanetary scale. Torrence Johnson and colleagues "calculated the planetesimal composition for exoplanet systems with different carbon-oxygen ratios (C/O)." This was done since, "Given the observed range in stellar carbon to oxygen ratios in exoplanet host stars, condensates might range from more water and volatile rich than solar system objects to volatile poor and silicate/metal rich. [And] for more carbon-rich stars (C/O greater than about 0.8) refractory material in the inner part of the systems might be dominated by carbides rather than silicates."

Volatile ice composition would depend on availability of oxygen for formation of H_2 ice condensations. Systems with less than the solar value for C/O of 0.55 would have very ice rich planetesimals. A number of stars with photospheric abundances greater than the solar ratio were examined with the chemical abundance applied to the complex coalescence processes within the presumed protoplanetary disks surrounding the stars early in their life histories.

Atmospheric Studies of Solar System and Extrasolar Planets

Findings, of course, rest on assuming that circumstellar and stellar photosphere elemental abundances are similar. But are they? Inquiring of several attendees about this problem, one suggested verification could come through continued study of solar system abundances preserved in meteorites, asteroids or comets. This brings us back to examining isotopic ratios to determine ages and original abundances of both refractory and volatile materials. We note reports in 22 March 2013 *Science* [**References 1 & 2**], discussing the same issue of extrasolar planet compositions and volatiles, but using ground-based Keck II Observatory results. The introduction notes that abundances of elements heavier than helium (C, N, S) in the atmospheres of Jupiter and Saturn exceed solar abundances by factors of 3 and 7 respectively; and that "enhancements of specific elements provides a fingerprint of the planet formation process." Infrared spectrum results for three exoplanets exceeding Jovian mass shape the discussion.

An intriguing extrasolar planet situation is that of an Earth-like world located near enough to a red dwarf star to experience heating similar to the solar constant (1,380 Watts per square meter), but also experience low rotation rates due to increased tidal effects from the star. The authors of paper **[#2787]**, within limits of their models that included a variable reflectance, identified thermal saturation conditions leading to runaway greenhouse effects if the night side of the planet could not radiate off into space stellar heat at a rate to match the buildup on its permanently illuminated side (1,640 Watts per square meter maximum stellar heat flux constant). With rotational rates increased to values approaching Earth's angular rate, the boundary dropped to 1,550. There's something to ponder here for Earth's future as well.

Isotope Abundance Ratios, Age Estimations and Points of Origin

In the fourth session of the first morning, **Early Solar System Chronology [M104]**, a paper by Y. Amelin and others provided an interesting introduction to isotopic evidence trails in meteorites. Though cryptically titled, "U-Th-Pb Systematics of CAIs from CV Chondrite Northwest Africa 4502," **[#2690]**, it had links to other presented papers that would resonate outside the conference halls. Still, the program lead did not yield information easily: "Four CAIs from CV chondrite NWA 4502 have Pb [lead] isotopic age of 4,567.40 ± 0.27 [million years], and uniform $^{238}U/^{235}U$ of 137.808 ± 0.019." In translation we conclude that a meteorite from West Africa is under examination for age through a process known as Pb-Pb isotopic dating, and that the age is found to be similar to other CAIs (calcium aluminum rich inclu-

(Continued on page 9)

(Continued from page 8)

sions). Toward lunchtime, paper **[#1841]** reported about tests on another chondrite, NWA 6704. Based on $^{238}U/^{235}U$ ratio of 137.88, an age of 4.56334 billion years with +/-300,000 years uncertainty was reported.

In the two-page abstract of another paper examining other NW African meteorites (7388 and 7605), similar age but far different composition and origin conclusions are drawn; and for a similarly ancient NWA 7325, investigator Anthony Irving, speaking Wednesday morning in a session devoted to science results from the Messenger spacecraft, suggests a quite extraordinary explanation of origin **[#2164]**. While we note that some NWA meteorites have been traced to Mars by investigations (e.g., NWA 7034 and 6162 in several papers of session **[W302]**; 7034 is discussed as well in **Reference 3**), Irving argues that 7325 could have originated on Mercury!

Beta decays are attributed to weak force interactions within the nuclei of atomic isotopes, the source of much natural radioactivity. Each isotopic configuration of the nucleus has its characteristic rate of decay which we associate with an isotopic level of instability or stability. As a result we can determine the age of ancient cave camp fires or the formations of the oldest rocks from atomic remains. In broad terms, radio carbon dating tracks from nitrogen-15 decay to carbon-14 (^{14}C) and back to stable ^{14}N for the cave, reckoning over thousands of years; and planetary geophysics tracks deposits of slower decays over billions of years, for example, assessing uranium-to-lead abundance ratios when a molten mix might have settled out into a solid ore (Table 2).

Not all isotopic abundance ratios are assessed to determine a decay rate, however. Comparing deuterium-to-hydrogen ratios in the atmospheres of Earth, Mars and Jupiter might give an estimate of how much hydrogen might have escaped from each world over eons, with the heavier of the two atoms (^2H) less frequently reaching escape velocity. As mentioned,

- There are abundance ratios in the solar photosphere which have been altered by solar nuclear reactions,
- There are abundances in the giant planets which might reflect the original abundance ratios of the clouds from which they formed, and
- In the terrestrial planets there are atmospheric abundance ratios for nitrogen, oxygen, carbon and the inert gases such as argon, plus the abundance ratios of many stable and unstable isotopes of elements in rocks and ores extracted from their interiors or obtained on Earth as meteorites.

More Monday Reports

In the **MSL Geology and Environment** session **[M102]** by Palucis and others **[#1259]** discussed the Peace Vallis fan system that drains into the Curiosity landing area. Its similarity to other fan systems in the Martian southern highlands suggests a period in Mars' history of widespread fluvial activity [related to rivers or streams]. The authors propose snowfall as the water source. They estimate the source regions to be too high in elevation for it to be ground water. If the water source were rainfall, based on terrestrial experience, they would expect more fine scale branching of the tributaries.

In **Lunar Remote Sensing [M103],** Hayne and others **[#3003]** find evidence or the effectiveness of relative regolith thickness as a dating tool. Regolith is the upper layer of finely divided material - dust and small rocks - that covers the Moon. They think they will be able to use thermal inertia as a measure of upper regolith thickness. Braden and co-authors **[#2843]** reported small-scale volcanic units in many maria; some smooth, some rough. [The singular of maria, Latin for seas, is mare; maria are large, dark plains of volcanic origin on the Moon, according to Wikipedia, which explains that astronomers initially mistook them for seas.] They estimate ages for smooth volcanic units between 18 and 50 million years, fantastically young for the Moon. They ask the question, "What kept these areas active for so long?" Greenhagen and co-authors **[#2987]** report that Tsiolkovsky crater, on the far side of the Moon, is weird in a number of respects. For one thing, it contains lots of rocky blocks, which is not expected for a crater thought to be about 3.2 billion years old, based on crater counts in mare-filled areas.

Monday afternoon at the session called **Planetary Dynamics and Plate Tectonics [M155]**: Leone and co-authors **[#1089]** offered a new idea for the cause of the Martian hemispheric dichotomy, where the southern hemisphere of Mars is at very much higher elevation than the northern, and the boundary between them is in many

(Continued on page 10)

Table-2 *Radioactive Decays for Planetary Science

Process	Symbol	Half-Life (Years)	Stable End Product
Thorium	^{232}Th	$1.39x10^{10}$	^{208}Pb (lead)
Neptunium	^{237}Np	$2.25x\ 10^6$	^{209} Bi
Uranium	^{238}U	$4.51x10^9$	^{206}Pb
Actinium	^{235}U	$7.07x10^8$	^{207}Pb
Carbon-14	^{14}C	$5.73x10^3$	^{14}N

*Adapted from *Principles of Modern Physics*, Robert Leighton, McGraw-Hill, 1959. The text notes a terrestrial $^{238}U/^{235}U$ abundance = 138.5.

$N(t)/N_0 = 2^{-t/T_{HL}}$ Half Life Decay Formula or

$N(t)/N_0 = \exp(-\lambda\ t)$ where $\lambda = \ln(2)/T_{HL}$

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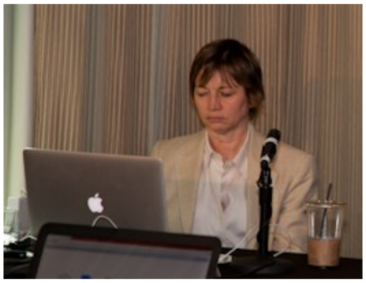


Above: Dr. Maria Zuber from the NASA GRAIL mission at the GRAIL/LRO press briefing. Image credit: LPSC royalty-free images.

Above: Kurt Retherford, Principal Investigator for the NASA Lunar Reconnaissance Orbiter (LRO) mission at the GRAIL/LRO press briefing. Image credit: LPSC royalty-free images.

(Continued from page 9)

places relatively sharp and steep. They propose a giant southern impact with impactor radius around 1,600 kilometers. The planet's response to the impact is volcanism, crustal production, and crustal thickening. This contrasts with an existing idea for a giant northern impact, which would make the northern lowlands the floor of a gigantic impact basin. There are other models not involving impacts.

At the session called **Planetary Volcanism in the Solar System [M154]**, Huang and co-authors **[#2288]** offered evidence for explosive volcanism on early Mars. They identified 75 ancient volcanoes in the southern part of Mars, and found a new type of knobby terrain. Their evidence tells them that explosive eruption was a dominant volcanic style on early Mars.

Tuesday

Morning at **Terrestrial Planetary Differentiation [T201]:** James M. D. Day **[#1835]** reported a ubiquity of late-accretion signals on terrestrial planets. Material was added to the planets after they had differentiated and their main core growth was over. In the **MSL** at **The Rocknest Sand Dune [T202],** Archer and co-authors **[#2168]** offered reasons for thinking perchlorates may be widespread on Mars. Found already by the Phoenix lander, they are relatively stable in Mars conditions and do not react readily with organic matter. Some terrestrial organisms use them as an energy source. They can suck up water and form brines. When heated, they readily decompose, releasing oxygen, so they could be destroyed, rather than discovered, by lander instruments that heat samples.

At **Origin and Evolution of the Moon [T204]**, Nakajima and Stevenson discussed two variations on the giant impact model for the origin of the Moon

- Impact into a fast-spinning proto-Earth, and
- Collision between two "sub-Earths" of similar size.

Most giant impact models consider a Mars-size object colliding with a much larger proto-Earth. Visscher and Fegley **[#1546]** discussed chemistry in the debris disk from which the Moon formed. How much water is retained in the eventual Moon depends on the initial water inventory and the solubility of water in melt lavas. Lanueville and co-authors **[#1594]** noted that there is a strong enrichment of heat sources (radioactive uranium, thorium, and potassium) on the near side of the Moon. Nearly 90% of the Moon's volcanism occurred on the near side. They estimate that near side volcanism stopped roughly one billion years ago, and that far side volcanism stopped around three billion years ago. Joliffe and co-authors **[#2655]** report that re-interpretation of Apollo seismic data points to a thinner crust on the Moon than previously thought, with an average thickness between 34 and 43 kilometers. This is in accord with GRAIL mission gravity data, which also indicates a thinner crust.

Tuesday's Wholly GRAIL

GRAIL is familiar to most of our readers, NASA's recent and successful Gravity Recovery and Interior Laboratory (GRAIL) mission to use high-quality gravitational field mapping of the Moon in order to determine the Moon's interior structure (Wikipedia). In the session **GRAIL Explores the Moon's Interior [T255]**, Zuber and co-authors **[#1777]** described their lunar gravity model of degree and order 660. This represents block sizes of 8.3 kilometers on the lunar surface. Work on a model of degree and order 900 is in process. Plans for models beyond degree 1,000 are also in work, making the team the largest current users of NASA supercomputer time. They are currently limited by Lunar Orbiter Laser Altimeter (LOLA) topography data from the Lunar Reconnaissance Orbiter (LRO). As map comparisons show, at short wavelengths on the Moon, gravity closely follows topography.

Williams and co-authors **[#3092]** worked on the Moon's J_2 and C_{22} gravitational terms from GRAIL data, and the Love number K_2, measuring lunar elastic response to tidal forces. They cannot get the Love number to make sense if the Moon's core is entirely solid; some part of it must be liquid. They give lunar radius as 1,737.15 kilometers, a slight difference from the current standard value. Inner solid core radius equals 240 kilometers. The outer fluid core starts at 240 kilometers, with its top at 330 kilometers. Mean lunar density is 3,345.6 kilograms per cubic meter. Taylor and co-authors **[#1783]** report that some far side locations have crusts up to 50 to 60 kilometers thick. GRAIL data imply less aluminum in the Moon than previously thought. This means the Moon is probably not enriched in refractory abundance when compared with Earth.

Wieczorek and co-authors **[#1914]** find that the Moon is highly fractured by cratering,

(Continued on page 11)

(Continued from page 10)

which leads to a higher porosity of the upper several tens of kilometers of the Moon than previously thought, ranging from 5 to 20%. Many craters have a lower porosity interior, with higher porosity just outside. This results from crustal thinning inside, and dumping excavated ejecta outside. Similar patterns have been observed for terrestrial craters.

Kiefer and co-authors **[#2030]** report buried high density material near Aristarchus, the Marius Hills, and the Cauchy-Gardner area. South of Aristarchus may lie a buried mass concentration (mascon) crater, although that's not the only possibility. North of Aristarchus, there must be basaltic intrusions. The Marius Hills must have at least 12 kilometers thickness of intruded material. Sori and co-authors **[#2755]** pointed out that we don't know how much mare area there originally was. Some may be buried under later highlands ejecta. They used GRAIL data to look for buried denser material, and they found some.

Neumann and co-authors **[#2379]** used GRAIL data to take inventory of impact basins and search for previously hidden ones. They provided a list of confirmed new basins. One or two very large "megabasins" are still under assessment. Miljkovic and co-authors **[#1926]** report that GRAIL data shows evidence of a hemispheric asymmetry in basin sizes. Eight basins larger than 300 kilometers in diameter are on the near side of the Moon, and one such basin is on the Moon's far side. The crust is thinner, on average, on the near side of the Moon than on the far side. At the time of the impacts, there was also a thermal difference between these hemispheres, due to the near side concentration of radioactive heat sources mentioned earlier. Their modeling shows that the differences in target materials and temperature would have resulted in the same impactor producing a far larger crater on the near side than on the far side of the Moon. This new lesson learned contradicts the idea that a collection of larger impactors struck the near side of the Moon, as compared to smaller impactors striking the far side of the Moon. The new lesson learned is: the Moon responded differently to impacts on the near side, as compared to impacts on the far side.

Wednesday's Vesta Dawn Celebration, Plus Mars and Mercury

In Wednesday morning's session on NASA's Dawn asteroid mission, **Vesta from the Inside Out [W301]**, Russell and co-authors **[#1200]** compare Vesta spectra with spectra from the HED (Howardite, Eucrite, Diogenite) meteorites, thought to come from Vesta. Euchrite (crustal) spectra dominate in the north, Diogenite (interior) spectra dominate in the south, and Howardite (a mixture) spectra dominate overall. This implies that more crust has been removed from the south part, which is what one would expect from the two giant overlapping impact basins at Vesta's south pole. Vesta is very dry, though there is evidence for water in the mineral apatite, and perhaps in some craters.

Fu and co-authors **[#2115]** point out that Vesta's equatorial bulge is far larger than expected for its current spin rate. They wonder if there could have been a roughly 6% late de-spinning. Raymond and co-authors **[#2882]** report that Vestatia Terra, located on the rim of the giant south pole impact basin Rheasilvia, is the highest terrain on Vesta. It is ancient and dense; perhaps it is a surviving plutonic (defined as: formed by solidification of magma deep within the earth and crystalline throughout <*plutonic* rock>) complex. Bowling and co-authors **[#1673]** conclude that Vesta's equatorial troughs were likely generated by the Rheasilvia impact. The maximum extension during this proposed impact event is near the equator.

In the Fluids on Mars [W305] session, Hauber and co-authors **[#2513]** find that Martian deltas previously studied are younger than Noachian (less than 3.7 billion years old) and not all the same age. They think some deltas could form in single, short-duration events with limited water supply, but not necessarily by a regionally connected water table. Older deltas have longer feeder valleys; perhaps episodic surface runoff could be responsible. Not finding water-altered minerals suggests short term activity.

In the **Messenger Results from Mercury [W303]** session, Ernstand co-authors **[#2364]** report the volcanic plains interior to the Caloris basin to be at least 2.5 kilometers thick. Selvans and co-authors **[#2773]** report more scarps (defined by Google as very steep banks or slopes) in the south of Mercury than the north. They are oriented more east-west near the poles, and oriented more north-south near the equator. The researchers ask if this could be connected with mantle convection.

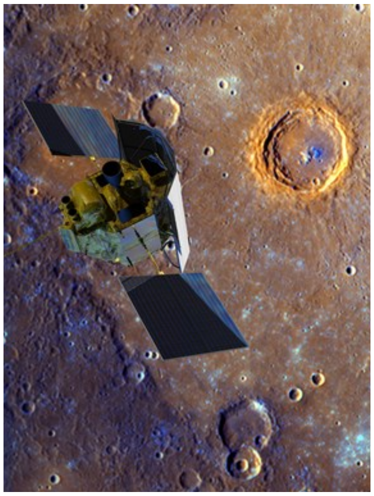
In the **Volatiles at Mercury [W353] session**, Chabot and co-authors were able to use

(Continued on page 12)

Cover Story

Above: Mark Robinson of the NASA Lunar Reconnaissance Orbiter (LRO) at the GRAIL/ LRO press briefing. Image credit: LPSC royalty-free images.

Cover Story



Above: NASA's Messenger robotic spacecraft over Calvino Crater. A depiction of the MESSENGER spacecraft is shown flying over Mercury's surface displayed in enhanced color. The crater ringed by bright orange is Calvino crater. The enhanced color imagery of Mercury was obtained during the mission's second Mercury flyby in 2008. Visit this page to learn more about this high resolution sequence of color imagery from Mercury flyby 2. Image credit: NASA/Johns Hopkins University Applied Physics Laboratory/ Carnegie Institution of Washington.

(Continued from page 11)

indirect scattered sunlight to image within permanently shadowed areas in craters Prokofiev and Kaninski near Mercury's poles. Permanently shadowed areas match areas that appear radar-bright from Earth. They also show high reflectivity to the laser altimeter, which is interpreted as water ice at the surface. Those areas also look bright in wide-angle camera (WAC) clear-filter images. Two research groups proposed that mysterious hollows on Mercury, which look like neither impact craters nor volcanoes, are formed by volatization of subsurface materials, followed by collapse of material above.

During noon break between sessions, we heard from the **Lunar Exploration Analysis Group (LEAG)**, a group of scientists who advise NASA about science related to lunar exploration. The next full meeting of LEAG will take place Oct. 14-16 of this year in Laurel, Maryland, at the Applied Physics Laboratory (APL). Michael Wargo made a presentation where he explained that the NASA Lunar Science Institute (NLSI) is being replaced by the NASA Solar System Exploration Virtual Institute (SSERVI). Basically, the institute is being renamed and its mission is being expanded. Lunar science is not being excluded; rather, other topics are being added.

Thursday

In the morning at **Mineralogy of Martian Aqueous Environments [R402]**, Carter and co-authors **[#1755]** show evidence that surface weathering was widespread on early Mars. This implies early Mars was warmer and wetter than today. The deeper the spectral analysis, the more aluminum clays they see. These clays require weathering and water to form. They conclude ages for these materials are from 3.65 to 3.80 billion years, similar to ages of valley networks. In the related **Ice, Glaciers and Polar Processes on Mars [R451]**, Bibring and Forget **[#2161]** claims that Mars preserved a record, with stratigraphy, from before the late heavy bombardment times. *[The Late Heavy Bombardment (LHB) took place from 4.1 to 3.8 billion years ago, according to the Wikipedia article.]* They wondered how this was possible, and considered the possibility that studied areas may have been covered by ice. Clifford and co-authors **[#2881]** investigate the water inventory in the middle of Martian history. They show the presence of massive ground ice in the northern hemisphere.

In **Lunar Samples and Experiments [R404]**, Borg and co-authors **[#1563]** find a lot of ages around 4.35 billion years. This implies either (1) a widespread magmatic event 4.35 billion years ago, or (2) the primordial solidification of the Moon taking place at that time. Wilson and Head **[#1169]** report that most magmas erupted onto the lunar surface and had high volume rates, at least in their early stages.

In the **Impact Mechanics [R405]**, Schultz and Hermalyn **[#2589]** report from their experiments that only 1/3 to 1/2 of the mass displaced during an impact actually gets out of the crater. Crater depth and diameter grow differently with impactor size. For oblique impacts into strength controlled targets, results seem more controlled by projectile momentum than energy. In some cases, crater diameter continues to grow after depth growth stops. Targets with layers of different materials also affect things.

Friday

At **Lunar Volatiles [F505]**, Thomas-Keprta and co-authors **[#2103]** report carbon-rich material on Apollo black glasses that was clearly indigenous to the Moon. The carbon was in an amorphous phase which could have been kerogen-like material; its source it not yet known. *[Google provides this definition of kerogen: a complex fossilized organic material, found in oil shale and other sedimentary rock.]* Armand and co-authors **[#1957]** report that apatite is the main water-bearing or hydroxyl-bearing phase in mare basalts. *[Google provides this definition of hydroxyl: of or denoting the radical -OH, present in alcohols and many other organic compounds.]* The water in the lunar interior seems to show a common origin with water in Earth's interior.

Session **Lunar Imact and Cratering [F555]** began with a tribute by Everett Gibson to the late Dr. David McKay. Both Gibson and McKay trained the Apollo astronauts in geology. Dr. McKay had been a leader in lunar and planetary science ever since. There followed a paper by the Kickapoo Lunar Research Team and G. Y. Kramer **[#1426]**, students at Kickapoo High School, Springfield, Missouri. They looked at LRO Narrow Angle Camera (NAC) images of layered boulders around Aristarchus Crater, in Mare Undarum. They presented arguments that these layers came from layering within an

(Continued on page 13)

(Continued from page 12)

intrusive igneous body, a "pluton." Kalynn and co-authors [#1309] confirmed that at a given diameter, highland craters are deeper than mare craters. Highland craters are deeper than previous results indicated. It is now easier to distinguish between fresh and modified craters. Central peak heights, on average, increase with crater diameter at least up to diameters of 100 kilometers, though there remains variability in this, influenced by impact parameters and/or target properties.

Spacecraft and Mission Proposals

Both Tuesday and Thursday evenings had poster sessions dedicated to future missions and instrumentation and some new missions were discussed in oral presentations as well. In the Thursday session, for example, on **Planetary Atmospheres [R453]**, J. N. Goswami of the Indian space agency describes plans for a Mars mission launch this year to examine atmospheric composition and to detect methane. Both science objectives and engineering approach were described in remarkably comprehensive detail **[#2760]**, given the limited briefing time.

Tuesday provided the majority of new missions or instrumentation poster presentations. **Planetary Mission Concepts [T638]** and **Instrument and Payload Concepts [T641]** provided 37 and 72 poster slots respectively. The four posters in **Current and Future Mars Landing Sites [T640]** group implied the need for a few more missions. Thursday, the mainstay was **Asteroid Analysis: Missions and Tools [R735]**, with eight more presentations. This last session split between ground-based analysis systems, a Hayabusa 2 mission and some small spacecraft comet exploration proposals. The designs and proposals ranged from discussions of capabilities for exploration, such as the NASA Space Launch System (SLS), overall orbiter and lander designs, and individual payload instruments or packages. In the final element, the instrumentation, we could say that our loop is closed, taking us back to the environments and surfaces we are exploring currently and how we intend to continue the process.

Horizons Reporters Among the Posters Tuesday and Thursday Nights

Tuesday Poster Session

Arkani-Hamed and Roberts examined how a giant impact on Mars could stifle core convection. It might not come back full strength for 900 million years and perhaps never. If core convection stops, the planet's magnetic field disappears with it. This could explain how Mars lost its early magnetic field. A poster by Dietrich and co-authors presented topographic evidence for multiple lake levels in Gale crater (the Curiosity landing site) **[#1844]**. Lakes stood at different heights at different times.

J. Berk, a Space Studies U. of North Dakota, graduate presented "Space Station 2.0: A Transformational Architecture for Space Development" [#**1861**]. To place spacecraft around the Moon at an affordable price using NASAS's Commercial Orbital Transportation System (COTS), a multipurpose module is proposed to be delivered from Low Earth Orbit (LEO) via solar electric propulsion. Citing the NASA Air Force Cost Model (NAFCOM), lower cost and higher mission performance were projected.

P.E. Clark and co-authors of Lunar Cubes **[#1233]** explain how a constellation of CubeSats can be sent to the Moon for science missions via low-thrust trajectories, citing CubeSat success in reducing space missions costs. More information is available at http://www.lunarcubes.com/purpose-scope.

J. Straub, also working on CubeSats for the University of North Dakota (UND) as the Director of the Open Orbiter Small Satellite Development Initiative presents, "Open Orbiter: A Platform for Enabling Planetary Science" [#**1424**]. Open Orbiter is to be North Dakota's first student-designed satellite. Currently, CubeSats cost between $15,000 and $100,000, but Straub aims to reduce the costs to $5,000. Building from scratch, CubeSat hobbyists and engineers will only need three to six months to build them. Straub estimates that with the approximately 300 students and faculty members at UND working on this project, it will take the team eighteen months to two years to develop. Following an open source approach, all CAD files and design instructions with video will be online. A list of suppliers will be available with many options presented for those interested in constructing their CubeSat.

Thursday Poster Session

In side-by-side Thursday posters, Bland and co-authors **[#1655]**, and Dombard and Schenk **[#1798]** in poster session **[R721]**, presented argu-

(Continued on page 14)

Cover Story

Above: An image from one of the LPSC poster sessions. Image credit: LPSC royalty-free images.

Cover Story

(Continued from page 13)

ments that if Ceres is differentiated, with ice at the top and rocky materials below, it should retain few impact craters over geologic time, except at the poles, due to viscous relaxation. Lemmon and co-authors reported Curiosity's MastCam observing two transits of Phobos across the Sun and one transit of Deimos **[#1787, R715].** We were especially impressed by posters with high school student authors. At poster session **[R721, #1613]** E. E. Burgess and H. V. Frey discuss improving the crater retention age estimate for the Moon's South Pole-Aitken impact basin. Because Ms. Burgess is a high school student in Maryland, her schedule did not permit her to be at the LPSC in person. Her advisor, Dr. Frey, well known in the lunar science community, was present to discuss the poster.

E. B. Patmore and co-authors reported on, "Video Analysis of High Speed Asteroid Impact Simulations" **[#2982]**. The team tested shooting small aluminum bullets at pieces of rock at the NASA Ames Vertical Gun Range (AVGR) to simulate asteroid impacts. The bullets traveled at five kilometers per second and cameras recorded the effects of the impacts. They are not sure if the rocks match the asteroid type, but in the future they will use more asteroid-like rocks.

T. Hirabayashi of the University of Colorado at Boulder worked on "Constraints on the Size of Asteroid 216 Kleopatra Using Internal Stresses" **[#1592]**. A spinning asteroid such as Kleopatra can disintegrate if it spins too rapidly. Hirabayashi looked at central asteroid segments most prone to stress failure assuming a uniform density derived from constraints placed on asteroid physical properties. Minimum friction angles were derived from three different computations.

Similarly D. Cotto-Figueroa and co-authors at Ohio University researched "Radiation Recoil Effects on the Dynamical Evolution of Asteroids" **[#2945]**. Thermal re-emission from irregularly shaped bodies results in a torque that can change the rotation rate and the orientation of the spin axis. This force is known as the YORP effect. In a classic simulation scenario, an asteroid spins up to a certain point before it slows down and changes its spin again. The rotation rate of asteroids suggests that most asteroids are rubble piles. Since the YORP effect has a strong sensitivity to the shape of the asteroid, any deformation to the asteroid itself will cause a change in the YORP effect. The team revised the model by allowing the asteroid to change its shape due to the YORP effect; this in turn caused change in spin and more YORP effect, resulting in a significantly different spin rate than the classical rigid body simulation.

Geologists at Lund University, Sweden addressed the "Mass, Morphology and Internal Structure of Three Particles from the Hayabusa Sample Return Mission" **[#1937]**. They used synchrotron radiation X-ray tomographic microscopy (SRXTM) to precisely determine the masses of three grains.

J. B. Adler from UCLA examined the "Diurnal Yarkovsky Drift Rate for a Shape Model" **[#2527]** with asteroid Itokawa as a test case. A triangular mesh and a thermal model were used to extract the momentum vectors from each of the 49,152 triangular surface sectional areas of the modeled asteroid surface. Indirect photon momentum from thermal radiation forces ejected from one surface and absorbed by another was also examined. The decay rate of the semi-major axis was plotted for several starting locations of a test sphere and an Itokawa shaped model.

A. Venkataramanasastry from the University of North Dakota presented "A Space Debris-Enhanced Intervention Mission to a Near Earth Asteroid" **[#2449]**. The mission approach is a spacecraft rendezvous a with an existing space debris collection and transfer of the debris collector to the intervention spacecraft, which is then dispatched to strike the asteroid or orbit the asteroid as a gravity tractor.

(Continued on page 15)

References

1. Marley, M. S., "Probing and Extrasolar Planet", *Science*, Volume 389, March 22, 2013, pages 1393-1394.
2. Konopacky, Q. M. and co-authors, "Detection of a CO and Water Lines in an Exoplanet Atmosphere", *Science*, Volume 389, pages 1398-1401.
3. Humayun, M., "A Unique Piece of Mars", *Science*, Volume 389, February 15, 2013, pages 771-772.

Links for LPSC program notes and abstracts for oral and poster presentations can be obtained as follows, for example, abstract **[#2449]**:

http://www.lpi.usra.edu/meetings/lpsc2013/pdf/2449.pdf

and a Thursday session **[R721]**:

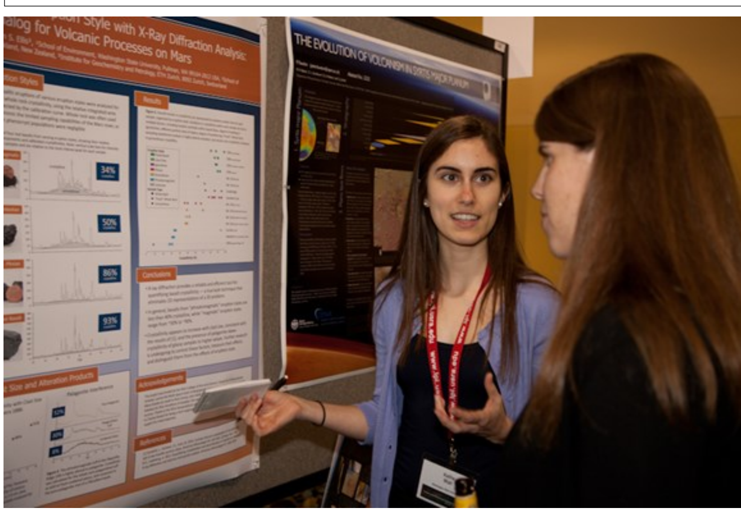
http://www.lpi.usra.edu/meetings/lpsc2013/pdf/sess721.pdf

(Continued from page 14)

Glossary

- CAIs: small calcium and aluminum rich inclusions found in carbonaceous chondrite meteorites, among the first solids condensed from the cooling protoplanetary disk.
- Dark halo craters: possibly volcanic in origin, surrounded by ejecta blankets darker than the adjacent area.
- GEMS: glass with embedded metal and sulfides. These are tiny spheroids in cosmic dust particles that are the building blocks of anhydrous interplanetary dust particles (IDP).
- Grand Tack: Jupiter's path in the early solar system. According to theory, due to multi-body dynamics, it migrated toward the sun, stopped, and then migrated back outward. See an earlier **Horizons** discussion of Nice Model. That is in the November / December 2011 issue of Horizons starting on page 18.
- HEDs: Howardite, Euchrite and Diogenite meteorites associated with Vesta and similar asteroid parent bodies.
- Late Heavy Bombardment: An interval between approximately 4.1 and 3.8 billion years ago, when many planetary scientists believe that a pulse of substantially increased cratering from asteroids and/or comets took place in at least the inner (and possibly the entire) solar system.
- Late Veneer Hypothesis: water and iron-loving elements added to the Earth late in its formation by impact with icy comets and meteorites.
- Noachian: Martian geological epoch from planet formation to about 3.7 billion years ago.
- NWA: a collection of numbered meteorite finds from Northwest Africa, varied origins, ages and composition.
- Regolith: the upper layer of finely divided material - dust and small rocks - that covers the Moon.
- SNCs: meteorites traced to Mars of three geographic groups, shergottites, nakhalites and chassignites.
- Volatiles: in planetary and satellite environments, sometime solids that transform to fluids liquid or gas.
- YORP effect: Yarkovsky–O'Keefe–Radzievskii–Paddack effect, a second-order variation on the Yarkovsky effect which changes the rotation rate of a small body (such as an asteroid). The term was coined by David P. Rubincam in 2000. In the 19th century, Yarkovsky realized that the infrared radiation escaping from a body warmed by the Sun carries off momentum as well as heat. Translated into modern physics, each photon escaping carries away a momentum $p = E/c$ where E is its energy and c is the speed of light. Radzievskii applied the idea to rotation based on changes in albedo and Paddack and O'Keefe realised that shape was a much more effective means of altering a body's spin rate. Paddack and Rhee suggested that the YORP effect may be the cause of rotational bursting and eventual elimination from the solar system of small asymmetric objects [Wikipedia].

Above: An image from the exhibit opening. Image credit: LPSC royalty-free images.



Left: An Image from one of the LPSC poster sessions. Image credit: LPSC royalty-free images.

(Continued on page 16)

Cover Story

Above: Media images from the Golden Spike web site including Alan Stern and Gerry Griffin, former Director of NASA/JSC.

(Continued from page 15)

Golden Spike

By Dr. Larry Jay Friesen

At noon on Monday, Alan Stern made a presentation about Golden Spike, a company he founded for the purpose of getting human missions to the Moon. Dr. Stern is a former head of the NASA Science Mission Directorate. His is now the principal scientist for the NASA New Frontiers mission, on its way to investigate Pluto and the Kuiper Belt. Stern is CEO and President of Golden Spike. Gerry Griffin, who is well known in the NASA / JSC community, is Chairman of the Board. The company includes employees with science, media and government expertise.

Stern believes he can get people back to the Moon for six to eight billion dollars for the first mission, with repeat trips costing about 1.5 billion dollars each, about the cost of a major NASA robotic planetary mission like Cassini. The company will use a commercial business model, relying on advance flight and media sales, and not relying on billionaires.

The reason for the low development cost is that they plan to use existing hardware wherever possible, including existing launch vehicles. That means much of the development cost has already been paid. Rather than develop a heavy-lift launch vehicle, they plan to use multiple launches of existing vehicles to get everything they need launched into orbit and launched to the Moon. They will require two or four launches, depending on what launch vehicle they select. They plan not to develop but to buy vehicles. Atlas and Falcon Heavy were two possible launch vehicles discussed.

They aim to put in place an affordable turnkey Earth-to-Moon transportation system to enable human lunar expeditions for science, commerce, etc. They envision two people being sent to the Moon per mission. They foresee a major market in what they call "mid-level" countries. These are countries which would like to take part in human spaceflight to the Moon. They have the scientific and technical abilities to take part, but they lack the budget to develop a lunar transportation system on their own. They have identified 25 to 30 candidate countries of this type. Corporations may be another market.

They are in the process of a crewed lunar lander system study. In this area, they probably will find it necessary to develop their own vehicle. They expect to be able to bring back a minimum of 50 kilograms of lunar samples per flight. They also plan to have lunar surface experiment packages to deploy at each landing site. They call them GoldSEPs, a reference to the Apollo Lunar Surface Experiments Packages (ALSEPs). They will offer a suite of scientific instruments from which customers can choose. If a customer wishes to supply an instrument of their own, that's fine, as long as it is compatible with the GoldSEP interface requirements.

This is a *sortie* mission mode. This is terrific for lunar science; not so great for those who want to put long term human settlements on the Moon. However (Larry Friesen's personal opinion here), I imagine that once this transportation system is up and running, would-be settlers can figure out ways to piggy-back off it.

Golden Spike is planning a workshop at the Houston Clear Lake area's Lunar and Planetary Institute (LPI), October 3-4, 2013. Information about that workshop can be found on the LPI web site.