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GRAIL twins toast new year from lunar orbit

Three-month 'formation flying' mission will study the moon from crust to core

By Mark Whalen

Above: The GRAIL team celebrates with cake and apple cider. Right: Celebrating GRAIL-A's Jan. 1 lunar orbit insertion are, from left, Maria Zuber, GRAIL principal investigator, Massachusetts Institute of Technology; Charles Elachi, JPL director; Jim Green, NASA director of planetary science.

JPL's Gravity Recovery and Interior Laboratory (GRAIL) mission celebrated the new year with successful main engine burns to place its twin spacecraft in a perfectly synchronized orbit around the moon.

By surveying the moon from the crust to the core using a JPL-built sensor, the mission will create the most accurate gravitational field map ever of Earth's natural satellite. In the process, the evolution of solar system's rocky planets will be further revealed, and navigation for future lunar visitors will be much improved.

GRAIL-B achieved lunar orbit Jan. 1, one day after GRAIL-A successfully completed its engine burn. The insertion maneuvers placed the spacecraft into a near-polar, elliptical orbit with an orbital period of about 11½ hours.

"Everything went exactly as expected for both lunar orbit insertions," said Deputy Project Manager Tom Hoffman. "The combined JPL/Lockheed Martin team performed excellently and the vehicles behaved flawlessly."

While team members' new year celebration was a bit deferred, it wasn't a problem. "The team still had operations to perform to repressurize the main tank on Jan. 2, but I am sure they had a good evening knowing that they had gotten not one, but two vehicles successfully into lunar orbit," Hoffman noted.

Project Manager David Lehman noted that a maneuver prior to orbit insertion changed the GRAIL-A spacecraft's speed by just 0.05 mile per hour. "That's how small we had to make this change in order to affect going into orbit precisely around the moon," he said. "So it does take a lot of planning, a lot of testing and then a lot of small maneuvers in order to get ready to set up to get into this big maneuver when we go into orbit around the moon."

A series of engine burns is planned to circularize the twins' orbit, reducing their orbital period to a little more than two hours before beginning the mission's 82-day science phase. "If these all go as planned, we will be ready to start science data collection no later than March 8," Hoffman said.

After their Sept. 10 launch, the GRAIL pair—each about the size of a washing machine—cruised for about 3½ months to reach the lunar orbital period. While the Apollo missions took only about three days to reach the moon, GRAIL needed the extra time for several reasons, explained Hoffman.

"Apollo and other missions that took a direct trajectory to the moon have had huge propulsion systems," Hoffman said. "Our spacecraft are very small, because they have just one instrument, the lunar gravity ranging system. Smaller is better, because that makes them more stable during the science phase of the mission. For us, having a large propulsion system would be expensive, and also would not be as good for the science.

"The low-energy trajectory worked perfectly and allowed us to only expend about 24 kilograms of fuel for each spacecraft, which produced about 190 meters per second in delta-V," Hoffman added. "This is a low cost for entering lunar orbit."

Stability is critical for the GRAIL twins as they have embarked on an encounter of intricate and precise formation flying, as each spacecraft measures differences as small as a micron between the two. For example, after one of the pair flies over a mountain, a few minutes later the other spacecraft will accelerate towards that mountain to measure it. The change in the distance between the two is noted, from which gravity can be inferred.

One of the things that make GRAIL unique, Hoffman said, is that it's the first formation flying of two spacecraft around any body other than Earth. "That's one of the biggest challenges we have, and it's what makes this an exciting mission," he said.

The GRAIL team includes a number of staff members who also worked on JPL's Gravity Recovery and Climate Experiment, or GRACE, a mission comprising two spacecraft flying in tandem that has very precisely measured Earth's gravitational field for almost 10 years.

GRACE used GPS, which is critical for both positioning and timing when trying measure small changes in relative velocity. With no GPS for the moon, GRAIL had to recreate those two portions of the system. Hoffman said the mission's time-transfer system essentially sends a "coded time stamp" between the two orbiters; an ultra-stable oscillator continuously keeps track of the relative time on each of the two. A radio science beacon sends data to the Deep Space Network from each of the two vehicles.

GRACE payload manager Charlie Dunn served in the same role during GRAIL's development, and many subsystem engineers, cognizant engineers and test technicians were in the same group that developed the GRACE instrument. Bill Klipstein, payload systems engineer for GRACE, is now payload manager for GRAIL. JPL's Michael Watkins is the project scientist, with Sami Asmar as his deputy. JPL co-investigators are Alex Konopliv and James Williams. GRAIL's principal investigator is Maria Zuber of the Massachusetts Institute of Technology.

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NuStar, Dawn, Mars Science Lab to highlight 2012

Four launches and several encounters made 2011 a banner year for JPL. The Lab will be busy as well in 2012, as JPL launches another spacecraft and carries out a number of key mission events.

NUSTAR

NuStar will launch from a Pegasus XL rocket.

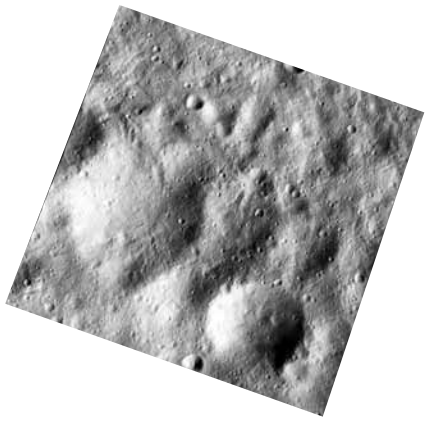
In March, the Lab will launch the **Nuclear Spectroscopic Telescope Array**, or NuStar, which will embark on a two-year quest to study the cosmos with unprecedented sensitivity using high-energy X-rays.

Led by Principal Investigator Fiona Harrison of Caltech, the NASA Small Explorer mission will map supernova explosions and search for black holes and other phenomena. Deployed on a 10-meter (30-foot) mast that separates focal-plane detectors from optics modules, NuStar is the first satellite mission to use focusing X-ray optics at energies above 10 kiloelectron volts (keV). For comparison, NASA's flagship Chandra X-ray Observatory works in the low-energy, or "soft" X-rays, below 10 keV. NASA's Swift mission works at NuStar energies and beyond, but without focusing optics. This means that NuSTAR will make much crisper images of the high-energy X-ray sky than previously possible above 10 keV, providing 100 to 200 times more sensitivity than Swift.

Key JPL staff on NuStar are Project Manager Yunjin Kim, Project Scientist Daniel Stern and Project Systems Engineer Jason Willis. About 20 JPL employees are working on the project through launch, and three JPLers are on the science team.

NuSTAR will launch into a low-Earth orbit on a Pegasus XL rocket from the Kwajalein Atoll, the world's largest coral atoll, which lies midway between Australia and Hawaii. NuSTAR will be the fourth Pegasus launch conducted from the area. Orbital Sciences Corp. built the rocket, which will be released at about 40,000 feet from a Stargazer L-1011 aircraft.

For more information, visit *www.nustar.caltech.edu.*



This image, one of the first obtained by Dawn in its low altitude mapping orbit, shows many buried craters located within Vesta's equatorial trough region.

DAWN

JPL's **Dawn** spacecraft, which has been orbiting the giant asteroid Vesta since July, sent back the first images from its low-altitude mapping orbit on Dec. 13, 210 kilometers (130 miles) above the surface. The images show the lumpy surface in detail never seen before.

The focus of the low-orbit investigation is to determine Vesta's elemental composition and to measure its gravity field to high accuracy. Scientists plan to acquire data in this orbit through mid-February. As a bonus, the mission team is acquiring additional images and visible and infrared spectra.

Dawn will begin its ascent to higher altitude about April 1. From mid-May to early June, the mission will conduct another intensive science campaign at an altitude of about 680 kilometers (420 miles). By May, the progression of the seasons at Vesta will allow Dawn to see newly illuminated parts of the surface.

Following that, Dawn will begin its gradual climb out to escape from Vesta, stopping along the way to observe the asteroid again as the season continues to advance. Dawn will leave Vesta in late July to begin an interplanetary cruise to Ceres, which will be reached in February 2015.

MARS SCIENCE LABORATORY

On its way toward touchdown next summer, JPL's **Mars Science Laboratory** bypassed a planned trajectory-correction maneuver in December due to an ultra-precise orbit placement following its launch a month earlier. The first trajectory-correction maneuver during the trip is now planned for Jan. 11.

When Curiosity has been slowed to nearly zero velocity, the rover will be released from the descent stage. A bridle and umbilical cord will lower the rover to the ground. The rover's front mobility system will be deployed so that it is essentially ready to rove upon landing.

The mission's car-sized Curiosity rover in December began monitoring space radiation, research that will aid in planning for future human missions to the Red Planet. Curiosity's Radiation Assessment Detector instrument monitors high-energy atomic and subatomic particles from the sun, distant supernovas and other sources. The particles constitute radiation that could be harmful to any microbes or astronauts in space or on Mars. The rover also will monitor radiation on the surface of Mars after landing.

Ten instruments on Curiosity will assess whether Mars' Gale Crater could be or has been favorable for microbial life.

The spacecraft is on course to land at Mars' Gale Crater on Aug. 6, 2012, Universal Time (evening of Aug. 5, Pacific Daylight Time). A new entry, descent and landing system comprising a "sky crane" lander structure will be employed to reach the surface. The spacecraft can fly "S" curves in the upper atmosphere of Mars for added precision in landing.

Visit *http://mars.jpl.nasa.gov/msl.*

GRAIL Continued from page 1

Overall, about 100 JPLers contributed to GRAIL, including about 60 at orbit insertion.

Many students will also be part of the mission, as each of the GRAIL twins carries a digital video imaging system used as an educational/public outreach activity: Moon Knowledge Acquired by Middle school students, or MoonKAM. Led by former astronaut Sally Ride and her team at Sally Ride Science in collaboration with undergraduate students at UC San Diego, thousands of fifth- to eighth-grade students will select target areas on the lunar surface and send requests to an operations center in San Diego. Photos of the target areas will be sent back by the GRAIL satellites for students to study.

More than 2,100 schools have signed up to participate. The first MoonKAM images will be taken after the first week of mapping in March.

A student contest that began in October 2011 also will choose new names for the twin spacecraft. The new names are scheduled to be announced in January.

Hoffman thanked the greater JPL community for its support of the GRAIL team, from the early development phase through operations today. "The success of a mission such as GRAIL is dependent not only on excellence of the project team but also upon the significant contributions of all of JPL," he said. "We really have needed everyone's support to get to where we are today and will need that to complete the mission."

GRAIL is the 11th mission to launch as part of NASA's Discovery Program. For more information, visit *http://solarsystem.nasa.gov/grail.*

Proposal seeks InSight of Mars beneath the surface

By Mark Whalen

Discovery Program mission would launch in 2016

The InSight spacecraft would closely resemble JPL's 2008 Mars Phoenix lander.

Over the years, numerous discoveries and findings have resulted from the many investigations conducted at the Red Planet. As JPL-managed Mars orbiters continue to explore from above and the Opportunity rover sustains its quest for knowledge, Curiosity is on its way there to join the party next summer in a search for signs of habitability.

Mars' earliest evolution, however, remains largely a mystery, as little is known about what lies beneath the surface. But if JPL researcher Bruce Banerdt and colleagues have their way, in a few years the secrets of Mars' thermal evolution and its relation to that of other rocky planets could also be revealed.

Banerdt is principal investigator for Interior exploration using Seismic Investigations, Geodesy and Heat Transport, or InSight, a NASA Discovery Program proposal that would deliver a stationary lander to the Martian surface in 2016 for a two-year mission. InSight is one of three proposals now under consideration for development.

The spacecraft's three instruments will seek to discover Mars' interior's thermal properties, determine the planet's geodesy, measure any tectonic activity, and determine the composition and size of the core and mantle. In so doing, the mission could reveal clues about the formation of more than just Mars.

"What we're after is understanding the processes that formed the terrestrial planets—Mercury, Venus, Earth, the moon and Mars," noted Banerdt, who is currently the project scientist for the Mars Exploration Rovers mission. "We have evidence that the Martian crust is more than 4 billion years old. We think the evidence we'll find in Mars—from the thickness of the crust, the layering of the crust and mantle, the size and composition of the core—will tell us about the processes that turned the planet from a jumble of homogeneous meteorite rock into the fairly complex, structured system that we see today."

The InSight spacecraft very closely resembles JPL's 2008 Mars Phoenix lander, and in fact will inherit Phoenix's system architecture. Key components such as avionics, electronics and software will be updated. InSight Project Manager Tom Hoffman noted another critical component of Phoenix's heritage in JPL's favor.

"Absolutely, the most important thing we can inherit from Phoenix is the people," said Hoffman. "They're invaluable. They understand what needs to be done, and if they've been on that similar project they'll know what in the past they've tried that didn't work." More than two dozen former Phoenix team members are expected for the InSight team, Hoffman said.

InSight's major difference from Phoenix lies in the proposed mission's landing site. The InSight team wants nothing to do with the frozen landscape of Mars' northern polar area that was Phoenix's home.

"We're looking at a strip of land very near the equator, so our solar panels get the maximum amount of energy to live a long time," Banerdt said. "We want to find someplace that's really boring, with as few rocks as possible."

Selecting a landing site this early helps firm up the system design, Hoffman added. "If we know where we're landing and know what the elevation is, we'll know that our Phoenix heritage will hold together, which is really important to us from a risk and cost standpoint. We also can take a look at our power use for that location and can do system analysis to ensure if we're well within the power capabilities of the landed system; then we can run scenarios for basically the entire mission to provide a proof of concept."

Once landed, the mission calls for a bustling first 30 to 60 days, the period of instrument deployment.

To check for quakes beneath the surface will be the Seismic Experiment for Interior Structure, provided by the French Space Agency. The Heat Flow and Physical Properties Package (HP3), a self-hammering nail that digs about 5 meters below the surface, is provided by the German Space Agency.

A camera mounted on a robotic arm takes stereo images on the surface to create a 3-D map of the workspace for the instruments. The arm then picks up the instrument, takes it off the deck and places it on the ground. "This allows us to get the full sensitivity of the seismometer and give access for the mole to dig into the ground," Banerdt said.

In addition to the seismic and heat-flow experiments, the Rotation and Interior Structure Experiment (RISE), led by JPL, will use the spacecraft communication system to provide precise measurements of planetary rotation to determine the core structure and composition.

The InSight proposal survived the first round in the Discovery Program competition, which initially had 28 proposals submitted.

Now in phase A of the process, each proposal team is preparing its preliminary design. By mid-March, they will deliver a concept study report to the agency, describing a much deeper level of detail of the design, operation and the planned components of the mission. In late May 2012, a NASA review board will pay a visit to JPL—and the sites hosting the other two considered proposals—for final questions and demonstrations.

The selected mission will have a cost cap of $425 million, plus the cost of the launch vehicle, in FY 2012 dollars.

If InSight is selected, Hoffman said, JPL's role would be project management, systems engineering and mission design. JPL would also lead systems engineering for entry, descent and landing, mission operations and ground data systems. Lockheed Martin would build the spacecraft; provide integration and assembly, test and launch operations activities; and provide payload accommodation.

Besides Banerdt and Hoffman, the InSight team includes deputy principal investigator Suzanne Smrekar and deputy project manager Henry Stone. Co-investigators on the mission come from the United States, Austria, Belgium, Canada, France, Germany, Japan, Switzerland and the United Kingdom.

Banerdt, who has worked on, proposed or advocated a mission like InSight for more than 15 years, feels confident about this effort.

"It's actually pretty well developed. We've identified the entire science team already, and most of the people working on this have been identified," he said. "We have a lot of experienced people; people who have worked with Lockheed Martin, Mars missions and other missions that our hardware is coming from, so we have a great team here," he said.

The other proposals being considered for Discovery funding are the Comet Hopper, which would land on comet 46P/Wirtanen multiple times and observe its changes as it interacts with the sun (Jessica Sunshine of the University of Maryland is principal investigator); and Titan Mare Explorer, which would land in and then float on a large methane-ethane sea on Saturn's moon Titan. Ellen Stofan of Proxemy Research Inc. in Gaithersburg, Md., is principal investigator.

A decision on the Discovery Program next new mission is expected next July.

News Briefs


Chris Webster

Webster to lead Microdevices Lab

Senior Research Scientist Chris Webster has been appointed director of JPL's Microdevices Laboratory.

Webster, currently program manager for the Planetary Science Instruments Office in the Solar System Exploration Directorate, will serve as Microdevices Lab director as an additional duty. A 30-year JPL employee, Webster pioneered the development of tunable laser spectrometers for balloon, aircraft and spacecraft instruments, leading some 500 aircraft and 22 high-altitude balloon missions. He also developed innovative miniature instruments for planetary missions to Mars, Venus and Titan, and is the JPL principal investigator on the Tunable Laser Spectrometer instrument on Mars Science Laboratory's Curiosity rover. This instrument is enabled by the quantum-engineered, infrared interband cascade lasers developed at the Microdevices Lab.

Webster has won the NASA Exceptional Scientific Achievement Medal twice (1992, 2004), the Ed Stone Award (2004), and has led numerous NASA Group Achievement Awards.


Mark Adler


John Brophy


Richard Hofer

Three named institute fellows

JPLers Mark Adler, John Brophy and Richard Hofer have been named associate fellows of the American Institute of Aeronautics and Astronautics.

Adler, at JPL for 19 years, currently manages the Low Density Supersonic Decelerator Technology Demonstration. He has previously been the Cassini lead mission engineer, Mars Exploration Program architect, Mars sample return chief engineer, Mars Exploration Rover Spirit mission manager, chief mission concepts architect, and advanced concepts development manager.

Brophy is project element manager for the ion propulsion system for the Dawn spacecraft. After working on solar electric propulsion at Marshall Space Flight Center, he later managed NASA's Solar Electric Propulsion Technology Application Readiness Project, which led to the successful demonstration of ion propulsion on JPL's Deep Space 1 spacecraft. He has also served as manager of JPL's Advanced Propulsion Technology Group.

Hofer, a senior engineer in the Electric Propulsion Group, joined JPL in 2005. He serves as the technology lead responsible for the development and qualification of Hall thrusters for deep-space missions. He is a member of the AIAA Electric Propulsion Technical Committee, and in 2011 he received the NASA Exceptional Achievement Medal and the JPL Lew Allen Award for Excellence.

Formal presentation of the trio's fellowships will be in conjunction with the 50th American Institute of Aeronautics and Astronautics Aerospace Sciences meeting in Nashville, Tenn. in January.

Durden named institute fellow

For his contributions to microwave remote sensing and radar systems, including spaceborne cloud radar, JPL researcher Steven Durden of the Radar Concepts and Formulation Group (334G) has been named a fellow of the Institute of Electrical and Electronics Engineers, the highest grade in the organization.

Durden joined JPL in 1986 and has worked on a number of airborne and spaceborne atmospheric radars, including CloudSat, as well as various research tasks involving modeling and analysis of radar data. He is a member of the American Geophysical Union, and currently serves on the NASA Precipitation Measurement Missions Science Team.

Passings

John Schlue, 75, a retired engineer and supervisor, died Nov. 8.

Schlue joined JPL in 1961. He contributed to numerous missions during his 44-year career, including Surveyor; Mariners VI and VII; the first two Vikings; SeaSat, the first dedicated oceanographic satellite; and the Shuttle Radar Topography Mission. He also served as manager of the Product Assurance Office and the Mission Assurance Office.


John Schlue

Schlue earned the the NASA Exceptional Service Medal in 1990 and 1991. He is survived by his wife, Dottie, son Craig and daughter Karen.

Chialin (Charlie) Wu, 64, a principal systems engineer in the Radar Science and Engineering Section, died Nov. 10. He had worked at JPL since 1974.

A researcher of digital signal processing techniques for radar and image sensors, Wu developed algorithms to accommodate spaceborne data, and co-authored a U.S. patent on the interferometric synthetic aperture radar apparatus for JPL missions. He also designed the scatterometer radar on the SeaWinds/QuikScat project, and was integration and test manager for the cloud profiling radar on CloudSat. Most recently, he participated in integration and verification tests for several radar instrument development projects and the terminal descent sensor for Mars Science Laboratory.

Wu was a recipient of the NASA Exceptional Service Medal.


Chialin Wu

He is survived by his wife, Yini Loh; sisters Chia-Cheng and Chia-Wei; children Emily, Michael and Jennifer; and grandchildren Matthew and Kaitlyn. Services were held Nov. 20 at Rose Hills in Whittier.

Retiree **Patrick DeCarolis Sr.**, 91, died Nov. 28.

DeCarolis maintained communication antennas for the NASA Mariner program, which launched a series of robotic probes to investigate Mars, Venus and Mercury from 1963 to 1973. He also contributed to the Voyager, Viking and Magellan missions. He retired in 1987.

DeCarolis is survived by his wife, Josephine; children Elaine DeCarolis Wilson, Jean Marie Pintarelli and Patrick DeCarolis, Jr.; grandchildren Dan Wilson, Gina Calderon, Kaci Wilson and Gemma and Shaelee DeCarolis; and great-grandchildren Luke Calderon, Cami Wilson, Cori Wilson and Charlie Wilson.

Services were held Dec. 3 at the Assumption of the Blessed Virgin Mary Church in Pasadena.

Letters

I would like to thank my fellow coworkers on the GRACE and CloudSat projects for the outpouring of emotional support during my son Robbie's illness. Your words of encouragement and your prayers carried me through those 15 harrowing days with him in the hospital. Lemierre Syndrome: "It's not just another sore throat!" He is home now and is expected to make a complete recovery. Thank you.

Mona Witkowski

The family of Katalin Herman expresses its warmest gratitude to our JPL family for the very meaningful event celebrating Katalin's life. The support and love expressed for us and for our dear Katalin touched us deeply and helped to comfort us during this very difficult time. Special thanks to Donna Cummings and Jackie Akers for all the work they did to make the event happen. We likewise appreciate all the support of the organizational leadership in 346, 314, Cassini and MRO, of the von Kármán staff, and of Visitor Control and Investigations.

In addition, I thank the leadership of 314, 31 and the MRO project for their rock-solid support during my leave of absence so that I was able to ensure that Katalin's final journey was experienced in a secure, comfortable, dignified and loving environment. I also thank all of our special friends who reached out to us, who were there for us and who supported us during that difficult journey.

David Herman

John was right when he always commended JPLers for being a large family of supportive people. Upon his death, you were close at hand, giving us your comfort, generosity and assistance, and filling our hearts with the fondest memories of his life. We thank you for remembering John Schlue in so many special ways: your donations to the American Cancer Society, beautiful plants, pictures and cards and the words you wrote on them. The ERC plant is cherished as are all of you.

Dottie, Craig and Karen Schlue

My family and I would like to thank all the members of the Facilities Division for your kind words of comfort and the ERC for the beautiful plant you so kindly sent in remembrance of the sudden passing of my brother, Frank Phillip Mayer. I would personally like to thank everyone for your kind thoughts through this very difficult time. We celebrated his life in a memorial service Dec. 27.

Andrea Ollier

I would like to thank everyone for the beautiful plant and support we received following the passing of my father-in-law. It was greatly appreciated.

Garson Yee

My brother George and I would like to thank our friends, colleagues and all of the wonderful people who make up the JPL family for the beautiful flowers and plant in remembrance of our mother. Your cards, e-mails, kind words and prayers have been a strength to us and to our family. Thank you all so very much.

Tom Fraschetti

Retirees

The following JPL employees retired in December: **Alan Hoffman**, 49 years, Section 513; **Michael Sander,** 44 years, Section 1000; **Elizabeth Emmons**, 38 years, Section 2501; **Rigoberto Medina,** 37 years, Section 268; **Larry Bright,** 35 years, Section 343P; **Tamlin Antoine**, 29 years, Section 280; **Deborah Mahoney**, 24 years, Section 3819; **Terry Durham**, 23 years, Section 272; **Karen Woodson,** 22 years, Section 3417; **Dan Handayan,** 14 years, Section 2632; **Anthony Bird,** 10 years, Section 2126.

Correction

Due to incomplete information provided to Universe, an article in the December issue about JPL contributions to NASA's Southeast Asia Composition, Cloud, Climate Coupling Regional Study incorrectly stated the number of JPL instruments flying on the campaign. There are five JPL instruments, four of which will fly on the ER-2 aircraft; omitted was the Microwave Temperature Profiler, led by JPL principal investigator Michael Mahoney. A proposal led by Simone Tanelli to provide radar observation of cloud microphysics and dynamics in convective environments will fly on the DC-8.

Universe

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