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Two years at Ceres

By Franklin O'Donnell

Before the Dawn spacecraft slipped into orbit around the dwarf planet Ceres in March 2015, many on the mission team thought they'd be lucky just to get to the icy world and collect some data. Optimistically, they thought, the spacecraft might be able to manage 15 months in orbit there.

Two years later, Dawn's tour at Ceres has turned out to be full of surprises of the happy kind. The spacecraft not only made it to the end of its prime mission last June 30, but has kept on going through six science orbits at various altitudes around Ceres. Currently it's completing an extended mission that ends this June.

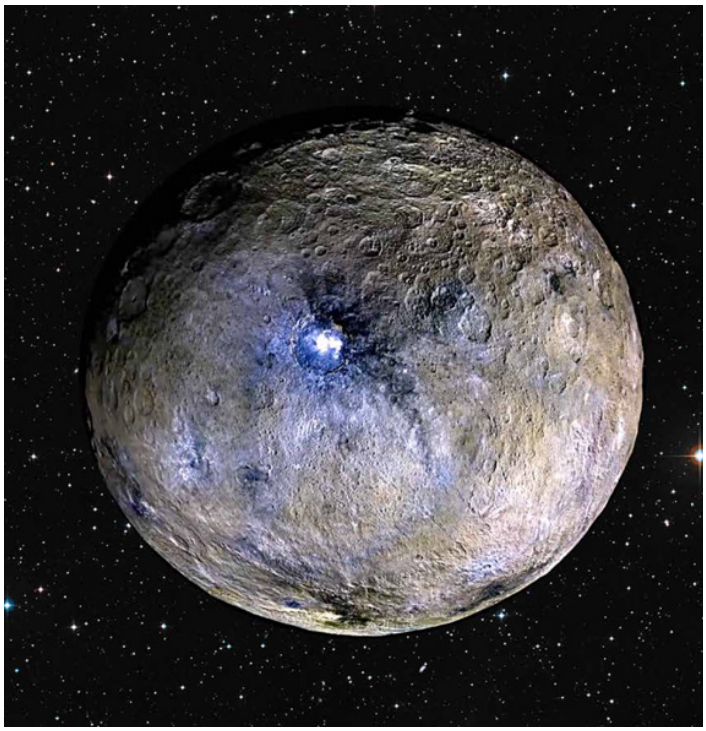
"It's really a testament to the ingenuity of the flight team," said Marc Rayman, Dawn's mission director and chief engineer. He said the 35-member team has "been brilliant in their conservation of hydrazine"—the fuel that powers the spacecraft's thrusters.

Expectations for Dawn's Ceres tour were guarded because of hardware issues that cropped up over the mission's 9½-year lifetime so far. Launched in 2007, Dawn is equipped with ion propulsion providing just enough gentle acceleration to allow it to achieve a first: orbiting not one but two different solar system targets beyond Earth's orbit. In Dawn's case, the targets were Ceres and the protoplanet Vesta, the two largest objects in the solar system's asteroid belt.

In order to maintain its orientation in space, Dawn carries four reaction wheels. Three of the gyroscope-like devices are needed to control the spacecraft's roll, pitch and yaw. They are augmented by a system of hydrazine thrusters.

So when two of the four reaction wheels failed before Dawn got to Ceres, the mission turned into a nail-biter. The team could compensate by turning to the thrusters to control the spacecraft's orientation, but hydrazine was a far from limitless resource.

"Last year at this time, we expected to run out of hydrazine later in 2016, or maybe early 2017," said Rayman. "But thanks to the team's ingenuity we have enough to continue operating at least until the end of our extended mission in June."



Dwarf planet Ceres is shown in these false-color renderings, which highlight differences in surface materials.

Dawn began its stay at Ceres in a relatively high circular orbit, gradually moving to lower orbits, collecting different science data at each altitude. In the extended mission that began last July, Dawn spent more time at a low altitude—closer to Ceres than the International Space Station is to Earth—before moving to higher altitudes last fall.

One of the main reasons to move to a low orbit was to measure nuclear radiation emitted from material down to about a yard underground—offering insight into the elements found there. That yielded "eight months of absolutely beautiful data," said Rayman.

As beautiful as it was, the data could be improved by another

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DAWN *Continued from page 1*

change in the orbit. By moving higher, Dawn could measure nuclear radiation from cosmic rays originating far outside the solar system. This could be subtracted out from the readings Dawn took at Ceres, making the data freer from noise.

Raising the orbit had another payoff. Low orbits, said Rayman, require much more hydrazine fuel, and if Dawn had stayed in a low orbit it would almost certainly have run out by now. Going to a higher orbit extends the mission lifetime.

Currently Dawn is executing another orbital change to achieve even more bonuses in science data. From Feb. 22 through April 24, Dawn is adjusting the angle of its polar orbit with respect to Ceres and the sun. This will provide a different illumination angle for imaging—much like moving a strobe in a photo studio.

"This orbit change is very difficult to achieve," said Rayman. "But the science will be worth it. Subtle changes in brightness will allow scientists to draw conclusions about the texture of surface materials on Ceres, even at the microscopic level of salt crystals."

Because of the new lease on life provided by the mission's thriftiness with hydrazine, the Dawn team is working with NASA Headquarters to identify possible options for further operations beyond the current extended mission. But even if the mission comes to an end June 30, Rayman says it has achieved fabulous results.

"We have really pushed the limits of Dawn's instruments and the entire flight system to take as much scientifically compelling data at Ceres as possible," he said. "We've gone way beyond the original plan for science data acquisition, conducting many measurements we never even conceived of prior to launch – and, in some cases, even before arrival at Ceres. The team has done a spectacular job."

Ceres Science: The Top 5

Dawn Deputy Principal Investigator Carol Raymond's picks of the top 5 science stories from the spacecraft's time at Ceres:

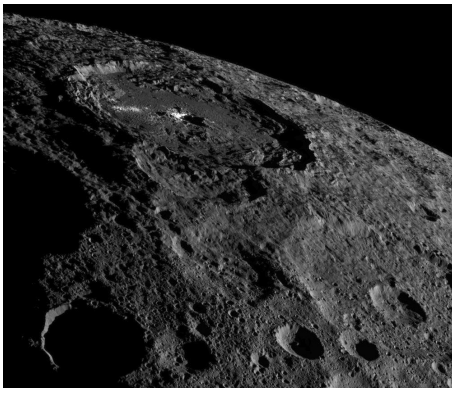
1. **Bright Spots:** First there were two of them, spied in Occator crater on Ceres as Dawn was arriving. Later the number of bright spots mushroomed to 130 or more, located all over Ceres' surface. Scientists found that the very bright material within Occator's central dome and other young craters is dominated by sodium carbonate. Known as soda ash or washing soda on Earth, it is a compound also found in the plumes on Saturn's moon Enceladus.

2. **Water Clues:** Ammoniated clays found all over Ceres' surface indicates extensive interactions between water and rocks. It also argues in favor of theories holding that Ceres itself, or the material from which Ceres formed, may have migrated from the colder environment of the outer solar system, moving inward towards Ceres' current position orbiting the sun in the main asteroid belt.

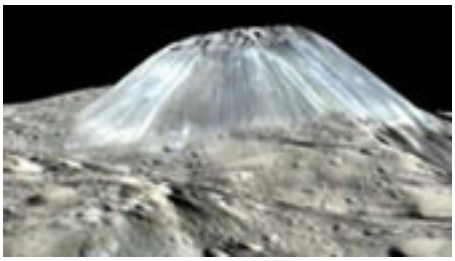
3. **Cryovolcanism:** Ahuna Mons, the largest mountain on Ceres, appears in fact to be a cryovolcano constructed when briny fluids erupted onto the surface. Cryovolcanism, possibly induced by impacts, may also contribute to flows and bright deposits in young impact craters.

4. **Organics:** Last month, Dawn scientists announced that one of the spacecraft's spectrometers found evidence for organic material in and around a northern-hemisphere crater called Ernutet. Organic molecules are interesting to scientists because they are necessary, though not sufficient, components of life on Earth.

5. Past **Subsurface Ocean:** Ceres' shape, gravity and surface morphology indicate separation of volatiles and rock within the interior during global scale alteration, leading to a subsurface ocean early in its history. This conclusion is supported by the presence of a shallow ice table a few meters deep at the equator, and just beneath the surface in polar regions, as revealed by gamma ray and neutron data.



An Oct. 17 image from about 920 miles above the surface shows Occator Crater, home of Ceres' intriguing brightest areas. Occator displays evidence of recent geologic activity.



Ceres' lonely mountain, Ahuna Mons, is seen in this simulated perspective view. Elevation has been exaggerated by a factor of two.

The Dawn science team found that the red areas around Ernutet crater are associated with evidence of organic material.

GRACE in triple overtime

By Franklin O'Donnell

Thanks to a special JPL GPS receiver, the twin satellites of the Gravity Recovery and Climate Experiment, or GRACE, mission can measure the distance between them to within 1/10th of the width of a human hair when they are 220 kilometers apart. This remarkable capability allows them to detect minute variations in Earth's gravity, enabling scientific findings in areas as varied as sea-level rise, melting glaciers, river hydrology, underground aquifers and earthquakes.

When GRACE launched in March 2002, JPL and its international partners expected the Earth-orbiting mission to last five years. Fifteen years later, GRACE continues to operate, though the state of its hardware requires special management. A successor mission, GRACE Follow-On, is planned for launch within the next year. Here, GRACE Project Manager Rob Gaston and Project Scientist Carmen Boening reflect on the mission.

The GRACE satellites have outlived their intended lifetime by a factor of three. How are they doing?

Gaston: We're thrilled that we've gotten 15 years of great science data. We're looking to do everything we can to achieve continuity with the GRACE Follow-On mission.

Of course, we're dealing with two aging satellites. It takes quite a bit of extra care to keep them going these days. We're just focused on doing the best we can with what capability remains with both satellites.

What are the main issues that you're dealing with?

Gaston: The primary one is the degradation of the satellites' batteries. These batteries have been in space longer than we ever expected, and as time has gone by, they are not putting out as much voltage as they did originally. That requires us to spend a lot of time working with the batteries and with satellite operations to maximize the science return.

Another factor is the cold gas, the compressed nitrogen used in the thrusters for attitude control. There is some uncertainty about exactly how much gas is remaining, due to different results we obtain when we calculate it in different ways. We think that in a worst-case scenario the gas will be fully consumed by the end of June 2017.

And another area is the altitude of the

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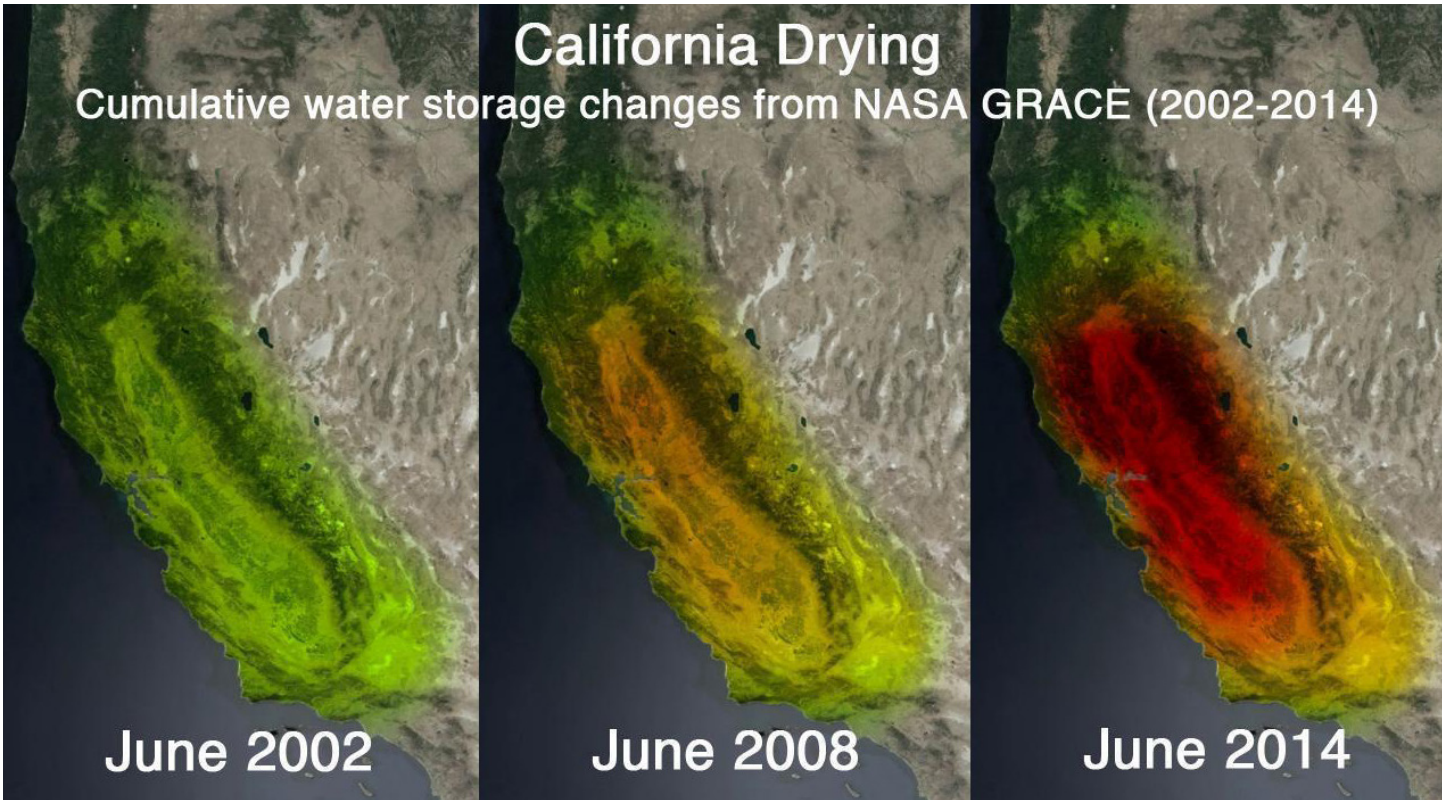


This trio of images depicts satellite observations of declining water storage in California as seen by NASA's Gravity Recovery and Climate Experiment satellites in June 2002 (left), June 2008 (center) and June 2014 (right). Colors progressing from green to orange to red represent greater accumulated water loss between April 2002 and June 2014.

Mission assured

New training program for systems engineers

JPL is initiating a new, career-enhancing training program in order to create a pipeline of talent to serve in the critical project role of mission assurance manager, a key function that combines leadership with strong technical know-how.

The mission assurance manager is one of only two independent technical authorities on every JPL flight project.

Candidates for the program, called "Safety and Mission Assurance Rotational Training (SMART)," will be nominated by division managers in the Engineering and Science Directorate (3x) and the Office of Safety and Mission Success (5x). Five to 10 candidates will be selected for the initial 12-week training period, from June through September.

The interactive training will feature real-life case studies, interactions with senior managers, facility tours and mentoring. Funding will be covered by 5x, and the time commitment is estimated to be four to five hours per week.

"We need people who think broadly, see the big picture and can lead a team," said Office of Safety and Mission Success Director Jan Chodas.

Trainees will be rotated though each of the mission assurance disciplines: mission assurance, reliability and environmental assurance, quality assurance, component engineering and system safety.

It's beneficial for engineers to spend some portion of their career in 5x, Chodas said. "The more you broaden, the more valuable you are to JPL."

"We value flow back and forth across the 3x and 5x boundaries," she added. "Those we have hired who have subsequently transitioned to 3x have the knowledge and experience of the independent risk perspective that we bring to projects, they understand our disciplines and expertise, and they develop a certain way of looking at their work."

Similar to project systems engineers, mission assurance managers report functionally to project managers. Chodas, former project manager for the Juno mission to Jupiter, "thought of my project systems engineer and my MAM as my left and right hands."

GRACE *Continued from page 3*

satellites' orbits. Over the years their altitudes have been gradually decreasing. When solar flares occur, it causes Earth's atmosphere to expand, causing more friction that slows down the satellites, lowering their altitude. Fortunately the sun has cooperated through much of the mission—early on in the mission they didn't anticipate we'd be able to stay up as long as we have. We're not expecting drag to bring us down until spring or summer 2018. Right now we anticipate the cold gas would be the thing that most likely would terminate the mission.

What science findings come to mind as some of the most important results from the mission?

Boening: I think one of the most important early findings was the Greenland ice sheet melt. Before GRACE, people sort of knew that the Greenland ice sheet was melting, but couldn't really quantify how much it was melting, and with GRACE we had the first tool that was able to see that.

Beyond that, one of GRACE's great advantages is that it provides a global measurement, so you get a sense of the global water cycle and how the ocean is connected to land and how that is connected to the ice. Having a comprehensive view of the water cycle was new to scientists. Before that, oceanographers looked at the ocean, hydrologists looked at land and glaciologists looked at ice—but they didn't think so much about the connections between the systems. With GRACE we're now able to study these connections better.

Do any other science findings come to mind as key results from the mission?

Boening: In the area of groundwater, one important result was trends we noticed in India related to the water use there. Another was the connections with how the whole water cycle was involved when we analyzed the sea level drop—how the sea-level drop was related to floods in Australia, and that in turn was caused partly by La Niña.

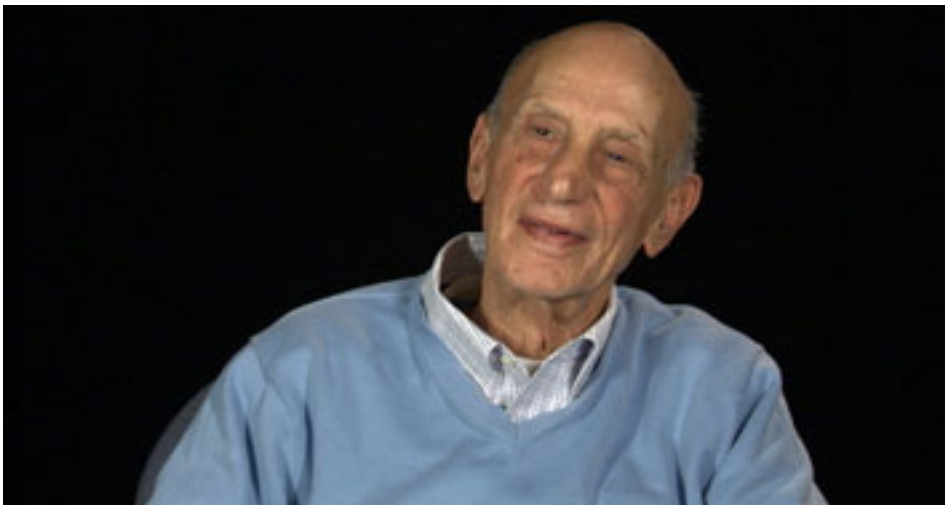
As you move from GRACE to the GRACE Follow-On mission, is there any new ground you'd like to break in science investigations?

Boening: With GRACE's data record established over many years, we're better able to see long-term trends versus short-term fluctuations in a variety of different areas—for example, in sea level, just to name one. We're better able to see how fast sea level is rising versus just increasing because of the natural variability in the water cycle. GRACE Follow-On will be important to continue that time series.

But what I think is really groundbreaking now that we're using GRACE data more and more for operational use for water management. I would like to see that happening more in the future. When GRACE Follow-On launches, the project will produce what is called a quick-look product—data that is available within a couple of days, instead of once a month. This will allow scientists and organizations using the data to react more quickly, and would be very useful in areas such as drought monitoring.

60 years a JPLer, Savino will be missed

Joe Savino, who died March 4 at the age of 85, is remembered by many for the strong impact he had during his 60-year career at the lab. Joining JPL in 1956 to work on missiles during JPL's era as an Army lab, Savino went on to contribute to numerous space missions for NASA over his long career. He became a JPL Fellow in 2009, and his most recent role was as the Division 34 chief engineer. Here, three leaders in the JPL engineering community share personal recollections of Savino's lasting influence.



John Casani, former chief engineer

Joe and I were hired here at JPL within a week of one another. I think I started on a Wednesday and he started either on the following Monday, or the preceding Monday.

We both were hired in to what was Section 17 at that time—this was before NASA was created, this was 1956—and the section manager was Jack James. I was in the missile equipment group, and Joe was in the ground equipment group.

The big project that JPL was working on at that time was something called CODORAC—coded Doppler ranging and command system. It was a guidance system. I was working on the stuff that was going to be in the missile, and Joe was working on the ground system. We both were working on parts of the system that had to interact with one another, and that's how I got to meet him. We became pretty good friends right from the beginning, and remained that way through our whole careers.

Just about every other project, we worked on together. All the Rangers and Mariner projects. I became the Voyager project manager, and he worked on Voyager, he worked on Galileo. Joe worked on every project that anyone else worked on here at JPL. We worked together a lot.

Joe was a problem solver. Joe could usually see his way right to the end, to the core issue of any problem. People just liked to talk to him, and he could always come up with something that was useful or helpful.

We have a lot of good engineers at JPL, but sometimes if you give them a problem and it's not hard enough, sometimes they'll find a way to make it harder. And Joe would catch people at that and say, no, you have to find the simple way. That's what I loved about him.

Jennifer Trosper, mission system manager, Mars 2020

I loved Joe Savino, because he was a person who would talk to anybody. He was interested in a lot of different stuff, he was not just interested in JPL—although he was loyal and committed.

He was a Renaissance man of his time. I knew him when he was older than that, but it was fun to hear all about the fascinating stuff that JPL was doing. I appreciated the stories about the intensity and the commitment and the loyalty that those folks had towards national goals that this laboratory has really led the nation in. I think Joe was a significant part of that, and I think he's a national hero because of what he contributed to the lab, and how that led to just us being at the forefront of space exploration.

Joe knew how the basic systems worked at their fundamental level. As a systems engineer, or a software engineer, we'll gloss over or sometimes forget to eat our meat and potatoes. He was a meat-and-potatoes guy when it came to engineering. I really appreciated how it was all basic and practical and sensible. He had a good way of focusing us back on the basics of how things worked, and forcing us to understand that.

Joe landed a job for me on [Mars] Pathfinder—which was the best job—and that was the springboard for all the things I do today.

Chris Jones, JPL chief engineer

He was a teacher at heart. Finding a young engineer who knows very little about the laboratory, and then helping them out, helping them cross that divide, I think was important to Joe. I think he wanted to share what he knew. He probably found himself fortunate to work at a place like this. He worked here for 60 years, when he passed.

It was interesting, because like a magnet, people were just drawn to him. Old friends would go over—I did many times—to sit down with him and ask him what he's working on. It was always something interesting; it was always something challenging. That's just how he was—he had a work ethic that just wouldn't quit. Even if he was eating lunch and was 85 years old, he wanted to give JPL his all. And that's what he did.

Physics conference aids women undergrads

JPL scientists helped UCLA students see the value of a career path to science and engineering

In recognition of the value of STEM education for young women and their careers, JPL recently co-hosted the 12th annual American Physical Society of Undergraduate Women in Physics conference at UCLA.

Led by Associate Chief Scientist Cinzia Zuffada, the event brought together a number of JPL scientists who appeared in panel discussions and interacted with about 250 women participating from a number of universities, including UCLA. A group from the Education Office staffed an outreach booth.

The students learned about the opportunities available to them from JPL and NASA.

"Participation in this event is very important to JPL," said Zuffada. "UCLA is a strategic partner and this is exactly one of those activities that increase our visibility on their campus. Also, JPL is engaged with NASA Headquarters in the "Women and Girls" initiative to reach out to female students, and graduates in physics are an attractive pool of potential new hires for JPL."

Rosaly Lopes, manager of the Planetary Science Section, moderated a career panel featuring women working in national laboratories. "We were providing perspectives on careers that are different from those in academia or industry," she said. "The energy in the room was incredible, it was so rewarding to see so many bright young women asking great questions."

"I was very impressed at the caliber of the students' work and their well-developed skills in presenting and interacting," said Annmarie Eldering, deputy project scientist in JPL's Earth Science Section. "I think they benefitted from a completely new set of information about possible career paths, and JPL will benefit in the long run when more young scientists and engineers think of us as their first choice for a career.

"I have greatly benefitted from role models and mentors in my career, so I would like to give that back to the next generation," added Eldering, who is an adjunct professor at UCLA.

Associate Chief Scientist Cinzia Zuffada led JPL's participation in the conference at UCLA.

Other JPL scientists on hand were Amy Mainzer and Farisa Morales (both UCLA alumnae), Alina Kiessling (astrophysics), Ashley Karp (propulsion), Christine Fuller and Moogega Stricker (robotics and planetary protection), Hui Su and Ming Luo (Earth science) and Jordana Blacksberg (instrument development).

News Briefs

Chattopadhyay gets alma mater honor

Goutam Chattopadhyay

Division 38 Senior Research Scientist Goutam Chattopadhyay has received the Distinguished Alumni Award by his undergraduate alma mater, the Indian Institute of Engineering Science and Technology, "in recognition of his outstanding contribution to the profession, scholastic achievement and dedicated service."

Chattopadhyay received his Ph.D. in electrical engineering in 1999 from Caltech, where he is a visiting associate in the Division of Physics, Mathematics and Astronomy. He is a Fellow of the Institute of Electrical and Electronics Engineers (USA) and the Institution of Electronics and Telecommunication Engineers (India) and an IEEE Distinguished Lecturer.

New solar-system book by Buratti

Bonnie Buratti

Bonnie Buratti, supervisor of the Comets, Asteroids, and Satellites Group, has published a new book, "Worlds Fantastic Worlds Familiar: A Guided Tour of the Solar System."

Written for non-specialist readers, Buratti provides a personal perspective about what it's like to be involved in a major scientific enterprise, with all its pitfalls and excitement.

Buratti has contributed to numerous JPL solar-system projects since joining the Lab in 1985. She earned the NASA Exceptional Achievement Award in 2006.

Passings

Bill Varga, 79, a retired senior instrument specialist in the Mechanical, Electric and Metals Fabrication Division, died Jan 12.

Varga worked at JPL from 1982 to 2002, contributing to Cassini, Galileo and Mars Pathfinder.

He is survived by his wife, Helen, daughter Emese, son Tamas and grandchildren Enikoe, Kinga and Sylvia.

A memorial service will be held April 8 at West Linn Lutheran Church in West Linn, Ore.

JPL systems engineer Patrick Wu, 66, died Jan. 24.

Wu had been with JPL since 1987. He is survived by his wife, Mirin, and children Ellen and Lina. Services were held at Rose Hills Memorial Park in Whittier.

Retirees

The following JPL employees recently announced their retirements:

February

William Revere, 39 years, Section 3500; **Neal Kuo**, 32 years, Section 312B; **Brenda Franklin**, 31 years, Section 3223; **Jessica Revere,** 31 years, Section 5114; **Daniel Walsh,** 27 years, Section 329H; **Lawrence Lee,** 25 years, Section 352B; **Annette Ling,** 25 years, Section 1000; **Cheryl Baker,** 21 years, Section 252E; **Edmund Hayes,** 14 years, Section 2814; **Wesley Traub,** 12 years, Section 3200.

January

Barbara Kachachian, 30 years, Section 3813; **Frances Taylor,** 27 years, Section 2724; **Jodi Befu,** 16 years, Section 3113.

Letters

I'd like to thank my colleagues for the plant and card after my father passed away in January. In particular, I owe a debt of gratitude to my colleagues in the OpsLab and the MSL ECAM team who covered my responsibilities during my lengthy absence. John Ellison was a true explorer who loved following along with the adventures of Curiosity and Opportunity and I am so very lucky to continue those adventures with my incredible colleagues.

Doug Ellison

E-MAIL US AT
universe@jpl.nasa.gov

Universe

Editor
Mark Whalen

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Classifieds

Ads submitted March 4 to 10.

Vehicles / Accessories

'99 HONDA Odyssey EX, 166,000 miles, charcoal metallic, fully loaded, original owner, very clean, well maintained and runs well, $3,500. 626-808-1009, Richard.

'12 NISSAN Rogue S sport utility, black, 81K miles, 2.5L I4 FI DOHC 16V engine, front-wheel drive, ~28 miles fwy, ~25.5 city, a/c, all electric controls for windows/mirrors, comes with a 2-bike rack, exc. cond.; moving abroad, can't bring it with us, we are the second owners and the car hasn't had any accidents or structural damages, can provide records for all maint./service for 2 1/2 years that we've owned it; $10,000. 818-268-3734 or peralta.lina@gmail.com; 818-325-7855 or nunez.paul@gmail.com.

Wanted

SPACE INFO/memorabilia from U.S. & other countries, past & present, for personal use (see http://www.youtube.com/watch?v=S7PvjGp7mCU). mrayman@alumni.princeton.edu, 818-790-8523, Marc Rayman.

Real Estate for Sale

TUJUNGA house, 2 bedrooms, 1 bath, 1-car garage, washer/dryer in unit, central air/heat; 8.5 miles to JPL, 15-20 min. on 210; $399,000. 714-497-0870, rgrealestate@msn.com.

For Rent

LOS ANGELES, master bedroom w/connected bath in shared 2-bed, 2-bath apt. overlooking Staples and Convention Center downtown, many attractions nearby; common areas fully furn., bedroom furnished on request; easy access to 110/10 frwys, across the block from Metro Pico station, many bus routes, 25-min. drive to JPL; utilities split 3 ways, 13-month lease; $1,325/mo. 951-454-9916.

PASADENA, furn. room in a lovely 4-bd./2-bath house, big backyard, hardwood floor, big closet, shared bathroom, kitchen and laundry privileges; 2 miles to JPL, close to public transportation; short- or long-term lease available; must like dogs and be very clean; $900 + $900 deposit. 818-960-8654.

SIERRA MADRE; 1-bedroom, 1-bath back house; internet, cable TV, trash and all utilities included; house has lots of storage with beautiful views of the mountains in a very quiet and private location; washer and dryer are in the garage; no smoking or pets; available April 1; $1,400/month. 626-644-7283.

TEMPLE CITY, 2 bedrooms, 2 baths, living rm., dining rm., lg. kitchen, lg. family rm., 2-car garage, single-family home in a quiet neighborh'd; walking dist. to Temple City High School, close to 210/10 frwys., Arcadia, Pasadena, San Gabriel; seeking long-term renter; asking $2,200/mo. 626-422-9032, Paula.

Vacation Rentals

MAMMOTH, Snowcreek, 2 bd., 2 ba. + loft, sleeps 6-8, fully equip'd kitchen incl. microwave, D/W, cable TV, VCR, phone, balcony w/mtn. vw., Jacz., sauna, streams, fishponds, close to Mammoth Creek, JPL discount, no pets. 626-798-9222, 626-840-3749 or valeriee@caltech.edu.

MAMMOTH, Snowcreek, beautiful updated condo, 2 bd., 2 ba. + loft (sleeps 6-8), great location by pond/meadow, new appliances, TVs, DVD players, free wireless Internet and washer/dryer, no pets. 818-952-2696 or BigMtnPrettySky@gmail.com.

MAMMOTH, remodeled 2 bed/2 bath + loft, short walk to Canyon Lodge; Courchevel 6 features full kitchen, cable/Internet TV, DVD, Blu-Ray, wireless hi-speed Internet, 2-car garage, Jacuzzis, grill, pool; no pets. http://Courchevel6.com.