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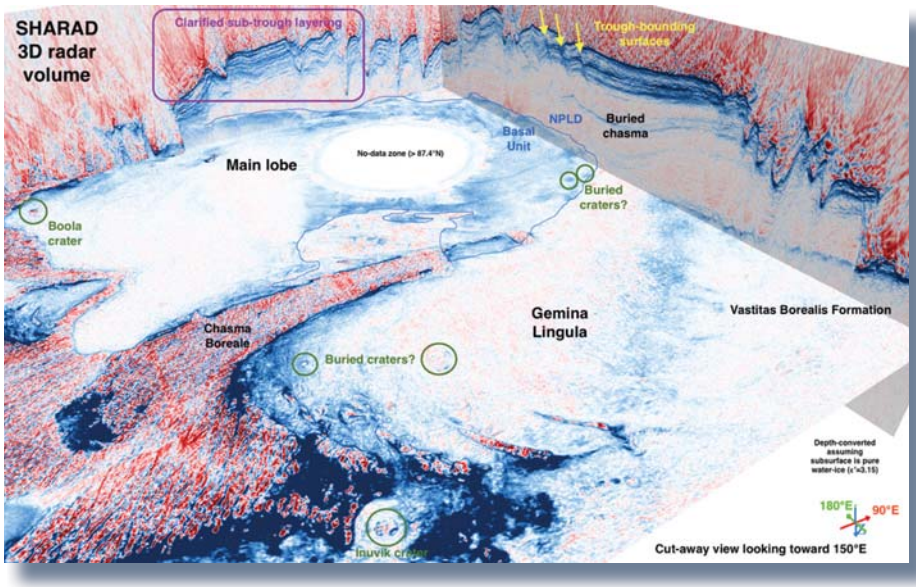
3-D Images Reveal Features of Martian Polar Ice Caps *by Alan Fischer*

Three-dimensional subsurface images are revealing structures within the Martian polar ice caps, including previously obscured layering, a larger volume of frozen carbon dioxide contained in the south polar cap, and bowl-shaped features that may be buried impact craters within both polar caps. This information will help scientists better understand Martian climate changes and may allow them to determine the age of the polar caps without using climate models. The 3-D data volumes were assembled from observations by the Shallow Radar (SHARAD) onboard NASA's Mars Reconnaissance Orbiter (MRO) during more than 2000 orbit passes over each Martian pole.

"We have applied industry-developed techniques in a very novel fashion to a Martian dataset, producing 3-D volumes that are each over 600 times larger than any terrestrial or planetary dataset of this kind," said PSI Senior Scientist Nathaniel "Than" E. Putzig, co-author of "3-D Imaging of Mars' Polar Ice Caps using Orbital Radar Data" that appears in a special section on remote sensing in the January issue of *The Leading Edge*.

"It is gratifying to see so plainly in the SHARAD volumes' structures that took years of effort to characterize with the single-orbit profiles," Than said. "I'm excited about what we will learn from newly revealed features such as the probable impact craters.



This cut-away view shows radar return power (blue high, red low) from features within Planum Boreum, the Martian north polar cap. The depth-converted 3-D volume of SHARAD data encompasses all of Planum Boreum. For scale, the no-data zone, in the main lobe, is 310 km across and the stack of NPLD layers to the right of the buried chasma is 2 km thick.

Credit: NASA/ASI/JPL/FREAQS/PSI/SI/WUSTL.

"While 3-D seismic and ground penetrating radar have become routine tools in terrestrial geophysical exploration, our 3-D treatment of the SHARAD data is a first in planetary geophysical exploration. The 3-D imaged SHARAD volumes significantly enhance the detectability and interpretability of features within the Martian polar ice caps," said Frederick J. Foss of Freestyle Analytical & Quantitative Services and lead author on the paper.

Layering seen at the surface of the Martian polar caps has been studied for decades. It has long been thought to represent a record of climate changes on that planet. The interior structures of the caps remained a mystery until the arrival of radar sounders at Mars in the last decade. Before, many important discoveries were made through analysis of data from collections of SHARAD single-orbit profiles, despite their inherent limitations. 3-D data products now exist for nearly the entire volume of polar-cap interiors.

Research led by PSI Postdoctoral Researcher Isaac Smith *(*published in *Science**) that found an early version of the north polar 3-D volume helped to assess the quantity of water ice transferred to the polar caps in the most recent retreat from a Martian ice age. First looks at the south polar 3-D volume indicate that previously mapped deposits of carbon dioxide ice are somewhat larger than reported. In both polar 3-D volumes known impact craters in and near the polar caps that are partially filled with ice have distinctive bowl-shaped signatures in the radar data. Similar signatures are found elsewhere within the polar ices but without any surface expression. Whether the latter structures truly are impact craters remains to be determined.

Age estimates of planetary surfaces throughout the Solar System rely on statistical data for impact craters on the Moon's surface calibrated to radiometrically dated samples returned during the Apollo program. This method has been used to estimate the surface ages of the Martian polar caps, but estimates for the ages

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Inside this issue:

Getting to Know Darby Dyar

Darby Dyar joined PSI in the spring of 2015 as a Senior Scientist and continues in her role as Chair and Professor of Astronomy at Mount Holyoke College (and serves on the Graduate Faculty at the nearby University of Massachusetts). Her move to PSI was motivated by her sense of isolation from other planetary scientists, a desire to work with junior colleagues, and the inability of the College to accept federal subcontracts.

Darby was a relative latecomer to science. Growing up in Indiana she hated her one year of required science (biology) in high school; she wanted to study writing, art, and design. She left Hoosiers behind for good when she went to Wellesley College, where she happily studied art history until her junior year, when she was again required to take a science course. Darby became interested in geology because of a female faculty member, Meg Thomson, who not only showed her that geology is a highly visual discipline (it used the skills she was already using to study art) but also that a woman could be a scientist. That and her love of the outdoors was all it took for her to become a geology major.

She also took exchange courses at Massachusetts Institute of Technology (M.I.T.), where she met Roger Burns* who talked her into going to graduate school there to work on lunar samples. He not only encouraged her as a scientist but also believed in letting her cultivate her artistic side; he looked the other way when she continued to sing in a capella groups (she is a coloratura soprano) and study painting throughout her M.I.T. graduate career.

Since then—and for more than 30 years— Darby has been fortunate enough to teach and work with students, finding joy in mentoring scientists at all levels. She views this as the centerpiece of her career. She sees her research as a means to getting others interested in science and a way to lend vitality to her classroom presence.

Her research builds upon her passion for mineralogy and all types of spectroscopy. Darby began with Mössbauer spectroscopy, and that lab remains part of her research group. There they study redox ratios of iron in a wide assortment of bulk materials from meteorites to mid-ocean ridge samples, pegmatites, cannonballs (from old shipwrecks), bio-minerals, and everything in between. That work quickly expanded into synchrotron studies of redox ratios in geological materials at microscales, an endeavor that continues today in her work at Argonne National Laboratory.Along the way, she became interested in other elements that are difficult to analyze in geological samples (oxygen, beryllium, boron, and lithium), and developed standards and new techniques that are now in use around the world.

A decade ago, a student showed her the power of multivariate analysis and machine learning techniques for understanding spectroscopic data of all types, and that work is growing into novel techniques for interpreting data from laser-induced breakdown, Raman, and VNIR-MIR spectroscopies. The harder the problem, the more it interests her! For example, Darby is currently working on technique development for instrumentation and spectral calibration of data from Venus' orbit and surface.

Darby with her two children, Lindy and Duncan Crowley.

In her free time, she tries to keep track of and support her two kids, now in college, and create art quilts. Darby also rows on the Connecticut River with a crew team from Holyoke; they have a lot of fun, even when they race. This past year she crossed a life goal off her bucket list by rowing in the premier crew race in the world, the Head of the Charles Regatta in Boston.

We are very happy to have you aboard, Darby!

Fall 2016, Darby (center) and her crewmates in front of their boat just after rowing in the Head of the Charles Regatta. *(Photos: Darby Dyar)*

**Roger Burns, a renowned professor of mineralogy at MIT, died in 1993; Darby was his last Ph.D. student. Burns Cliff on Mars was named after him.*

Front page banner: This painting by PSI's Bill Hartmann shows one of the eruptions from fractures at the south pole of Saturn's moon, Enceladus, that was discovered by the Cassini spacecraft. Enceladus is covered in part by fractured icy plains with few impact craters, implying geologically recent eruption of water, and a possible ocean under a cover of icy plates. Cassini then discovered actual geyser-like eruptions along fractures near the south pole from which jets of water vapor, other gases, and particles such as salt crystals are escaping. PSI's Joe Spitale pointed out that some of what look like single jets are actually curtain eruptions, seen edge-on along fractures. The foreground fractured ice blocks are based on crumpled lava blocks along a fracture in lava plates, which Hartmann painted outdoors on the floor of Kilauea Volcano in Hawaii.

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Chris Holmberg, Editor and Writer

Alan Fischer, Writer and Photographer

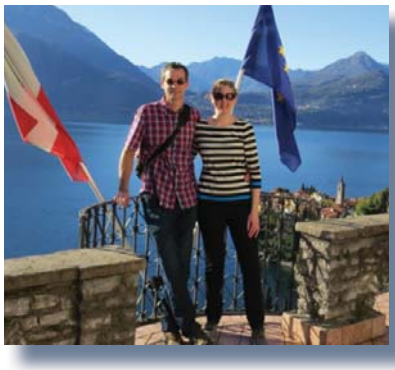
Special thanks to Kimberly Foote, Dianne Janis, and Elaine Owens

Than Putzig and PSI's New Colorado Office

Nathaniel Putzig ("Than") is a Senior Scientist at PSI and heads up our newly established office in Lakewood, Colorado. Than studies the near-surface properties of Mars using radar, thermal, and other data acquired from orbit. He holds a Bachelor of Science in Geophysical Engineering from Colorado School of Mines (1986), a Master of Arts in Geophysics from Rice University (1988), and a Doctorate in Geophysics from the University of Colorado (2006).

At Rice, Than participated in a deep-crustal seismic survey, modeling refracted signals to reveal a remnant of the Farallon plate pasted under San Luis Obispo, CA. In 1988, he went to work with Shell Oil Company, bringing his refraction skills to bear on near-surface seismic noise problems for oil and gas prospects in Michigan, West Texas, and Yemen. Joining the seismic software company Photon Systems Inc. in 1993, he helped expand their U.S. customer base from one to 100 clients in two years. Photon was sold in 1995 and after a year managing a 25-person software support group Than took up consulting, closing out the millennium providing seismic data analysis services.

Than was inspired by news of Mars Global Surveyor and Cassini to abandon industry and retool for extraterrestrial exploration, returning to graduate school in 2001 at the University of Colorado. Prior to obtaining his doctorate in 2006 (on the topic of the thermal inertia of Mars), he convinced Roger Phillips, then the U.S. lead on the Mars Reconnaissance Orbiter's Shallow Radar (SHARAD) Team, that he needed an understudy with seismic experience.



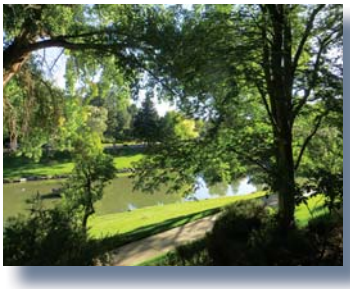
After a SHARAD meeting in Bologna, Italy, Than and his wife Lauren visited Lake Como. *(Photo: Than Putzig)*

After a brief post-doctoral position at Washington University in St. Louis, Than followed Roger in 2007 to the Southwest Research Institute in Boulder, taking on an increasingly larger role in SHARAD planning. In 2015, Roger began segueing into retirement and Than took over the lead of the U.S. SHARAD Team, relocating its headquarters to the PSI Colorado office in 2016.

Lobby of the Colorado office.

Despite a general lack of spare time, Than manages to squeeze in a bit of time to bake bread and go mountain biking and skiing.

Our Colorado office was established in July 2016 when Than and Postdoctoral Researcher Isaac Smith joined PSI. The PSI suite in the Denver West Office Park is equipped with a foyer, conference room, kitchen, library, IT/copy room, and five spacious offices. Research Associate Matt Perry joined the PSI Colorado staff in November 2016, and the current office can accommodate several more staff before an expansion is needed. The complex offers additional onsite meeting spaces able to host larger meetings and workshops (100+ attendees).



Snapshots from the PSI Open House in September 2016 at our new Lakewood location. The office complex—Denver West—features a picnic area overlooking a lake. Below, PSI Postdoctoral Researcher Isaac Smith (left) performs chef duty with his wonderful, smoky BBQ grill.

We welcome Than and the Colorado office to the Institute!

At the Colorado Open House in September, l-r: Than Putzig, PSI Research Associate Matt Perry, back of Matt Chojnacki (UA), and Fritz Foss (FREAQS, consultant to PSI on SHARAD 3-D radar projects).
(Colorado photos: Chris Holmberg)

3-D Images of Martian Ice Caps *(cont'd from front page)*

of the caps themselves have had to rely on numerical models of past climate changes.

If a sufficient number of the bowl-shaped features found in the radar volumes are shown to be impact craters, scientists will be able to assess the age of the polar caps using cratering statistics alone. The extent to which age estimates from this new volumetric method agree or disagree with those from climate models will have important implications for the accuracy of these dating techniques.

**Smith, I.B., N.E. Putzig, R.J. Phillips, J.W. Holt (2016). A Record of Martian Ice Ages. Science 352, 1075-1078.*

Planetary Science Institute support of SHARAD 3-D projects is funded by grants from NASA's Mars Data Analysis Program.

Introducing John Weirich

John Weirich joined PSI in 2015 as a Postdoctoral Research Scientist working with PSI Senior Scientist Eric Palmer. His current work is all about shape modeling and Digital Elevation Modeling using the Stereophotoclinometry (SPC) software written by another PSI Senior Scientist, Bob Gaskell. The software takes 2-dimensional images and generates a 3-dimensional shape that can be used for spacecraft navigation or science. His biggest project is getting the SPC software ready for the OSIRIS-REx mission. The shape model they generate will be used to navigate the spacecraft safely to the surface of asteroid Bennu, where a sample of regolith (loose soil) will be collected and returned to Earth. He is also using the SPC software to generate topography for the Moon, and is proposing to use it on Ceres and other small bodies and planets.

John Weirich checking alignment of a high-resolution image to low-resolution topography.

Prior to joining PSI, John's science focus was on age dating meteorites and other rocks that had been involved in collisional impacts using the $^{40}Ar/^{39}Ar$ method. A fraction of potassium (K) naturally decays to argon (Ar) over time, and this Ar will be removed by a large heating event such as a collisional impact. Since we know how quickly K decays to Ar by measuring the amount of K and Ar present in the meteorite, the age of the impact can be determined. Another large component of that work was writing code to model how the age was reset, with close attention to error analysis.

John obtained his Ph.D. in Planetary Science from the University of Arizona in 2011 under Tim Swindle, the current Director of the Lunar and Planetary Laboratory. After that John was at Arizona State University and then Western University in Ontario, Canada. Meanwhile, at PSI the SPC team was understaffed for the level of testing required by the OSIRIS-REx mission. Eric Palmer knew about John's coding experience and familiarity with error analysis and thus he was selected to be part of the team.

John's journey to a degree in space science is probably atypical. He grew up in Washington MO, a town with a population of 10,000, located 50 miles west of St. Louis. While he was interested in science from a young age, it was not space science in particular. When deciding which degree to pursue in college it was a toss up between computer science and physics. He chose physics based on his theory that it would make him a rarer commodity (John says: "Ha!"). He obtained his B.S. in Physics from the Missouri University of Science and Technology.

When it came time to think about graduate school, none of the fields really grabbed him. Astronomy seemed the most interesting so he wisely did a Research Experience for Undergraduates at the Maria Mitchell Observatory. The observatory on Nantucket is now a museum and the telescope is no longer used for research, so his projects involved the 12-meter radio telescope on Kitt Peak and the Maria Mitchell Observatory astronomical plate collections. There he discovered that although he wasn't too interested in stars, he was *very* interested in planets. After joining the graduate program at the University of Arizona he eventually narrowed it down to small bodies and impact craters and hasn't moved far from there since.

John with his wife, Laura, and their sons, Hugh (in plaid) and Stephen. *(Photos: Chris Holmberg)*

Having said all that, he's seen *Return of the Jedi* more than any other movie, so perhaps it did influence his decisions. He explains why he watched the same movie over and over: He was an only child, bored over summer break with no one his age close by, he couldn't drive yet, and there were few movies or books at home. Perhaps in an alternate universe he became a Kung Fu master since they also had *Enter the Dragon.*

However you reached PSI, John, we are so glad you did!

Meet Xiao-Duan Zou

Xiao-Duan Zou joined PSI in 2015 as a Postdoctoral Research Scientist, bringing with her an expertise in rocky minor planets. She studies the geological and physical properties of surfaces of the Moon, asteroids, and comets.

Xiao-Duan was born in Guiyang, China, not far from the five-hundred-meter Aperture Spherical Telescope, or FAST—the largest radio telescope in the world. Her husband worked on the FAST team before they moved to the U.S. Her interest in science began when she was about 5 years old and she decided she wanted to move to the nice, shiny Moon, only to be told that some Americans got there first, many years ago!

In college, she spent four years in Shanghai, earning her Bachelor of Science in Surveying Engineering from Tongji University in 2005. Then Xiao-Duan moved to Beijing and started working for the National Astronomical Observatories of China (NAOC). She earned an M.S. and then a Ph.D. in 2014, both in astronomy, from the Chinese Academy of Sciences.

Before she joined PSI, she worked as an Assistant Researcher at the National Astronomical Observatories of China,

Continued on pg 6

Director's Note

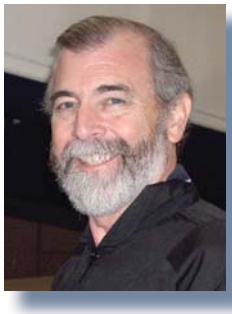
From one Newsletter to the next, there is always something exciting going on!

Our new Colorado office is terrific. Being originally from the Pacific Northwest, I love the park-like environs with all of its trees and water. The office itself is very inviting with good space and lots of wood, and of course the Great Seal of PSI! We are fortunate to have Than Putzig, Isaac Smith, and Matt Perry as our initial staff. The work they are doing with SHARAD (some of which is shown in the cover article) is amazing (who doesn't love what radar can do?) and they are a great group of friendly people. I look forward to seeing our presence in Colorado grow. I also look forward to another open house or other excuse to have Isaac exercise his culinary skills. At our first open house, Isaac barbequed about 40 pounds of pork, which was delicious and to die for —which is exactly what would have happened if we had consumed that much meat in one sitting!

There is good news for the Discovery program! This program was the workhorse of Solar System exploration from the 1990s through 2001; ten missions were selected for flight over a ten-year period. This past year, NASA selected five Discovery proposals for Phase A studies; PSI scientists are on four of the teams. NASA selected two missions to go forward (only two missions had been selected in the previous 16 years) and PSI is on one — a mission to the main-belt asteroid Psyche, which is thought to be the remnant metallic core of a larger disrupted asteroid.

PSI is also involved with NEOCam, a mission to survey the near-Earth object population and scan through the entire main asteroid belt. NEOCam was given "extended Phase A" support as efforts are made to find additional funding to build and launch it (in part because it is the only way NASA can meet the Congressional mandate of finding all NEOs with diameters >140 m — a little larger than the object that flattened over 2,000 sq-km of a forest in 1908 Russia).

In the meantime, there is much speculation about the future direction of NASA under a new Administration (as happens whenever there is a change in Administration!), particularly in the area of human exploration. One thing that is increasingly clear is that as we move beyond low Earth orbit and contemplate other worlds, whether the Moon, Mars or even near-Earth asteroids, the importance of the science we do in understanding these objects is more and more obvious. We are the "native guides."



Mark V. Sykes
March 2017

PSI Staff News

Alan Fischer and Emily Joseph Honored by NASA

Alan Fischer and Emily Joseph with a small scale model of NASA's Dawn spacecraft.
(Photo: Chris Holmberg)

In December, 2016, PSI Research Assistant Emily Joseph and Public Information Officer Alan Fischer were honored for their work in publicizing NASA's Dawn mission, which is currently on its way to the dwarf planet Ceres.

Emily and Alan are members of the Dawn Communications and Outreach Team that received a 2016 NASA Group Achievement Award "for outstanding execution of the Ceres public communications campaign, sharing the excitement of the Dawn mission with the world," NASA said.

Congratulations, Emily and Alan!

Mary Bourke on Irish Television

PSI Senior Scientist and Professor of Geography at Trinity College, Dublin, Mary Bourke was profiled on Irish Television in 2016. Mary, equipped with a drone and a pair of Wellington boots, sloshed around the coastline at Ballard Bay, County Clare, Ireland, studying the rocky cliffs to catalog and understand them. The drone is used to map the landforms, something she and her team do in spring, summer, and fall. They are watching the actual landforms over time, which she finds more useful than studying models, to truly understand the resilience of the cliffs.

***Mary Bourke** (courtesy of RTÉ One)*

"How resilient are the rock cliffs? How are they eroding? We need to know because once they are gone, they are gone for good. Cliffs do not re-form," she said.

Well done, Mary!

Another son for Yuki Yamashita

(Photo: Yuki Yamashita)

PSI Senior Scientist Yuki Yamashita and his wife Kumi welcomed their second son, Mutsuki, on Jan. 10, 2017. He weighed 7 lb, 7 oz. His name is the classical Japanese word for '"January." Older brother Mizuki is evidentally taking it all in stride.

Congratulations, Yuki and Kumi!

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Meet Xiao-Duan Zou *(continued from page 4)*

where she devoted eight years to the Chinese Lunar Exploration Project.

Xiao-Duan still remembers vividly when the Chang'E-1 mission started; she worked an entire week on 20 hours sleep! Using data collected by the Chang'E-1 probe, she produced China's first high-quality map of the Moon. She also processed the laser altimeter data and made the digital elevation model that provides insight regarding the Moon's topography and geology. During the Chang'E-2 mission, the probe was controlled to make a super-close flyby with asteroid 4179 Toutatis. She analyzed the detailed photos of Toutatis and was attracted to the small bodies world.

When Chang'E-3 started, Xiao-Duan was already a core member of the team. She was not only involved in the landing site selection process, making an evaluation of the potential landing site, but she also participated in the planning and processing of the Landing Camera, Monitor Cameras, and Panoramic Camera of the rover. Then she took part in the planning and landing sites selection in both the Chang'E-4 and Chang'E-5 missions.

Now at PSI she is working with Senior Scientist Jian-Yang Li on photometry modeling on different minor planets. She is on the science teams for the Dawn mission and OSIRIS-REx. As a photometric modeling group member, she is participating in software development and data analysis and photometry analysis of the asteroid Bennu. When the first batch of data returns from the spacecraft in 2018, she will be using photometric methods to analyze the geological properties of Bennu.

Xiao-Duan has been involved in science outreach programs ever since her days at NAOC. She has written many articles introducing planetary science and space missions to the public on the James Webb Space Telescope, OSIRIS-REx, New Horizons, and Lucy and Psyche. She is also enthusiastic about charity education programs. Her wish is to repay her hometown by helping its underprivileged children. By exposing every child there to the beauty of planetary science she hopes more young people will discover the life-changing opportunities that higher learning offers.

Xiao-Duan Zou's daughters, (l-r) Peggy and Daisy. *(Photos: Xiao-Duan Zou)*

Xiao-Duan is a mom to two little girls, Peggy (2) and Daisy (7). And she says: "Thanks to the schools of Maryland, I am learning correct American English from my daughters every day!"

PSI is very pleased to welcome Xiao-Duan to our science staff!