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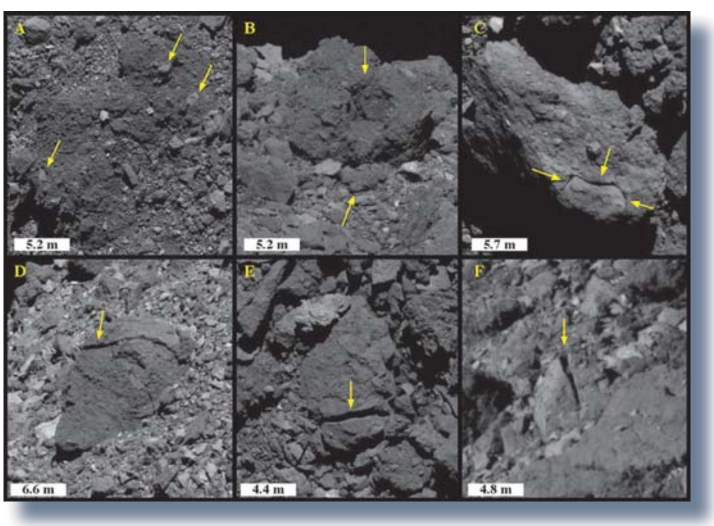
NASA's OSIRIS-REx Finds Heat and Cold Are Fracturing Rocks on Asteroid Bennu *by Alan Fischer*

Close-up observations of asteroid Bennu by NASA's OSIRIS-REx spacecraft have shown the first evidence of thermal fracturing of rocks on an airless body, a *Nature Communications* paper by PSI Research Scientist Jamie Molaro says.

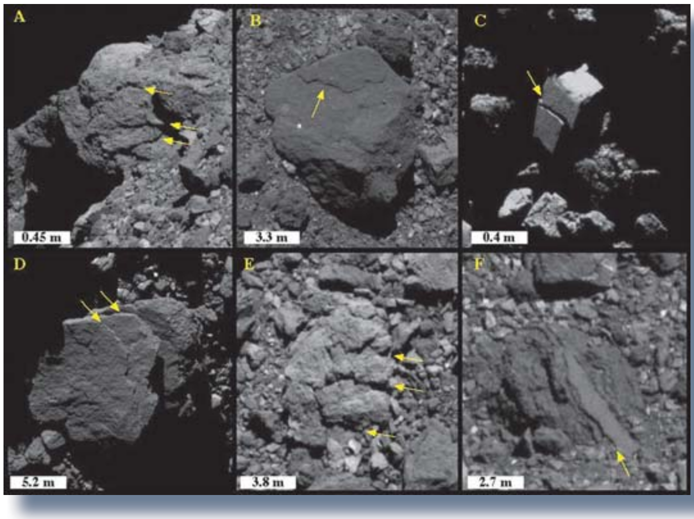
Thermal fracturing or thermal stress weathering occurs as rocks heat and cool each day, and mechanical stresses build up that can cause cracks to develop and grow. Over time the cracks grow larger and cause the rock to disaggregate or split into multiple pieces. For example, daytime highs on Bennu can reach about 400 degrees Kelvin (260 degrees Fahrenheit), and nighttime lows plummet to 200 degrees Kelvin (-100 degrees Fahrenheit).

"This is the first time thermal fracturing has been definitively observed on an object without an atmosphere," said Jamie, lead author of the paper "In situ evidence of thermally induced rock breakdown widespread on Bennu's surface" published June 9, 2020. "It is one piece of a puzzle that tells us what the surface used to be like, and what it will be like millions of years from now."

"This thermal induced breakdown has long been identified on Earth. The OSIRIS-REx Camera Suite (OCAMS) orbiting as close as 0.6 km (0.4 mi) has obtained images of the surface of Bennu at pixel scales down to about 1 centimeter per pixel, providing an



Examples of disaggregation (top) and linear fractures (bottom) in boulders of varying sizes on Bennu. *Credit: NASA/Goddard/University of Arizona*



Exfoliation features on a cliff face (a) and on boulders (b-f) with varying size and location. The bright dome on the horizon of panel (a) is a boulder behind the exfoliating cliff. *Credit: NASA/Goddard/University of Arizona*

opportunity to search over a wide range of scales for evidence of thermal breakdown occurring in situ," Jamie said.

"On Earth there are chemical weathering processes that help make thermal fracturing more efficient. The presence of air and moisture within cracks makes them easier to grow, and so on Earth this effect really cannot be decoupled from the effect of the thermal stresses themselves. We've observed evidence of thermal fracturing on Earth and on Mars, both environments where chemical weathering does or could help out. Therefore, while it was theoretically possible for thermal fracturing to occur alone, it was not clear whether or not the stresses could be strong enough to cause crack growth in absence of the chemical effects," Jamie said.

"Like any weathering process, thermal fracturing causes the evolution of boulders and planetary surfaces over time; from

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Hubble Observes Interstellar Comet 2I/Borisov Rich In Carbon Monoxide *by Alan Fischer*

Studies of a comet from beyond our Solar System have yielded insights into how other star systems may have formed.

Interstellar comet 2I/Borisov, observed using the Hubble Space Telescope, displayed a high amount of carbon monoxide, CO, relative to the amount of water it contains, compared to the comets from our Solar System, said PSI Senior Scientist Jian-Yang Li.

Comet 21/Borisov
Credit: NASA, ESA, K. Meech (University of Hawaii), D. Jewitt (UCLA)

"The biggest news is probably (that this is)the first measurement of the CO composition in a sample from another star. This has never been possible to do due to the enormous distance to another planetary system and the extreme faintness of these small objects around other stars," Jian-Yang said. "Given the frequency of recent discoveries of such interstellar objects – two in just two years – and thanks to the advance of telescopes and survey techniques, we can expect more and more such objects discovered and characterized in the near future. This comet may represent the start of a new era in studying extrasolar planet formation."

Jian-Yang led the acquisition and initial verification of the Hubble data and is co-author on the paper "The carbon monoxide-rich interstellar comet 2I/Borisov" that appeared in *Nature Astronomy*. Dennis Bodewits of Auburn University's Leach Science Center is lead author on the paper.

"I led the design and planning of the observations, and validation of the data, and also contributed to the interpretations of the results – what the data are telling us about the history of the comet," Jian-Yang said.

Observations were made in ultraviolet, which is severely blocked by Earth's atmosphere. Hubble, above the atmosphere, was needed to make the observations, Jian-Yang said.

"The high amount of CO is an indication that it comes from a very cold place, either extremely far away from its host star or from a relatively cold star. We think it's more likely to be the latter case – it comes from a cold red dwarf because there are far more red dwarfs in our Milky Way galaxy than other hotter stars," Jian-Yang said. "However, we are still far from saying exactly what's going on around its host star when planets formed there."

2I/Borisov offers scientists a glimpse of how other planetary systems may have formed. "All other comets that we have studied so far are formed within our Solar System, whereas this comet certainly comes from around another star," Li said. "We generally consider comets as the 'original building blocks' of gas giants and their major satellites in our Solar System. So this comet should represent the building blocks of exoplanets around their parent star."

Studying comets is important because astronomers are still trying to understand the role they play in the buildup of planets. They could also have redistributed organic material among young planets, and may have brought water to the early Earth. These activities are likely happening in other planetary systems, as demonstrated by 2I/Borisov's makeup.

"So far we've discovered thousands of extrasolar planets around other stars, but we know nothing about the formation conditions and processes. This comet is the first sample from another star that we can directly measure the composition to infer what's going on when planets form around another star," Jian-Yang said. "However, it is still too far from knowing exactly what happened during the planetary formation process around other stars from this one single sample."

Bennu Rocks *(Continued from Page 1)*

changing the shape and size of individual boulders, to producing pebbles or fine-grained regolith, to breaking down crater walls," Jamie said. "How quickly this occurs relative to other weathering processes tells us how and how quickly the surface has changed. It is one piece of a puzzle that tells us what the surface used to be like, and what it will be like millions of years from now. We don't have good constraints yet on breakdown rates from thermal fracturing, but we can get them now that we can actually observe it for the first time in situ.

"We show observations of boulder morphologies and fractures on Bennu that are consistent with models of thermally induced rock breakdown, and not easily explained by other weathering mechanisms. Boulders on Bennu exhibit many possible signs of thermal fracturing, but the clearest is images showing exfoliation, where thin layers of material flake off boulder surfaces," Jamie said. "These findings provide substantive and compelling evidence that thermal fracturing plays an important role on airless body surfaces, which has major implications for understanding the evolution of asteroid surfaces, orbits, and populations."

Jamie Molaro's research was funded by a grant to PSI from NASA's Participating Scientist Program.

Frontpage banner:
This is an infrared image of the Helix Nebula taken by NASA's Spitzer Space Telescope. At 695 light years from Earth, the nicknamed "Eye of God" is the nearest bright nebula to our Solar System and is in the Aquarius constellation. It was discovered in about 1824 by Karl Ludwig Harding. *Image Credit: NASA/ JLP-Caltech/ University of Arizona*

Katie Primm: Another Admirable Addition to the Institute *by Chris Holmberg*

Katie Primm and her husband Paul honeymooned in Ireland, in 2019.

Katie Primm joined PSI in 2020 as an Associate Research Scientist and works from her home in San Diego, California. She uses her foundations in astrobiology and geochemistry to study the surface chemistry and atmospheric interactions on Mars and Europa. She focuses on studying these interactions via laboratory experiments and modeling, using optical microscopy, Raman spectroscopy, and dielectric spectroscopy.

Katie grew up and attended primary and secondary school in Texarkana, Texas. She was very influenced by her two highly educated and industrious parents and her older sister. Her father taught history in high school, later earning a computer science and engineering degree. Her mother arrived from Hong Kong with a degree in Chinese literature and history and went on to earn a Master's Degree in Education in the U.S.

Katie, at right, on her second birthday with her influential older sister, Kara.

Katie followed in her older sister's footsteps in several important ways: She joined band in middle school and even attend the same college in Conway, AR – University of Central Arkansas. (Tip for parents: We've been writing about scientists for 18 years and playing a musical instrument appears to be a vital key to success.)

Katie mostly enjoyed math growing up, but discovered chemistry in high school. She was delighted to figure out that you can incorporate math into science: "You use math to explain things, such as the value of heat in a chemical reaction. You use equations to figure that out," she said.

Katie earned her B.S. in Chemistry at the University of Central Arkansas and her M.S. and Ph.D. in Analytical Chemistry at the University of Colorado-Boulder. In addition to her family, some wonderful mentors played a large role in her evolution as a scientist.

During graduate school at CU Boulder, Katie's advisor was Margaret Tolbert. There she worked on the brine and ice formation of pure perchlorate and chloride salts and mixtures with Mars regolith simulants and relevant minerals using Raman spectroscopy and microscopy. She also worked closely with Raina Gough, who is a part of the Mars Science Laboratory Science team, to help constrain the hydration and dehydration of perchlorate and chloride salts. Having two strong female role models in graduate school helped encourage her to work hard and continue a career in research science.

Shortly after earning her Ph.D., she worked with David Stillman at the Southwest Research Institute (SwRI) in Boulder as a postdoc and studied these same salts using dielectric spectroscopy. There she enjoyed one of her favorite moments in science, so far: She built a new Mars chamber that can remotely control humidity, temperature, and pressure while measuring the electrical properties of samples. The Mars chamber is a cylinder 11" x 12" that is designed to measure electrical properties of a Martian soil sample as it sits on a cold plate within the chamber.

Another great moment was winning her first NASA grant as principal investigator to study slope streaks on Mars. Slope streaks look very similar to recurring slope lineae (RSL) which are seasonal flows that are darker than their surroundings, but can be 10 times bigger and are rarely seen to fade.

Katie and her science team found that there was not a complete comprehensive study that brings all of the Mars Reconnaissance Orbiter observation techniques together along with modeling to understand how these slope streaks are formed. Beginning in August 2020, Katie will study the surface properties of these slope streaks to understand a formation mechanism with her co-investigators Hannah Kaplan (NASA GSFC), Rachael Hoover (SwRI), David Stillman (SwRI), and Tim Michaels (SETI).

She has advice for university students: "If you are thinking about graduate school, apply and go. You will receive a stipend to do research. I learned so much about myself, and intellectually. I always wanted to learn more and it was the best thing I ever did," Katie said. However, she adds this caution: "Make sure you have a direction out of graduate school."

Katie is an artist (painting and drawing), and a musician (clarinet). Her favorite tune to play on the clarinet is the theme from the Harry Potter films. She has yet to join a band in California as she just arrived in January 2020.

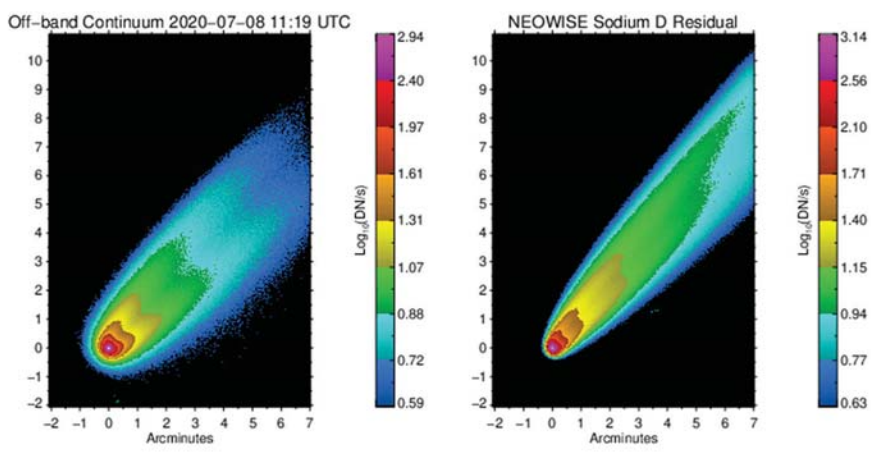
Katie and her dog, Maggie, in Colorado. *(Photos courtesy of Katie Primm)*

And, while during these COVID-19 pandemic days she misses seeing her friends and playing board games, she and her husband Paul still enjoy hiking the hills around San Diego with their dog, Maggie.

We are so proud to welcome Katie to PSI!

NEOWISE Comet Imaged at PSI Observatory Shows Strong Sodium Signal *by Alan Fischer*

In July, Planetary Science Institute Senior Scientist Jeffrey Morgenthaler used PSI's Io Input/Output observatory near Tucson, Ariz., to record the bright comet NEOWISE, as it approached the Sun for the first time in nearly 4,500 years. The images at right, produced from the raw data by Boston University Research Scientist Carl Schmidt, show the comet in two wavelength bands (colors) which help to isolate different materials in the comet.



Images of comet NEOWISE recorded by PSI's small observatory near Tucson. (In this false color presentation, red is the brightest part of the comet; blue is the faintest.) Left: light reflected from cometary dust, which is similar to the way it would look to the naked eye. Right: light emitted by sodium atoms, only visible using a telescope with special filters.

Credit: Jeffrey Morgenthaler, Carl Schmidt.

Jeff and Carl plan to monitor the comet's evolution as it races away from the Sun. The team are now using Monte-Carlo computer models to simulate the comet's sodium tail in order to understand the outgassing rates and speeds.

The Io Input/Output observatory (IoIO) was built with the support of an NSF grant to PSI to study the effect of Io's volcanic material on Jupiter's magnetosphere. IoIO has also recorded high-quality images of Mercury's sodium tail.

Comets are "icy dirtballs" and their tails are made of dust, gas and plasma (ionized gas). As comets approach the Sun on their highly elliptical orbits, heat from sunlight causes the ice to turn into gas (sublime) which drags material (generically called "dust") from the surfaces of the comet as it escapes. As sunlight reflects off of tiny particles of dust, they get a kick of momentum and drift away from the Sun. Heavier bits of dust are harder to push and drift more slowly. These forces affect the shape of the dust tail, very similar to the appearance of the comet as seen by the naked eye, shown on the left.

"Atomic sodium responds to sunlight in a similar way to cometary dust, but its momentum kick comes from a very particular wavelength of yellow light — the same color seen in sodium vapor street lamps," Jeff said.

This light is then re-emitted in a random direction, which allows us to see it here on Earth. "Thanks to acceleration by intense sunlight, the sodium tail takes on a different shape than the tail seen in off-band filtered images, which are dominated by reflected light from dust. In comparison, the sodium tail is narrower, longer and points directly away from the Sun," Carl said.

Since the push on sodium atoms is stronger than on the dust and other gas that comes off of comets, it provides a different perspective on conditions close to the comet's surface. "Sodium tails have only been observed in very bright comets, such as Hale-Bopp and the sungrazer ISON," Jeff said. While the element has been found in spectra of comets near the Sun, images of the emission are relatively rare, since the glare of the Sun makes this a challenging observation.

For observers in the northern hemisphere in mid-July, NEOWISE was faintly visible just before dawn; the next week it was visible at dusk as well. Although it grew fainter, when viewed through binoculars its showy tail continued to dazzle for several weeks.

Comet NEOWISE Photo by PSI's Roger Clark

by Chris Holmberg

In July, PSI Senior Scientist Roger Clark photographed the dazzling comet NEOWISE as it was setting over the Colorado Rocky Mountains, describing it as the best comet to have been visible to skywatchers in the northern hemisphere in many years.

In this photograph, the red and green banded airglow is from oxygen emission above 90 kilometers in our atmosphere. Comet NEOWISE displayed a yellow dust tail about 16 degrees long, which was an impressive sight, both with unaided eyes and with binoculars. The blue ion tail stretches about 25 degrees in this image, while the brighter portion could be seen in binoculars.

Find more detail about Roger's photographs and camera techniques at clarkvision.com/galleries/gallery.NEW

Image courtesy of Roger Clark.

Director's Note

COVID-19 has been a driving force in all professions these past six months, including planetary science.

Our employees have fallen sick along with their family members. Many employees have had to take on the education — and entertainment — of their children, as schools have shut down and people have isolated. And PSI offices closed.

Fortunately, NASA continues to function and our science and education staff have no problem working from home. Our administrative staff made the transition with aplomb! Everyone is becoming 'Zoom-aholics'. Work gets done, discoveries continue to be made, papers published, missions supported, and our knowledge of the Solar System expanded.

This is going to go on for a long time. We have recently instituted CDC recommendations for workplace openings, but to give people confidence in the safety of returning to work we need significant ongoing testing at our offices to identify, isolate, and contact trace those who develop the disease within days of exposure. There is no government program that provides such support to businesses, and the cost of using a private contractor is beyond exorbitant. So, we wait.

Looking forward, online participation in meetings will be part of the future, even if things return to "normal." It is an opportunity to expand participation beyond what is possible in face-to-face meetings. We are discovering this in our upcoming Retreat, which is virtual for the first time. In the meantime, we will continue to explore!

Mark V. Sykes
August 2020

PSI Staff News

PSI Senior Scientist **Susan Benecchi** has been named a co-investigator on NASA's New Horizons Extended Mission to the Kuiper Belt, as part of the Geology and Geophysics Investigation team.

Susan Benecchi Credit: S. D. Benecchi.

Using the Subaru telescope, her role is to help identify additional observable Kuiper Belt objects (KBOs), and a potential second flyby target for New Horizons. "We have a Hubble Space Telescope (HST) program that was just selected to follow any new discoveries this fall, so we can obtain orbits good enough for targeting those objects with the spacecraft. I'm also helping to interpret the distant KBO data already collected by New Horizons, in the context of the broader Kuiper belt," she said.

Susan has been working with the New Horizons project since early in her career, although never in an official capacity until now. Her past work includes using a variety of ground-based telescopes to search for, and characterize, KBOs for the spacecraft to observe after its 2015 Pluto encounter. As part of her thesis work in 2004 she participated in a pilot KBO search, and from 2011-2013 she was involved in additional searches using the Magellan and Subaru telescopes.

"After little success with ground-based searches, in 2014 our team received a 194-orbit HST grant to use the WFC3/UVIS camera to search for a flyby KBO, and we found one—Arrokoth!" she said.

We also found other KBOs to observe from New Horizons with better resolution than HST, which became part of the Distant KBO mission objectives in the Extended Mission design.

Before the Arrokoth flyby, Susan used HST to characterize it, obtaining colors and a non-unique rotation curve masked by Arrokoth's face-on orientation. The flyby confirmed and expanded upon all of her HST results, providing more insight into the nature of Arrokoth.

PSI Senior Scientist **Scott Mest** and Maiken Jepson were wed on April 10, 2020, at Pennsburg UCC, in Pennsburg, Pennsylvania.

Due to the pandemic, they had a socially distanced audience of five family members: Scott's mother and their newly blended family of four teenagers. Maiken's daughters are Selina (14), and Aaliya (17); Scott's children are son, Zachary (14), and daughter, Tori (17).

Scott Mest and his new bride, Maiken Jepson Mest.
Phoro courtesy of Scott Mest

PSI Senior Scientist **Jeff Kargel** welcomed his newest grandchild this spring.

Jeff's youngest child, Dianna, gave birth on April 22 to her third son, Malachi, who is four days old in this photo. He joins older brothers Ethan and Isaiah and his father Luke in their Bellingham, Washington home.

Jeff Kargel's grandson Malachi is a bright-eyed, four-day-old in this photo. Photo courtesy of Jeff Kargel

Congratulations and Best Wishes to our scientists!

Ryan Watkins Receives NASA SSERVI's Niebur Early Career Achievement Award *by Alan Fischer*

PSI Research Scientist Ryan Watkins
(Credit: Matt Watkins)

Planetary Science Institute Research Scientist Ryan Watkins has been honored by NASA's Solar System Exploration Research Virtual Institute with the Susan Mahan Niebur Early Career Award.

The Niebur award goes to a researcher who is within 10 years of receiving their Ph.D., who has made significant contributions to the science and/or exploration communities. The prize is presented, along with an invited lecture, at the annual Exploration Science Forum held each July at NASA Ames Research Center.

"It's a true honor to be given an award in the name of Susan Niebur. While I didn't know her personally, her passion for and commitment to advocating for early career scientists, women in science, and parents in science made her a true leader and catalyst for change in our community," Ryan said. "I have been an active advocate for early career scientists and for mothers in science for several years, and I plan to proudly carry the torch that Susan lit as I advance through my career.
"I have had many great opportunities to merge my passion for lunar exploration with my research on understanding the physical and compositional properties of the lunar surface, and I am incredibly grateful to Susan and others who have continually supported early career scientists," she said.

"Dr. Watkins' research focuses on integrating remote sensing data sets to characterize the physical and compositional properties of airless bodies, with particular emphasis on the lunar surface. She specializes in using photometry to understand physical and compositional properties of the lunar surface, and in integrating planetary data sets to assess landing site safety hazards for future missions," SSERVI said in a press release.

"Dr. Watkins is actively engaged in service and leadership within the planetary science community. She serves on the Organizing Committee for the Next Generation Lunar Scientists and Engineers (NextGen) group, on the Executive Committee for the Lunar Exploration Analysis Group (LEAG), on the Steering Committee for the Equity, Diversity, and Inclusion (EDI) Working Group, and on Blue Origin's Science Advisory Board for their Blue Moon lander project," SSERVI's release said. "In addition to research and planetary community service, Dr. Watkins regularly participates in Education and Public Outreach in her local community, and with the Solar System Exploration Virtual Institute (SSERVI) Toolbox for Research and Exploration (TREX) team. SSERVI is very pleased to present the Susan Niebur award to Dr. Ryan Watkins."

PSI
Planetary Science Institute

1700 E. Ft. Lowell Rd., Suite 106
Tucson, AZ 85719-2395
Phone: 520/622-6300
www.psi.edu

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NEWSLETTER STAFF

Chris Holmberg, Editor and Writer

Alan Fischer, Writer and Photographer

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