THE INTERPRETER FOUNDATION

Science & Mormonism Series 1: Cosmos, Earth, and Man

Chapter Title: The Outer Solar System: A Window to the Creative Breadth of Divinity
Chapter Author: Jani Radebaugh

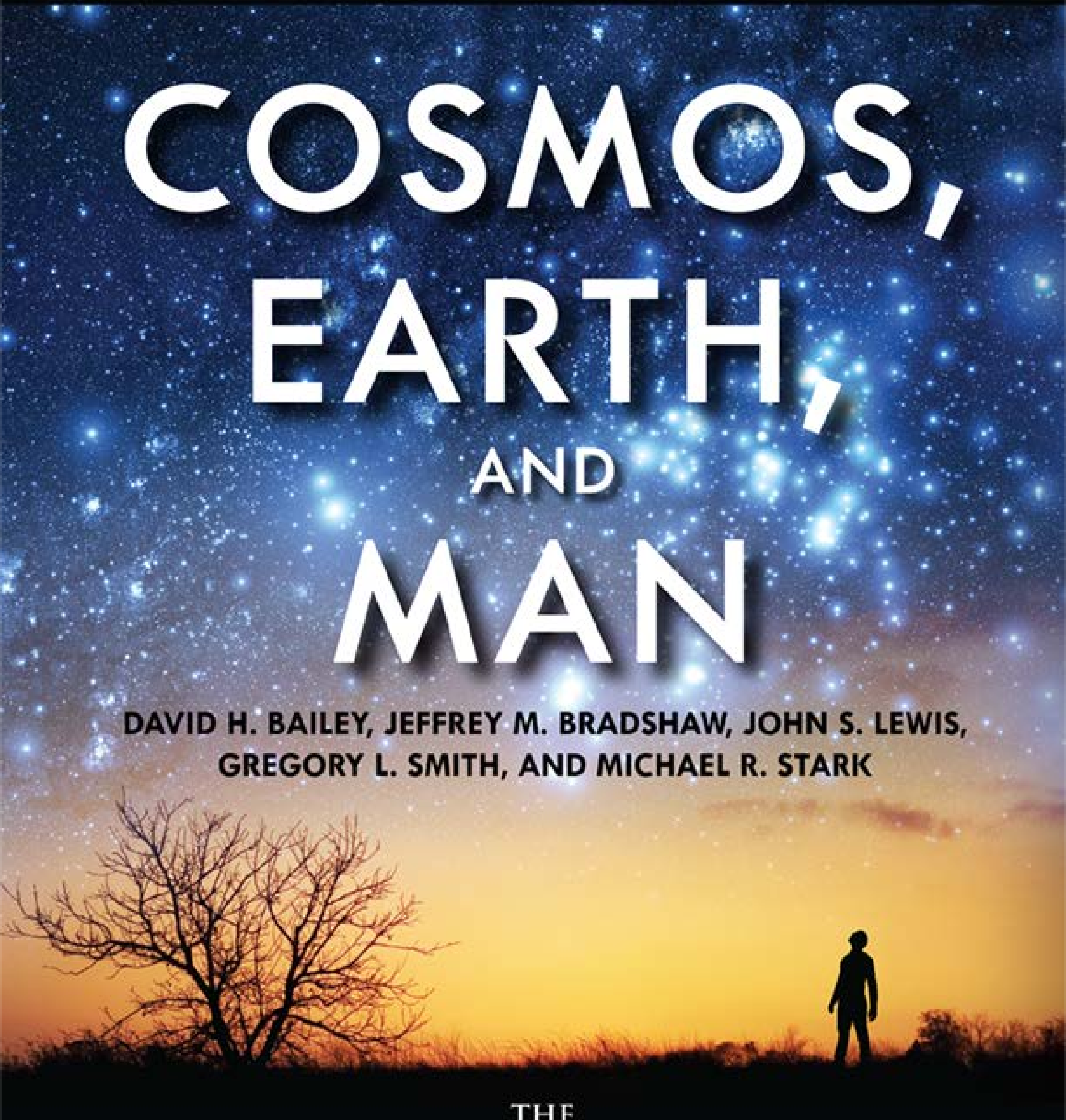
This book from which this chapter is excerpted is available through Eborn Books:
https://ebornbooks.com/shop/non-fiction/mormon-lds/mormon-science/science-and-mormonism-1-cosmos-earth-and-man-hardbound-jeffrey-m-bradshaw/

Recommended Citation
Jani Radebaugh, "The Outer Solar System: A Window to the Creative Breadth of Divinity" in *Science & Mormonism Series 1: Cosmos, Earth, and Man*, edited by David H. Bailey, Jeffrey M. Bradshaw, John S. Lewis, Gregory L. Smith, and Michael R. Stark (Orem, UT, and Salt Lake City: The Interpreter Foundation and Eborn Books, 2016), https://interpreterfoundation.org/reprints/science-and-mormonism/SM1Chap10.pdf.

SCIENCE & MORMONISM SERIES 1

COSMOS, EARTH, AND MAN

DAVID H. BAILEY, JEFFREY M. BRADSHAW, JOHN S. LEWIS, GREGORY L. SMITH, AND MICHAEL R. STARK



THE INTERPRETER FOUNDATION

SCIENCE AND MORMONISM 1: COSMOS, EARTH, AND MAN

David H. Bailey, Jeffrey M. Bradshaw, John S. Lewis,

Gregory L. Smith, and Michael R. Stark

The Interpreter Foundation
Eborn Books

2016

© 2016 The Interpreter Foundation. A 501(c)(3) nonprofit organization.

The goal of The Interpreter Foundation is to increase understanding of scripture through careful scholarly investigation and analysis of the insights provided by a wide range of ancillary disciplines. We hope to illuminate, by study and faith, the eternal spiritual message of the scriptures — that Jesus is the Christ.

Although the Board fully supports the goals and teachings of the Church, the Interpreter Foundation is an independent entity and is not owned, controlled by, or affiliated with The Church of Jesus Christ of Latter-day Saints or with Brigham Young University. All research and opinions provided are the sole responsibility of their respective authors, and should not be interpreted as the opinions of the Board, nor as official statements of LDS doctrine, belief, or practice.

All rights reserved. No part of this book may be reproduced in any format or in any medium without written permission from The Interpreter Foundation. Unauthorized public performance, broadcasting, transmission, copying, mechanical or electronic, is a violation of applicable laws. This product and the individual images contained within are protected under the laws of the United States and other countries. Unauthorized duplication, distribution, transmission, or exhibition of the whole or of any part therein may result in civil liability and criminal prosecution. The downloading of images is not permitted.

2020 19 18 17 16 5 4 3 2 1

Published by:
The Interpreter Foundation
Orem, UT
MormonInterpreter.com

and

Eborn Books
254 S. Main Street
Salt Lake City, UT 84101
EbornBooks.com

Cover artwork by Kelsey Fairbanks Avery.

Science and Mormonism 1: Cosmos, Earth, and Man / David H. Bailey, Jeffrey M. Bradshaw, John S. Lewis, Gregory L. Smith, and Michael R. Stark (eds.) — 1st edition

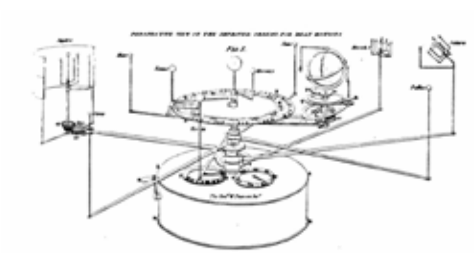
Includes bibliographical references.

ISBN-13: 978-1-89071-84-11 (Hardbound), 978-1-89071-84-28 (Softbound)

THE OUTER SOLAR SYSTEM: A WINDOW TO THE CREATIVE BREADTH OF DIVINITY

Jani Radebaugh

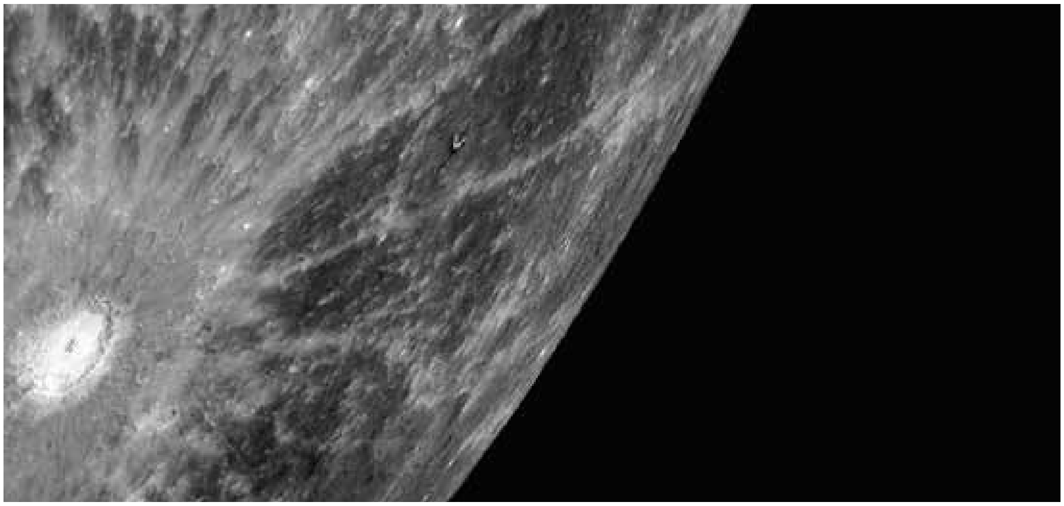
In this chapter I want to tell you why I love the science that I study and the religion in which I believe. I hope what I write will help you appreciate the creative side of our Creator — and as you read along you'll get to see a lot of pretty pictures.



Perspective View of the 1813 Orrery, 1830
William Pearson (1767-1847)

We begin our exploration with the inner solar system, which contains the celestial bodies that are closest to us. These are the bodies we understand best because they're the easiest to explore and study. We've been there for more than a half-century. The bodies of the inner solar system are also fascinating in their own right. Our nearest neighbor, the Moon, is a sort of black-and-white world, so when we look at it, we see a "grayscape"; we see a cratered landscape that's very old. Not much has happened to it since it formed four and a half billion years ago.

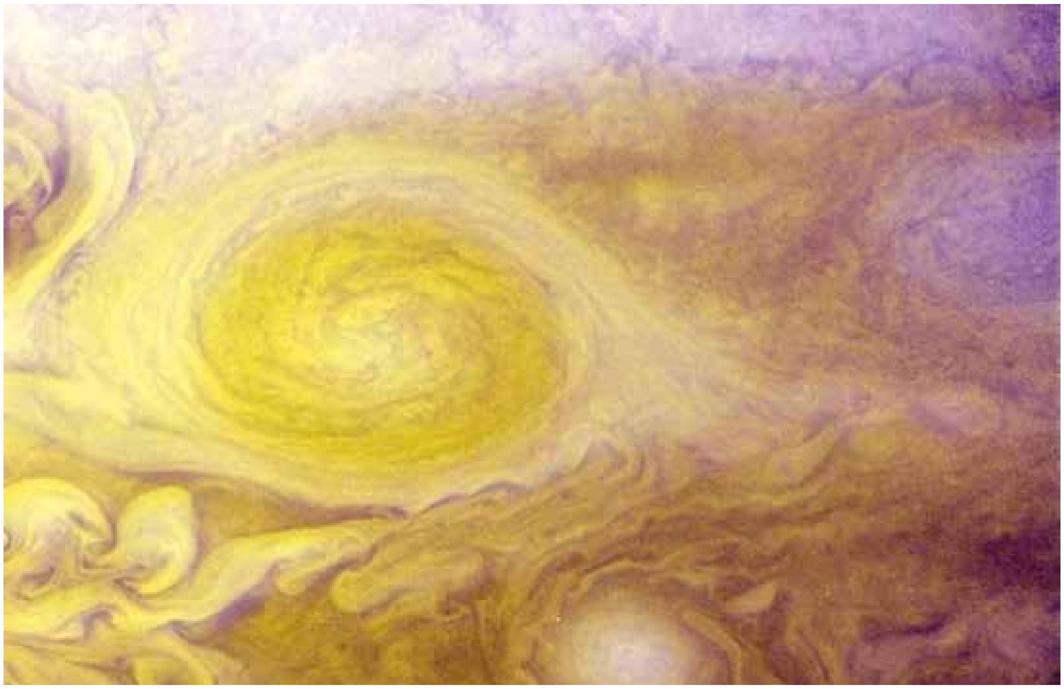
The same is true for the planet Mercury, which looks a lot like the Moon — so like the Moon that we see evidence of impact craters and lava flows. When we go to Mars, for example, we see impact craters, but we also see evidence of rainfall on the surface.

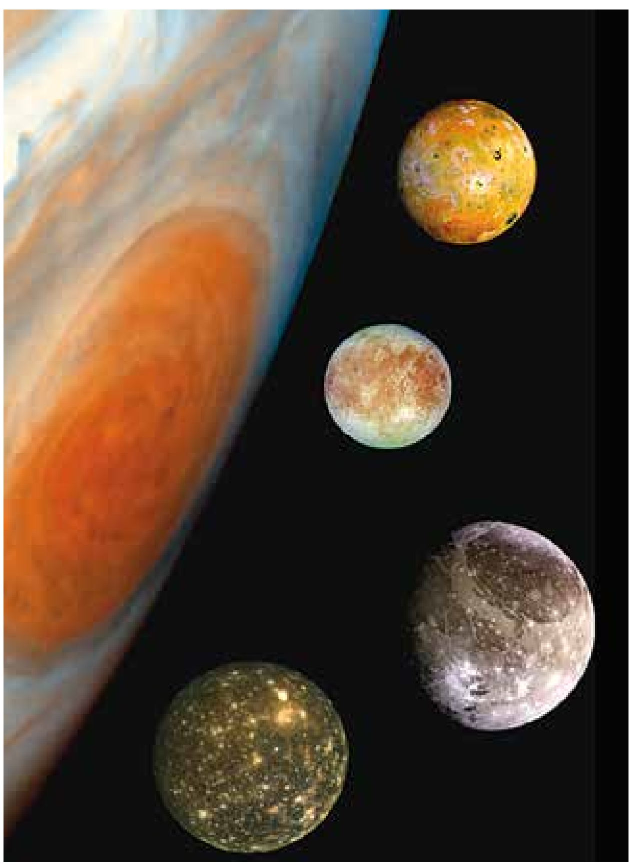


So there are some places on Mars that actually look a little bit like home, like what we could see in southern Utah, with dry river beds in a rust-colored landscape.

Can you remember the first time you saw a picture of Jupiter? The photograph above is from Pioneer 11, taken in 1974. The spacecraft had a camera thrown on it at the last minute because the scientists were not interested in pictures; they needed to take data of magnetic fields and things like that. But they did put some cameras on it, and all of a sudden a burst of color appeared when they started to look at Jupiter and the outer solar system. We could see beautiful clouds around Jupiter. The bands and the zones indicate the atmosphere is moving around. In the image above you can see Jupiter, and in the upper left corner is Io, tiny little Io, that I'll say more about below.

After this time, we began to appreciate the distant planets that are so beautiful and utterly alien to us. There's nothing imaginably like this on the Earth. Here we see a massive storm, and this storm is the size of the entire planet Earth. This is an image taken by the New Horizons spacecraft on its way past Jupiter to get a slingshot to head out to Pluto. It will arrive in a couple of years. On the next page, we can see a beautiful picture of a riot of clouds and storms in an array of patterns that result from an atmosphere that is so vigorous in its convection. Jupiter is so big that if we descend far enough down through its atmosphere, we'll reach a point at which the hydrogen in the atmosphere becomes a metal. There is so much pressure that the electrons are shed off the protons, and they move around at will. That's long before we get to the core, which contains rock and ice and metal.

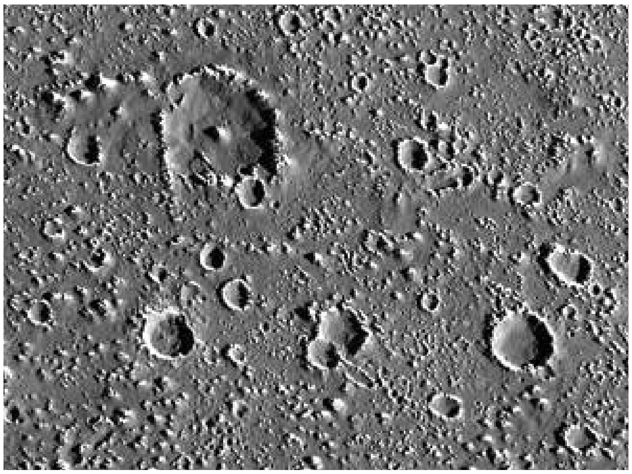




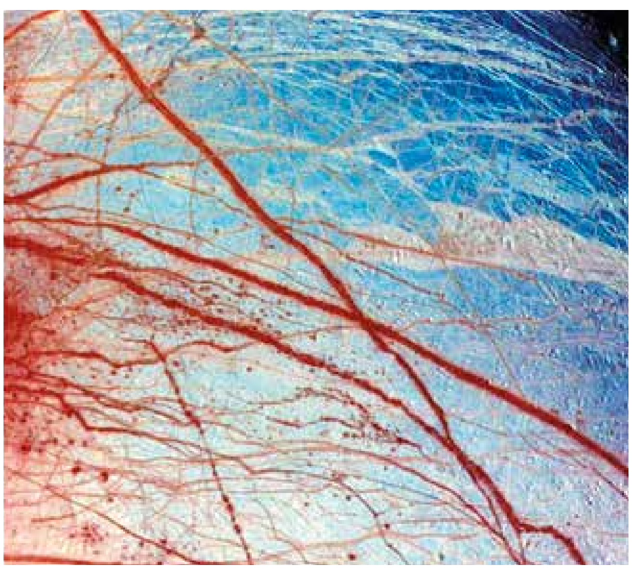
Another thing that's very interesting about these bodies is that they are beautiful in their own right with their atmospheres and their completely unique landscapes. Nobody ever thinks about living on Jupiter, but my twelve-year-old niece just wrote a short story about a girl who lives on Jupiter. You have to be a child to be creative enough to think outside of our experience and realize we could live there, and why not? She now has that story.

We look to the moons of Jupiter and Saturn and the other gas giants in the solar system for something that we can hold on to and appreciate. Our own moon and their moons have some similarities, yet each of these bodies are unique.

Four Galilean satellites of Jupiter are shown above. They're named for Galileo Galilei, who discovered them in 1610. They are shown here at the correct scale — remember that the red spot you see here is the same size as Earth. Io is in the upper portion, on the very top; it's the same size as Earth's Moon. Imagine if you lived on Jupiter and could see this bright yellow and orange body in the sky instead of our own Moon. Ganymede is the largest of the group — larger than Mercury. A European spacecraft is going there in the next decade to study it. These are unique and exciting terrains to explore.

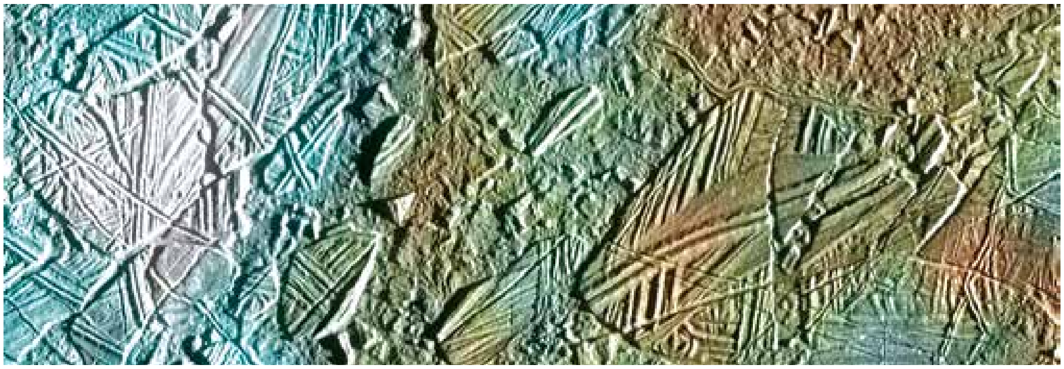


At left, you can see impact craters on Callisto, the farthest from Jupiter of all four of the Galilean satellites. These craters are somewhat different from those on the Moon. You can see their bright, shiny rims — they are bright because they're made of water ice. At these distances from the Sun, ice is actually a rock, and ice forms the crust of these bodies much like silicate rock does here on Earth. We think of sandstones and other rocks as being the kinds of things make up our crust, but on Callisto we have water ice; that's the crust, and it's covered in a layer of dust accumulated over many millions of years.



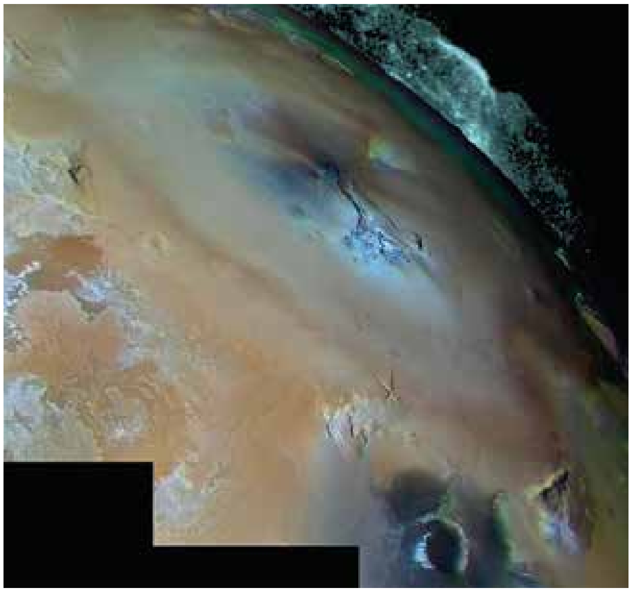
A little closer to Jupiter, we come to Europa, which is a little smaller than Earth's moon. It will be a unique and exciting place to visit someday. As we move out into the outer solar system, finding life or evidence of life having started will be a focus of interest. Where are the impact craters on Europa? There are not very many — the surface is very young, just a few million years old. We know this because the ice melts, overturns, or gets broken up by the tectonic processes that you can see as having happened. You can see the crust is split apart, and there are salts that have come up from an ocean not far below the surface. This is a liquid water ocean, and we think the ocean is connected with a seafloor.

On the next page is a close-up. This looks something like polar sea ice, doesn't it? If you work hard you can figure out a way to reconstruct the original positions of all the plates, and you can even pick out a zone that you might call a slushy

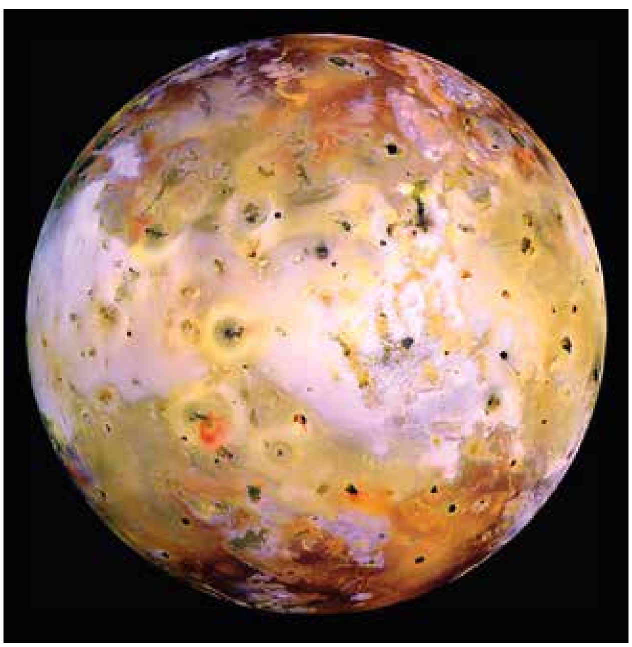


zone. We think this is solid ice now, but at some point in the past — perhaps the not too distant past — it was a slushy melt that enabled the ocean to accumulate on the surface. If we go down far enough, we might find deep sea black smokers on the bottom of this ocean, and this is one of the locations where scientists are thinking life might have gotten started on the Earth. So now we have a similar environment; we have the energy to drive these seafloors from Jupiter tugging on Europa. Sometimes Europa is little closer to Jupiter, other times it's farther away, and so can it can be stretched and kneaded, which creates a lot of internal heat, so maybe we have little volcanoes on the seafloor. This is a very exciting place for us to think about, trying to find evidence of life started somewhere far away from Earth. This is five times as far from the Sun as the Earth is.

If we go a little closer to Jupiter we can see tiny little Io hovering like a jewel up above the cloud tops. When the Voyager spacecraft flew past Jupiter in 1979, it was predicted that there would be volcanic eruptions occurring on the surface. This is based on the fact that Io orbits so close to Jupiter — sometimes it's close and sometimes it's



farther away. These tidal forces acting on Io's interior should cause melting and, sure enough, a massive volcanic eruption was seen by the Voyager spacecraft, happening out against the edge of Io. You can see the center of this volcano, which is called Pele. A lot of dark material is coming out at the center. Basalt and pyroclastic materials are also ejected out of this volcano along with dust, sulfur, and sulfur dioxide gases, and these rise up to three hundred miles above the surface and create a giant umbrella deposit that extends about eight hundred miles from the center of that eruption. These are massive eruptions, and hundreds of them are going on, dozens this size at any one time, and additional smaller trickles of lava coming out all across the body. This volcano, Pele, was named after the Hawaiian goddess of volcanoes.

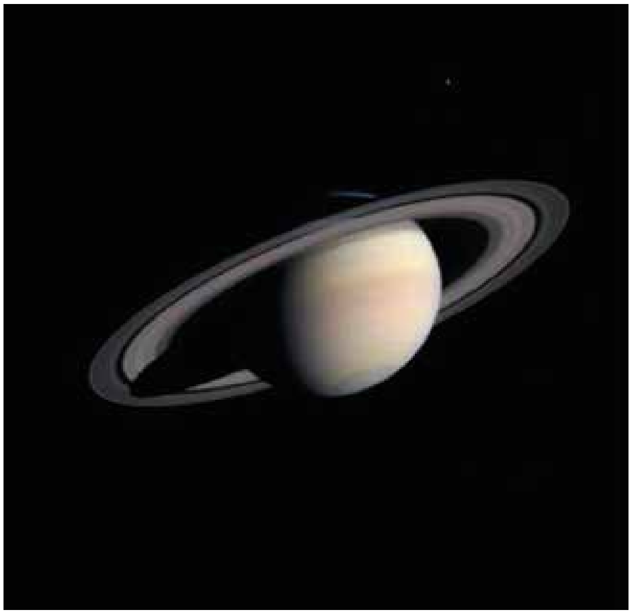


Looking at Io, we can see it is completely covered in volcanoes and volcanic products. All the yellow you see is sulfur from these eruptions; the red is molten sulfur that is currently being ejected from the volcano. All the dark spots are lava flows. This is an active paradise for volcanologists. We think it's a good analog for the early Earth. There's so much internal heat in Io that it's generating melt, and we think there may be a magma ocean down beneath the surface, much like we had on the surface of the Earth in its early days. There was so much internal heat in the Earth at the time of its formation that there was an ocean of magma on the surface.

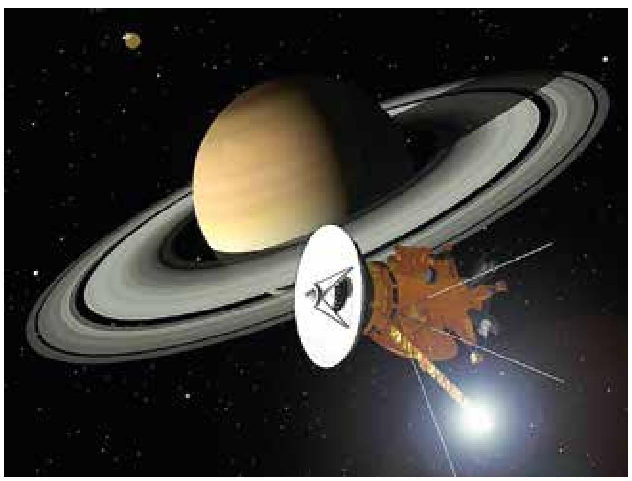
I had a chance to work on the Galileo Spacecraft as a graduate student. This spacecraft was making flybys of Io in the late stages of the mission — we didn't want to fly too close to Jupiter itself because of the strong magnetic field and all the charged particles moving along field lines. Those charged particles wreak havoc on the spacecraft and its instruments. Whenever the poor spacecraft flies close to Jupiter, Io, and Europa, it is bombarded by these particles. However, it was well worth it to get close enough to Io to see what was going on. With every flyby there was a chance the spacecraft would be bombarded so intensely by particles that it would go into safe mode. In that case, everything shuts down. The spacecraft turns toward Earth and asks "What do I do?" We try to restart it in time to get observations, but often we miss getting the observations entirely.

I wonder how many people have fasted for spacecraft? I used to do it on a on a regular basis before every flyby — "Come on, little Galileo." I remember one flyby in particular, I went to Hawaii for some fieldwork, and when I got off the airplane, I called my friend Moses and asked, "How did the flyby go?" He said, "It went into safe mode and we lost the whole observation." I lay on a bench under this beautiful palm tree and cried.

The difficulties of spaceflight make us appreciate things even more. With all the new spacecraft orbiting Mars, for example, there's a terabyte of data that comes down every day, there are images that people haven't even looked at yet, and it's wonderful, it's fantastic. From Galileo, every little trickle of data was precious, and it was a new way to look at data. I think at some point we'll figure out a way to put a spacecraft (not a person) on the surface of Io, right in the middle of a volcano. When that happens, we will be able to look back at Jupiter in breathtaking perspectives like the one simulated here.



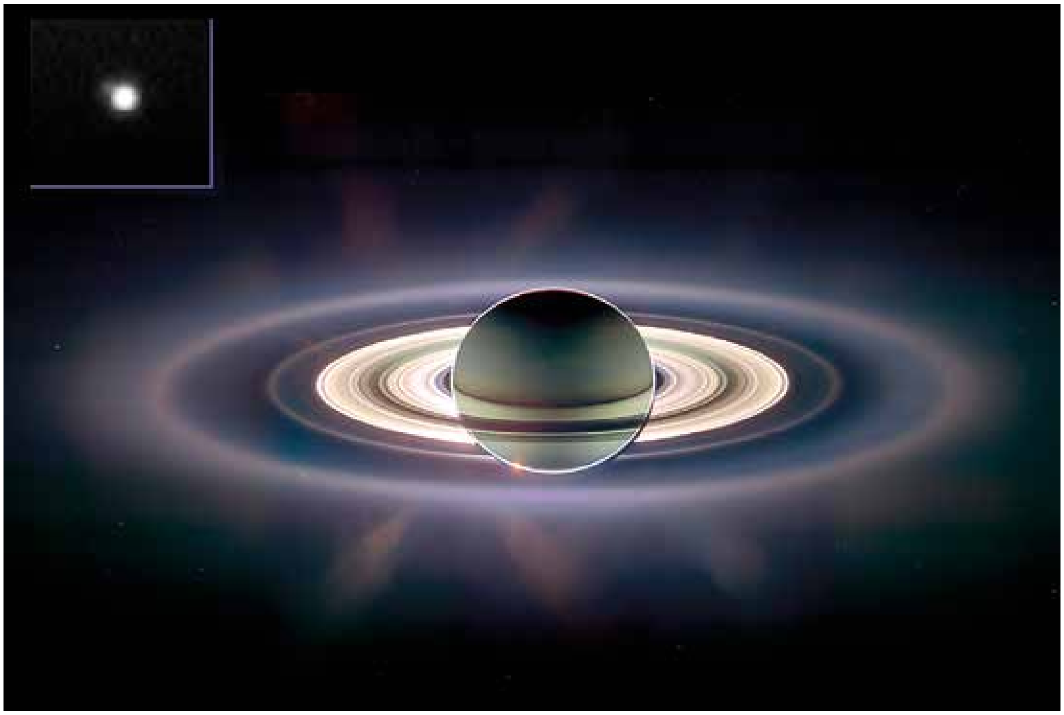
Let's go a little farther out in the solar system to Saturn — ten times farther from the Sun than the Earth. How many of you remember the first time you saw Saturn through a telescope? If you haven't yet, do that right away! Do you remember? Did you look at the back of the telescope to see if the scene had been faked by a sticker? I did, because I thought there was no way that such a scene could be real. This beautiful little planet with its tenuous, thin ring system hovers in a magical way.

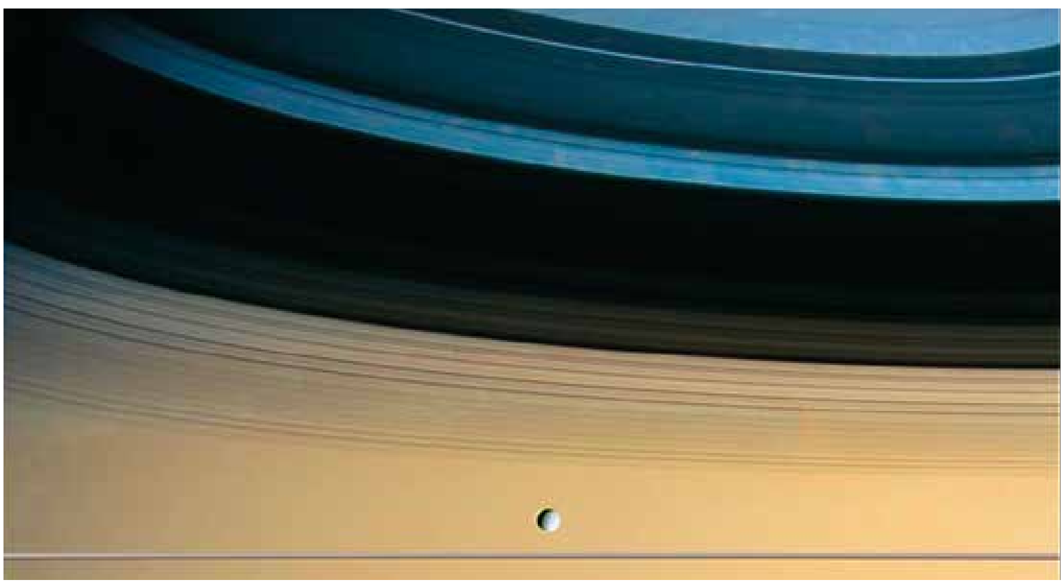


Lucky for us there is a spacecraft orbiting Saturn right now, the Cassini Spacecraft, which cost three billion dollars and is the last planned NASA flaghip missions. Space scientists would like to see other spacecraft like this one built, but the current financial climate has brought the effort to a standstill. Cassini is orbiting Saturn until 2017, studying its rings and its collection of moons.

One of my favorite photographs is shown on the next page. It could be taken only from a spacecraft. Can you imagine why? Because the sun is behind Saturn, we have to be on the far side of Saturn to take this picture. It has been enhanced, as you can tell, so we can see things like the atmosphere and the rings. Focus especially on that hazy, outermost "E-ring" — I'll come back to that later.

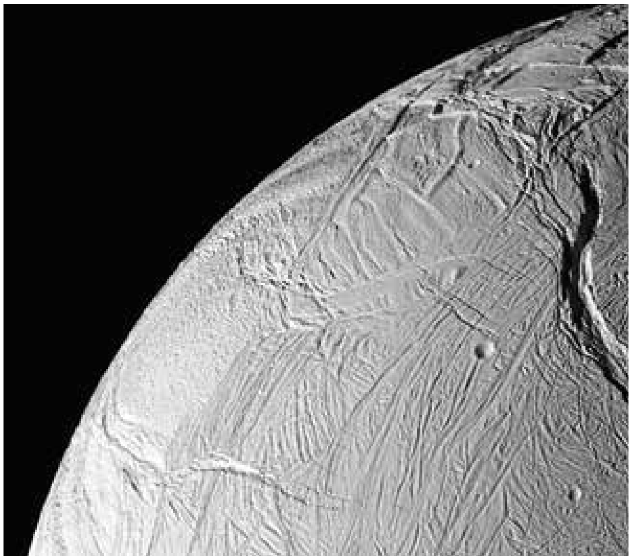
If you look very closely at this spot, you see a tiny dot in the upper left corner of the first, most detached ring. If we were to zoom in, we would see the Earth and the Moon as we look back toward the inner solar system. At this discance, our planet looks tiny. This is a point that I hope is sinking in as you've been listening to the talks today: The distances and times that we're working with are so enormous that it's difficult to comprehend — even for our own solar system — how far away these objects are. It takes a long time to get to these places.





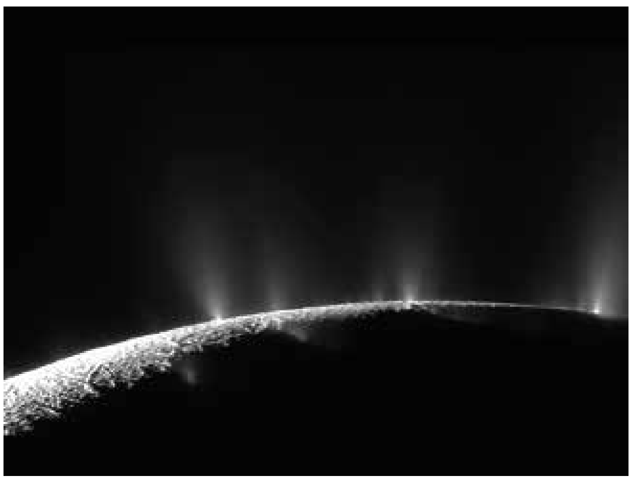
As we zoom into Saturn, we begin to see details of its atmosphere and rings. I love the picture above because it gives a good indication of what the ring plane is like — a very thin line parallel to the bottom of the image. This is the ring plane, and the dark, ring-like features you see at the top of the image are the shadows that the rings cast upon the surface of Saturn. The rings are only about one kilometer (half a mile) thick but hundreds of thousands of kilometers across. They are made of big ice chunks that range from particle-size up to house-size.

In this image, we can also see a beautiful, tiny moon hovering above the rings. This is Enceladus, 500 kilometers across, about the size of Great Britain. By all accounts it should be cold and dead. It's very small and should have lost its heat

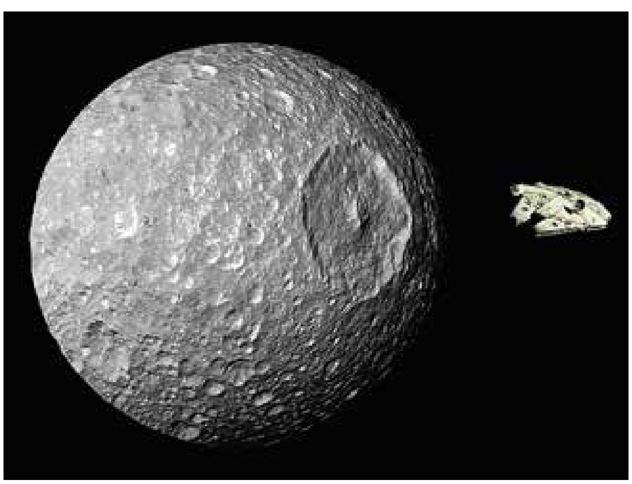


early in its lifetime. But when we got a close glimpse of Enceladus through the Cassini spacecraft, we saw a much more complex system.

We wonder: Where are the craters? Enceladus has a young surface. It has been heavily tectonized. It has been stretched apart. It has been shoved back together. And the greatest surprise of all is that there are geysers of water gushing out at the south pole!

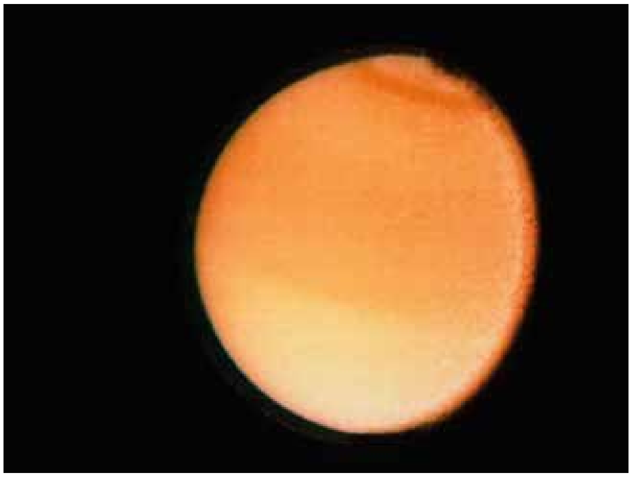


Those geysers contain methane, ammonia, carbon dioxide, and salts — everything that we'd expect a reservoir of water sitting inside the planet to contain. Here again, we enounter a body that has an energy source, liquid water, and organics. Those are the ingredients for life as we understand it on Earth, so this tiny, unlikely body is suddenly a good place for us to go and look for evidence of life. These geysers are the source of that large, diffuse E-ring you saw around Saturn. That's water being ejected out of the bottom of Enceladus right now.



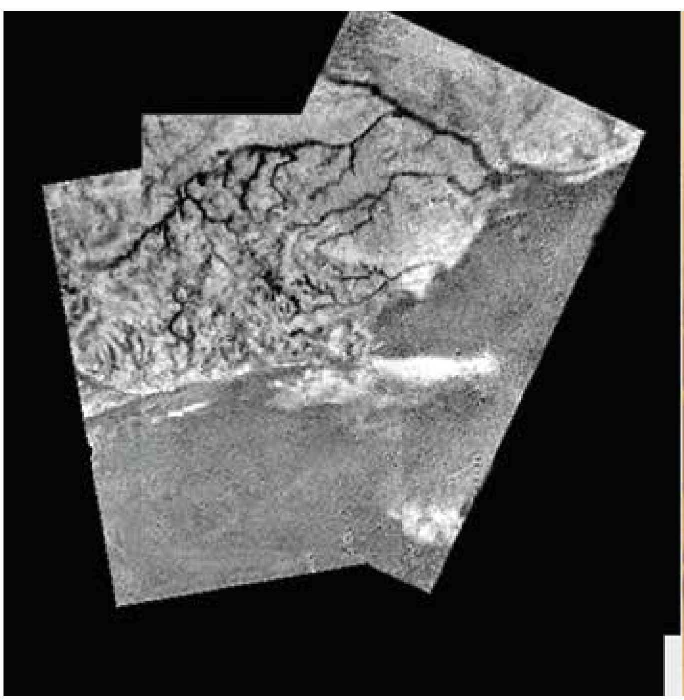
Here's a sort of companion moon that resembles Enceladus, except that it is cold and dead. Does this remind you of anything? We call it the "Death Star" moon, also known as Mimas.

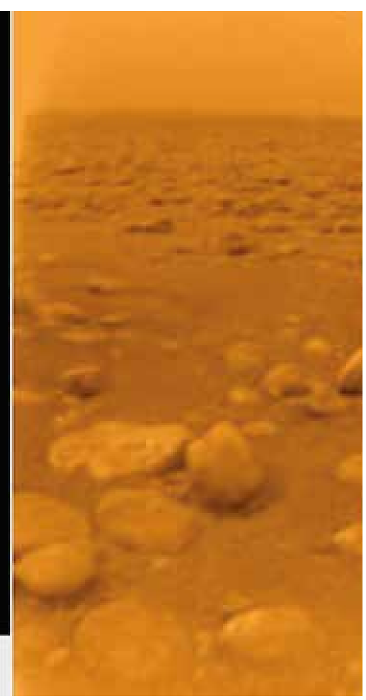
The crown jewel of the Saturn system — and in many ways the reason for the entire Cassini mission — is Titan. This is the largest moon of Saturn. It is larger than Mercury, and one thing we knew from looking through telescopes at Titan is that

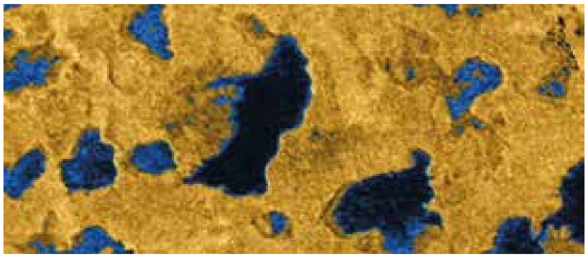


its atmosphere is made mostly of nitrogen, like the Earth's. In addition, it actually has the same atmospheric pressure as the Earth at its surface. But instead of containing water that forms clouds and rain, at Titan's location, ten times farther from the Sun than Earth, at a cold only ninety degrees above absolute zero, the liquid in the atmosphere and on the surface is methane. So we think there are methane clouds and methane rains on Titan's surface.

There was a probe specifically designed to go down through Titan's atmosphere and splash down into lakes and seas of methane or land on dry ground. As it was descending, we saw huge river channels, very well developed.



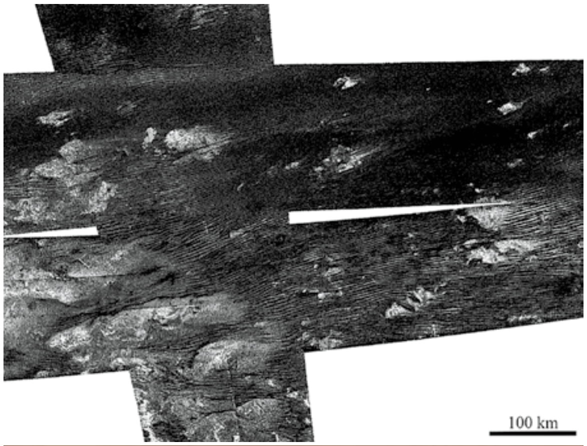


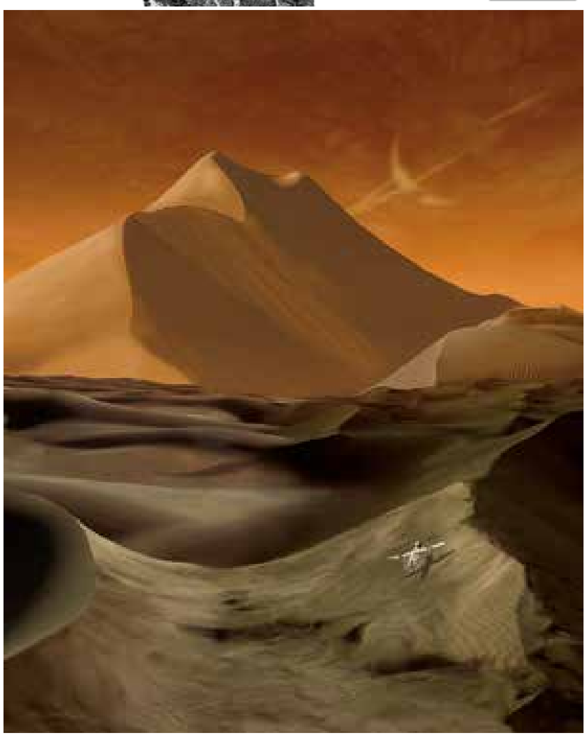


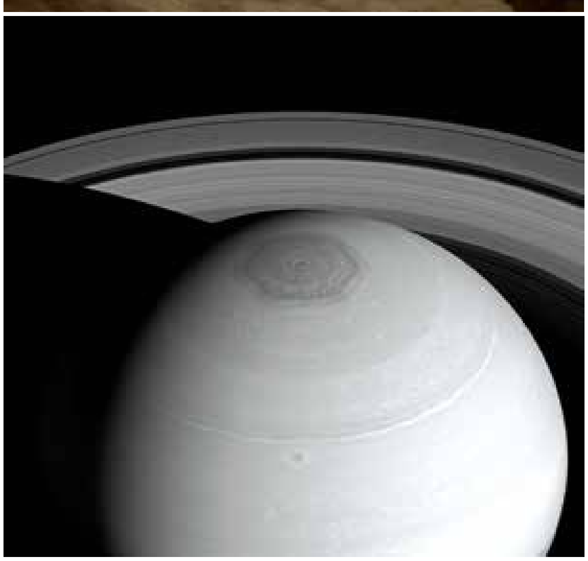
These channels are better developed than any river channels you see on Mars. The probe landed in what looks like a dried-up riverbed. It landed in the deserts. What we understand about these deserts is that they may once have contained ephemeral flows of liquid methane, but in this location it was dry when Huygens landed. We can only see rounded cobbles of water ice from the erosion of a crust of water ice, like we see on the Galilean satellites. As the spacecraft sat on the surface, it was a bit warm. It baked off a quantity of methane that vaporized into the local atmosphere.

Titan has turned out to be a very interesting place to study. It turns our thoughts back toward home because the landscape there is very much like Earth's. There are rivers and lakes and seas of methane; there are eroded mountain belts. These lakes and seas are full. Titan is the only other body in the solar system that has lakes and seas filled with liquid.

There are not only liquid seas on Titan but also seas of sand. No one expected this. These dunes are like those found in the northern Sahara and Saudi Arabia and Namibia, but the sand grains are made of organics. Methane high in the atmosphere is broken down by photo-dissociation from sunlight, and it recombines into long-chain organics. Ethane, propane, benzene, acetylene, and other long chain organic molecules clump together, sink down to the surface, solidify into layers, and erode







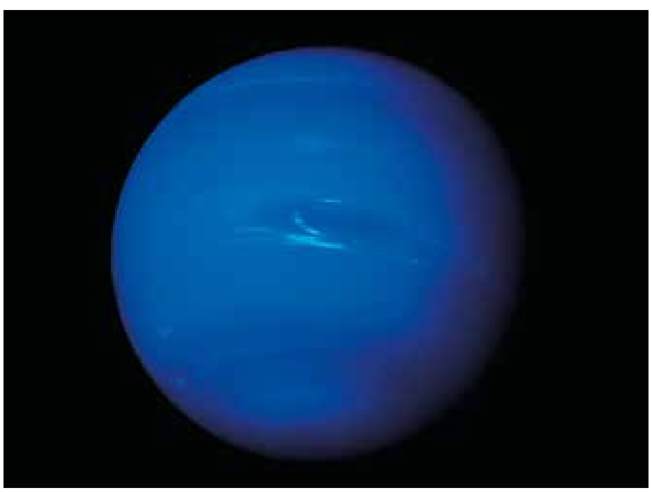
from cobble-sized down to sand-sized particles that get blown into sand dunes. So now there are lots of organics on the surface of Titan, in the organic sand particles as well as in the vast seas of methane and ethane.

Current thinking favors the presence of a liquid water ocean underneath an icy crust and an energy source that sometimes brings this liquid up in the form of volcanoes — "cryovolcanoes," we call them. Thus Titan is a great place look for astrobiology. Things happen at a very slow pace on Titan, but, to put things in perspective, if you lived there and looked down at Earth you would probably conclude that life on Earth is impossible because everything happens too fast. Titanians would think, "Earth has a 'magma ocean' on the surface" — which is our own liquid water ocean. "There's no way they could have life."

So we have to keep in mind that everything is relative. We have to keep our minds open to the possibility of unusual happenings.

Let's leave the sand dunes of Titan in our drone and take one last look at Saturn before we fly farther out to Uranus.

There's a very interesting hexagonal feature at Saturn's north pole. It's a very regular, beautiful shape. How did it get there? Because we don't expect such regular shape sto be formed in nature, these kinds of features are often attributed to deliberate design by something



intelligent. I heard about some experiments where the scientists took a pan of water and spun it, then applied energy at a certain frequency. And once it hit a resonant frequency with the spin, the water made a small hexagon. So there could be a natural explanation for the hexagon as a sort of a resonance feature within the atmosphere. In any case, it is really beautiful.

Now look how beautiful Uranus is, hovering in the sky. Uranus is so beautiful because it's smooth in texture — something no one expected. The blue color is from methane in its atmosphere.

Uranus was discovered in the late 1700s in England by William Herschel and his sister Caroline. They did a lot of work in astronomy. At that time, we had come out of the cold age of the scientific revolution, and we were entering the Age of Scientific Wonder as we began to expand our gaze outward from the orbit of Saturn. At this point, most people thought the universe — not just the solar system — ended at Saturn. Instead, the Herschels found a planet beyond Saturn, twice as far as the distance from Saturn to the sun. That got people thinking that the universe actually might extend farther than that. So, beginning in the late 1700s, there was a gradual opening of up people's minds that was summed up well by Humphrey Davy (1810): "Nothing is so fatal to the progress of the human mind as to suppose our views of science are ultimate; that there are no mysteries left in nature; that our triumphs are complete; and that there are no new worlds to conquer."

In a similar way, new details about bodies in the outer solar system we've discussed in this chapter have helped open our minds to the possibilities of other worlds with life in our galaxy and in the universe. If you've been watching the news, you notice that all of a sudden we're finding all these very exciting and unique bodies out in in the universe, especially in our own galaxy, bodies that are unique in their own way.

Some of them are so close to their suns that they are likely to be completely molten on one side and frozen solid on the other. But, in addition, there are many others that seem to have the potential for life. Recently, the National Academy of Sciences came out with a report that suggested that there might be as many as nine billion habitable planets in our own galaxy alone. Another way of saying this is that there are more habitable planets in our galaxy than there are people on Earth. (Of course, this doesn't mean they're actually inhabited, only that they're habitable.)

As Latter-day Saints, this should not surprise us too much. We should be able to look at these big numbers and say, "Well, we should have seen this coming because God already told us there were inhabited worlds without number" (see D&C 76:24; Moses 1:33).

References

Christiansen, E.H. and W.K. Hamblin. *Exploring the Planets*, www.explanet.info (accessed November 14, 2015).

Holmes, R. (2008) *Age of Wonder.* New York: Vintage.

Jet Propulsion Laboratory. http://www.jpl.nasa.gov (accessed November 14, 2015)

Lorenz, R. and J. Mitton (2002). *Lifting Titan's Veil*, New York: Cambridge University Press.

——— (2010). *Titan Unveiled*. Princeton, NJ: Princeton University Press.

JANI RADEBAUGH

Jani Radebaugh is a planetary scientist who specializes in the shapes and origins of landscapes on Earth and other planets in the solar system. She is an Associate Professor of Geological Sciences at Brigham Young University, where she interacts with many students through research and teaching a variety of courses. She obtained her PhD in planetary science from the world-renowned University of Arizona's Lunar and Planetary Laboratory and has been at BYU since 2006.

Jani analyses images of other planets obtained by spacecraft to determine the geologic histories of the surfaces and interiors. She studies landforms on Earth, where it is possible to walk around on them and obtain samples, to gain insight into similar landforms and processes on other planets. Her current investigations include giant sand dunes, mountains, volcanoes, rivers and lakes on Saturn's moon Titan from the currently operating Cassini spacecraft, and she studies actively erupting volcanoes and mountains on Jupiter's moon Io from the Galileo, Cassini, and Voyager spacecraft. She has done field work in the Egyptian Sahara, the Arabian peninsula, the Ethiopian Afar Rift Valley, Australia, the Argentine Altiplano, Hawaii, and the desert southwestern U.S. She is a regular participant in the U.S. Antarctic Search for Meteorites Program, where she spends six weeks at a time in a tent in the deep field, returning with hundreds of meteorites from around the solar system including the Moon and Mars. She seeks to understand how field studies on Earth, including work on big desert dunes and remote volcanoes, as well as meteorite searching in Antarctica, help us better understand processes in the solar system revealed by the myriad spacecraft at other planetary bodies.

Jani communicates the results, excitement, and passion of her research with the public through many avenues. She is a science contributor for the internationally syndicated Discovery Science Channel's *How the Universe Works* seasons 4 and 5. She gave a *TEDxBYU* talk and a BYU-wide forum on "Exploration for Discovery," and she regularly does other radio and public speaking events. She presents at the Spacefest convention, which draws most of the Apollo and Skylab and some space shuttle astronauts and their fans. Reconciliation of Jani's scientific and religious leanings began while she was a student at BYU, mainly under the tutelage of her geology professors, and now she continues to help educate students on the same path.

Jani was born and raised in the church and has five younger siblings and fourteen nieces and nephews. She has worked in a variety of church callings and has enjoyed attending church in many different countries. Jani is part of the church's diverse and talented singles community and has enjoyed the many singles wards she has been privileged to serve in throughout her life.