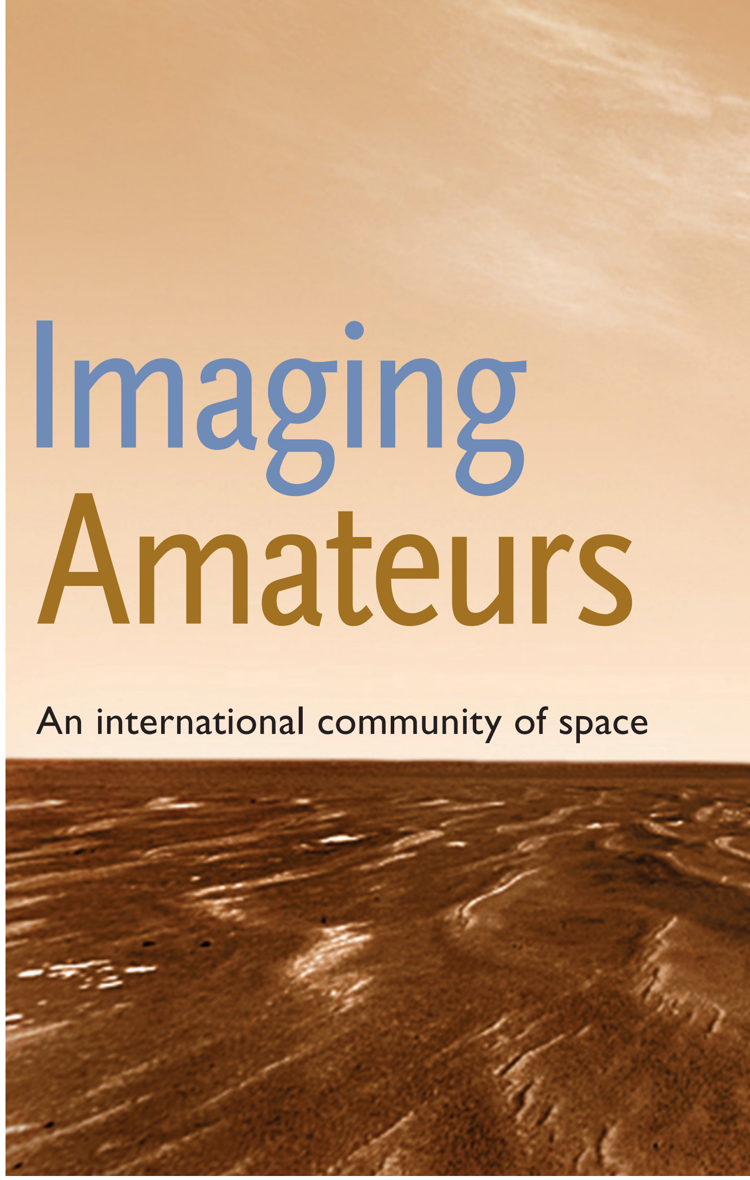
EMILY LAKDAWALLA

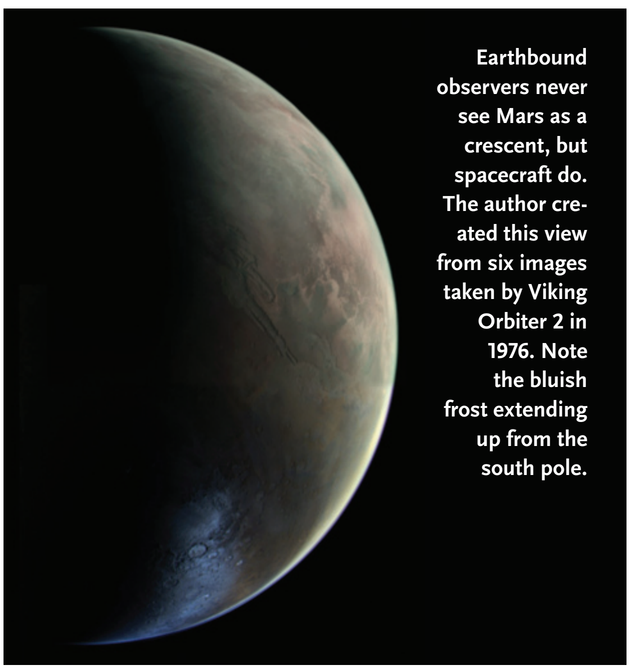
Spacecraft Imaging for Amateurs



An international community of space

This is Mars's Big Sky Country, a windswept, nearly featureless plain. Tiny ripples in the rust-colored sand march farther than the eye can see, to a horizon so flat one might be able to see the curvature of the planet. As far as anyone knows, those ripples have not budged in eons. But all is not still; gaze upward, and you might be surprised by the rapid motion overhead, where feathery cirrus clouds, frosty with bright crystals of water ice, float on high Martian winds.

The scene is from Meridiani Planum, composed from eight images captured by the Mars Exploration Rover Opportunity just before she reached a deep crater named Victoria, on the 950th Martian day of her mission. But the beautiful image was not created by anyone on the Mars Exploration Rover team; no scientist would likely have produced it, because it owes its beauty as much to art as it does to science.



Earthbound observers never see Mars as a crescent, but spacecraft do. The author created this view from six images taken by Viking Orbiter 2 in 1976. Note the bluish frost extending up from the south pole.

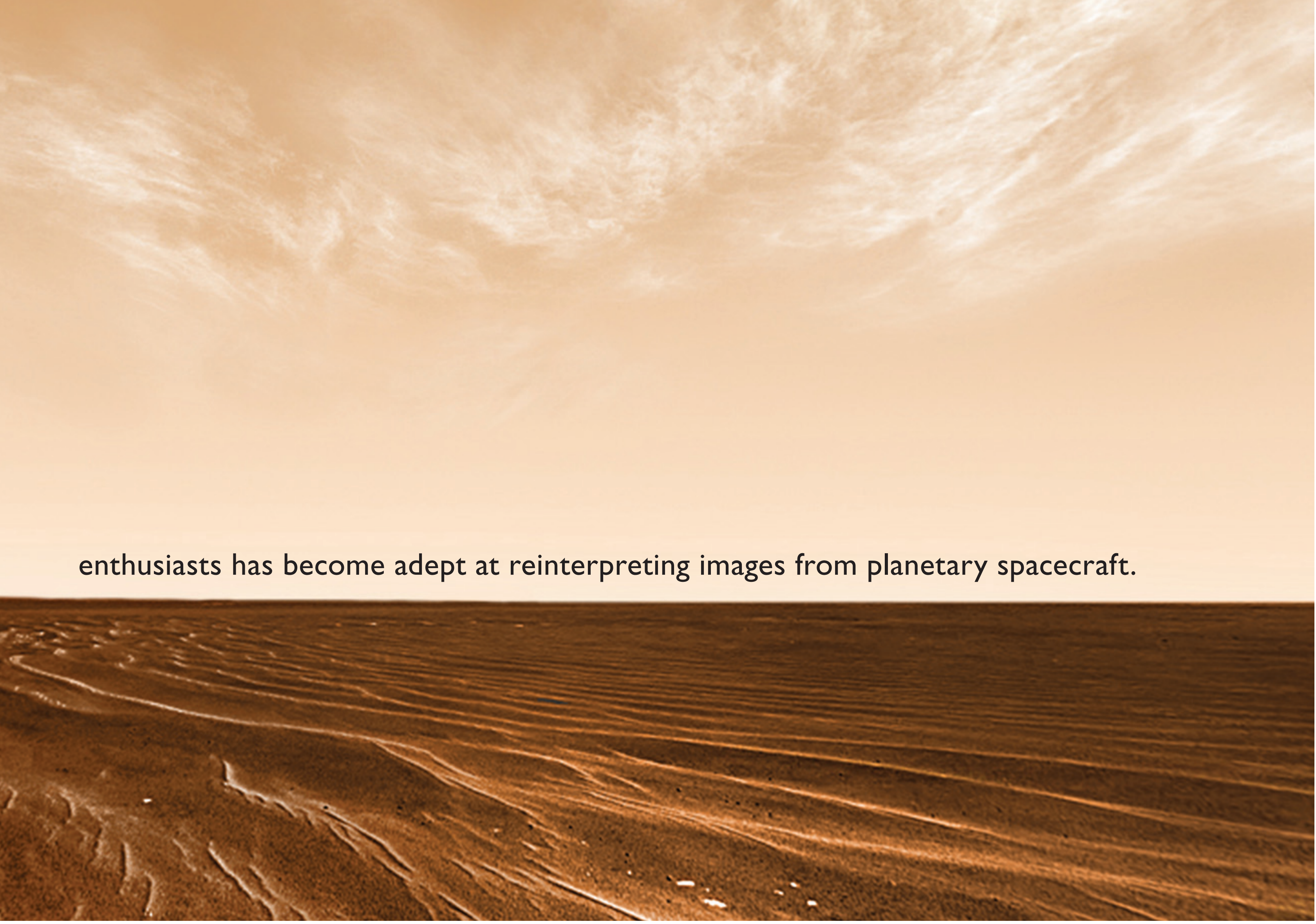
DATA: NASA / JPL

The image is the collaborative creation of a whole amateur-imagesmith community; six people, each from a different country, had a hand in it. Twelve hours after Opportunity took the photos, the data had been received on Earth and posted to the internet. Within another 17 hours, rover fans had found the photos, assembled the mosaic, and shaded the sand and sky based on color photos Opportunity had taken of a similar landscape the day before.

The entire sequence unfolded spontaneously on an internet forum. "There was no behind-the-scenes coordination or plan," explains key participant Michael Howard. "Each contributor just took the latest posted image and ran with it." See page 80 for the whole story.

The beautiful scene is just one of thousands produced by a lively international community of amateur image processors who are breaking down the barriers that formerly existed between interplanetary missions and the general public.

enthusiasts has become adept at reinterpreting images from planetary spacecraft.



DATA: NASA / JPL / CORNELL UNIVERSITY; PROCESSING: MICHAEL HOWARD / GLEN NAGLE

Buried Treasures

The vast majority of image data that has been sent to Earth from the dozens of interplanetary missions never sees official public release. For example, only a few hundred Voyager images have ever been prepared for publication, yet the two spacecraft returned more than 80,000 separate image products to Earth.

What happened to the rest of the data? It's always been available, just inconvenient for the general public to access. Since 1966, when the National Space Science Data Center (NSSDC) was established at NASA's Goddard Space Flight Center, the archived data from all science missions has been made available to researchers upon request and for a nominal fee. All NASA missions are required to archive their data with the NSSDC after a proprietary period has elapsed. Similar archives exist for the Japanese and European space agencies.

In 1977 NASA established a system of Regional Planetary Imaging Facilities (RPIFs). RPIFs are like NASA public libraries, storing collections of image data in both digital and print formats. I whetted my own appetite for space imaging at the Brown University RPIF, which hosts, among other goodies, the entire Magellan Radar and Lunar Orbiter image data sets in hard copy — thousands of stunning photographic prints up to 30 by 40 inches in size. I routinely dig into the archives for previously unpublished views of the planets, like the unusual crescent view of Mars shown at left.

Hyperlinks for all the websites mentioned in this article can be found at SkyandTelescope.com/amateur-spaceimaging.

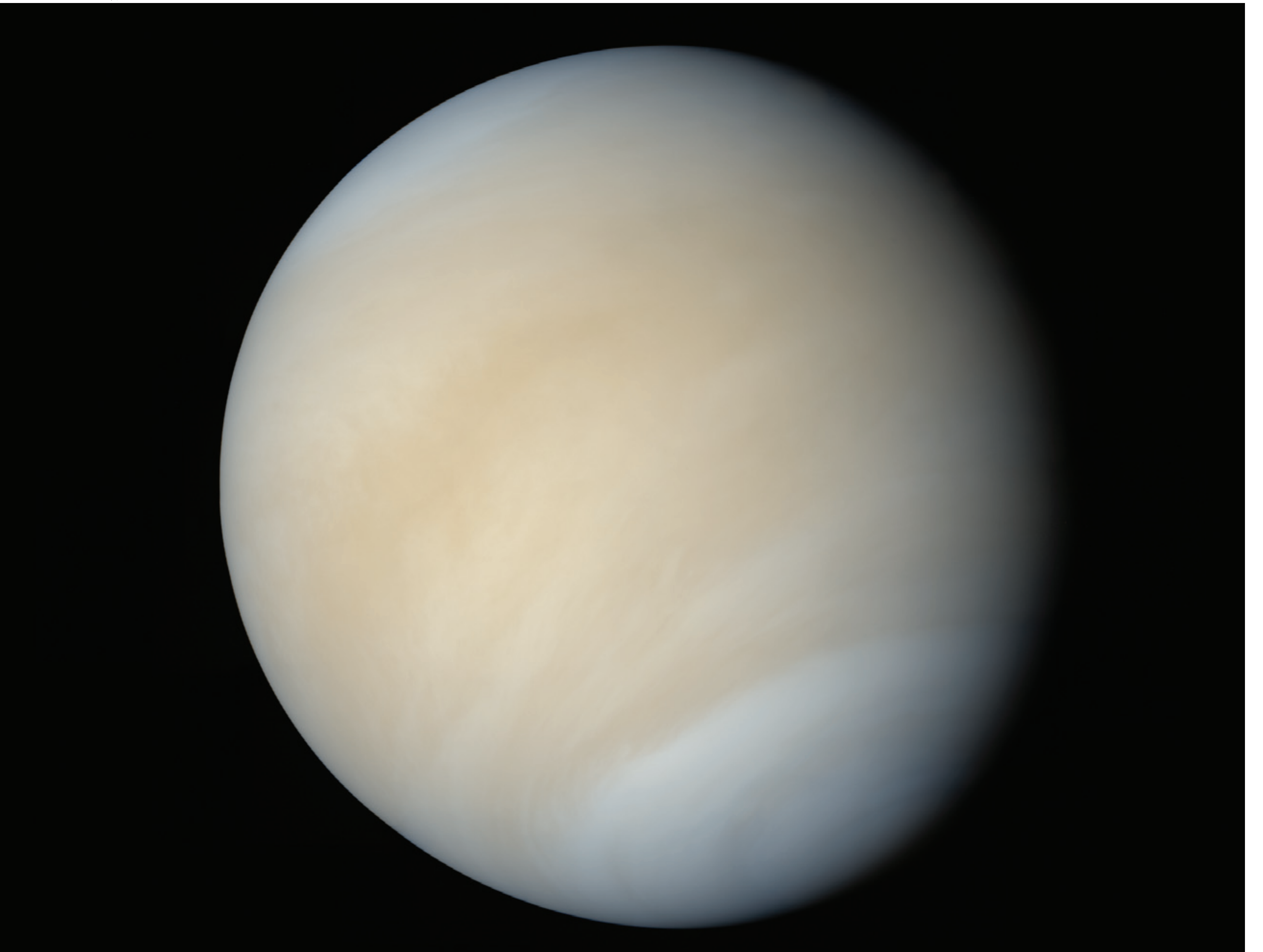
These resources were mostly only used by professional researchers until recently. As early as the 1980s, the NSSDC was distributing some data electronically, but few in the wider public had the bandwidth, hardware, or training necessary to download, process, or understand the data.

That's all changing. High-speed internet connections and blazingly fast home computers have brought the necessary bandwidth and hardware into people's homes. At the same time, the digital-photography revolution has given millions of people basic image-processing skills. In the past five years, several missions have given the public free access to raw image data almost as soon as it's received on Earth. As a result, amateurs can now download terabytes of data from dozens of planetary missions, some of it only hours old.

Of course, the most exciting images from any mission have most likely already been turned into products for public release. So what's in there to reward the amateur who digs into the planetary image archives?

Quite a lot, actually. For instance, until recently, nobody had seen an image of one of Neptune's moons passing in front of the planet. But last August, Ted Stryk (a professional philosopher and amateur planetary scientist) realized that such images probably lay hidden in the Voyager 2 archive. After much effort, he succeeded in locating the relevant images and producing the amazing composite view shown on the facing page of Despina and its shadow crossing Neptune's face. "Processing the Voyager images to get every last bit out of them is our only way to get better close-ups of these worlds in the near term," remarks Stryk. "The only serious proposal for a

DATA: NASA / JPL; PROCESSING: MATTIAS MALMER



This view of Venus was composed from 78 frames taken by Mariner 10 in 1974. The colors were synthesized from images taken with orange and ultraviolet filters. The clouds are more prominent than they would appear to the eye, but nowhere near as exaggerated as in pure UV images.

return to Neptune is a mission called Argo. But assuming it is approved (and that's very questionable), it won't get there until 2029."

I first encountered the amateur image-processing community after being frustrated in an online search for a photo of Venus as it might look to a human observer flying in space. This request is easy to satisfy for all of the other planets in the solar system, but the only spacecraft images of Venus that I could find either showed it as seen in ultraviolet light (which artificially exaggerates its cloud patterns) or stripped of its atmosphere entirely (in global views from the Magellan Radar Mapper).

During my searches I had stumbled across an online forum called unmannedspaceflight.com, which had started as a place for amateurs to share their work with raw Mars Exploration Rover images, but which had broadened to cover work with all robotic spacecraft data sets.

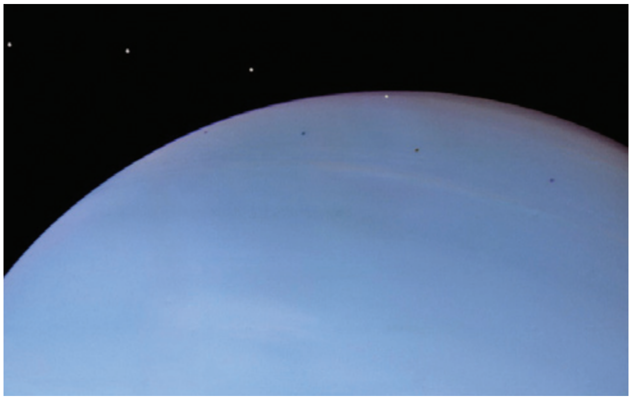
After posting my request I was rewarded with new views of Venus from Mariner 10, Venus Express, and Messenger. Why hadn't any of the missions produced such images for public release?

It's because cameras are sent to space to gather data for scientists, who have quite different goals from the general public. When scientists are in charge of image processing, they usually seek to emphasize faint features and subtle differences in color, while taking care not to compromise the quality of the images as science data. Fundamentally, a science image is a matrix of data, encoding how many photons of specific wavelengths of light are received at a detector from a given location in space. To process an image is to manipulate these matrices, performing calculations on the numbers. Excessive manipulation is not only unnecessary, it departs from the actual data gathered by the spacecraft.

The rest of us aren't so tied to data fidelity; we want pretty pictures that illustrate the adventure of space exploration and allow us to imagine ourselves out there in the solar system exploring these strange new worlds. So when non-scientists get their hands on image data, they process it in ways that scientists won't: they paint out data gaps, fiddle with contrast, sharpen photos by stacking or filtering them, and produce color as the human eye might see it by washing black-and-white images with color or by computing red, green, and blue channels from data taken in other wavelengths. The beautiful images that result are rarely useable for research, but are uniquely appropriate for illustration.

Sharing the Wealth

Space image data archives may be free, but they're difficult for neophytes to access. Images are stored in a peculiar format, and it takes considerable time and study to learn how to find and process them. However, since 2004 there has been an explosion in public participation in image processing thanks to the generosity of two scientists from the Mars Exploration Rover mission.


DATA: NASA / JPL

Twenty-year-old images discovered recently in the Voyager 2 archive by Ted Stryk (professor of philosophy at Roane State Community College) show tiny Despina and its shadow crossing the face of Neptune.

As NASA/Caltech's Jet Propulsion Laboratory (JPL) prepared for the launch and landing of the rovers, project scientist Steve Squyres and imaging-team leader Jim Bell, both of Cornell University, approached JPL with a new idea: to allow the general public to experience the rover missions as they unfolded by spewing all of the rovers' image data directly to the internet.

The proposal was revolutionary; scientists have traditionally held their data close to the vest for as long as possible. But, Bell says, "I truly believe that it's a privilege to be involved in exploring Mars. The folks who paid for the mission — and even those who didn't — deserve to see what's coming in every day, as quickly as we can make it available."

So as JPL prepared the ground systems that would process and distribute the rover data to the mission's scientists and engineers, they built a parallel system that would convert the data into a format easy to consume by the public and push it onto a server outside the lab's firewalls.

Since their landings in January 2004, every image captured by the Spirit and Opportunity has been posted within hours of its receipt on Earth to JPL's website. The raw images have been automatically contrast-enhanced and converted to JPEG format to make them easy and quick to browse. They proved so popular that JPL imposed the same protocol on its Cassini mission, which arrived at Saturn in June of the same year.

Visitors can tune in to JPL's website for daily snapshots showing where the Mars rovers and Cassini have most recently been. Since 2004, other missions that have shared raw image data with the public include Deep Impact, New Horizons, Phoenix, and an engineering camera on Europe's Mars Express.

DATA: NASA / JPL / CORNELL UNIVERSITY

Birth of an Image

PROCESSING: JAN VAN DRIEL

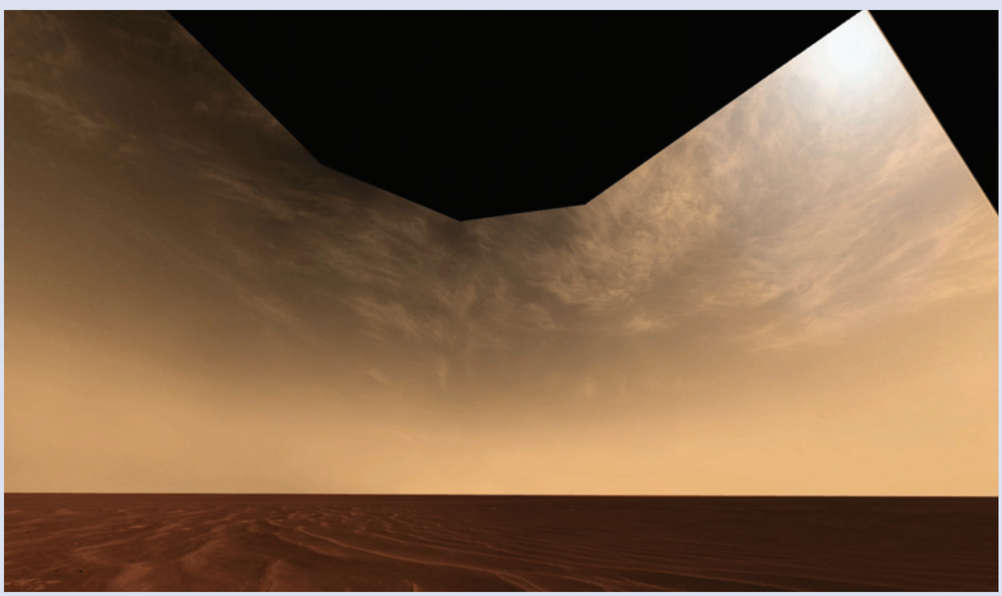
The image of Mars's Big Sky Country on pages 76–77 was the product of many hands and minds. The collaboration started when Jan van Driel from the Netherlands noticed some interesting cloud patterns in the most recent set of raw photos from one of the Mars Rovers (*top*). He stitched two cloud shots together (*right*) and asked for assistance in producing a bigger panorama.

Michael Howard (United States) figured out how to compensate for the fact that the clouds were drifting while Opportunity was photographing them and expanded van Driel's mosaic to four frames. He also made a mosaic of the ground beneath the clouds and remapped everything to a vanishing-point perspective.

Then Tayfun Öner of Turkey painted in the gap between the ground and sky, Damien Bouic of France colorized the image using data from a different camera, and Marco Di Lorenzo of Italy tweaked the color and contrast. The resulting image (*below*) became the Astronomy Picture of the Day a week later, on October 17, 2006.

Inspired by Di Lorenzo's image, Glen Nagle of Australia reinterpreted Howard's original mosaic. In the foreground, Nagle retained the brightness and (unrealistically high) contrast of the original Rover photos. Then he extracted the clouds from Howard's mosaic using a screening process and re-projected them onto a freshly painted sky. The resulting image, though arguably less faithful to the data than Di Lorenzo's, works better on the printed page, and may be more evocative to people familiar with deserts on Earth.

See SkyandTelescope.com/amateur-spaceimaging for a link to the web thread where the collaboration took place.



PROCESSING: MICHAEL HOWARD / TAYFUN ÖNER / DAMIEN BOUIC / MARCO DI LORENZO

These images allow the public to follow missions in real time, seeing the images as quickly as the science teams do. Depending on the relative timing of downlink and the sleep cycles of science team members, the public may actually see the data first!

Of course, this gives the public (or even other scientists) an opportunity to "scoop" the mission's science team, becoming the first to discuss new discoveries in public. For example, last summer, when the Mars Phoenix lander dug up some bright clods of soil that disappeared in the four days that separated two images of a trench, that event and the interpretation — that Phoenix had indeed become the first spacecraft ever to reach out and touch water on Mars — appeared first on unmannedspaceflight.com, and only later from the Phoenix press office.

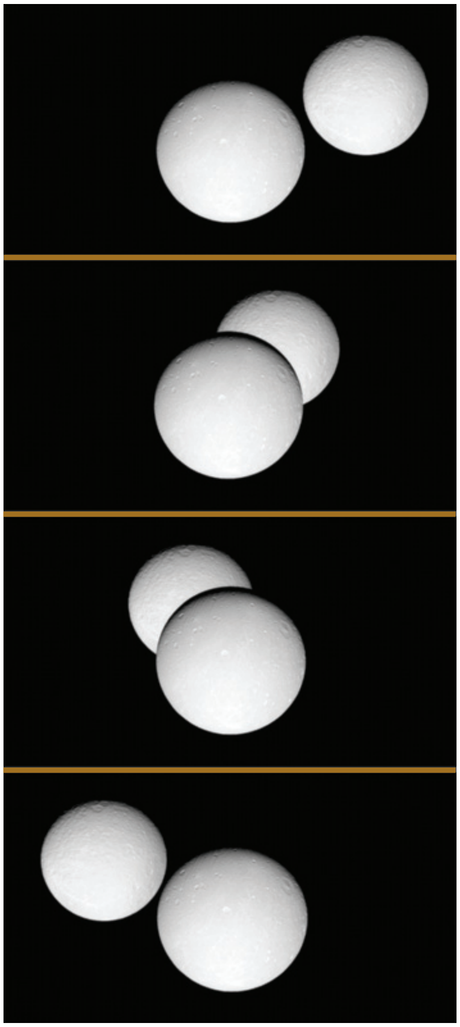
Scientists are divided on whether these issues of priority really matter. Bell says he's not concerned: "I don't think the scientists involved will really get scooped: quantitative scientific analyses require much more time and rigorous calibration work, and it's much more important to be right than to be first."

In contrast, many amateurs who have posted their own processed versions of raw Cassini images to forums and blogs have been contacted by the Cassini imaging team and asked to desist from manipulation of "their" data. However, Cassini mission management at JPL supports any public use of the mission's raw images, processed or not.

Probably the greatest scoop occurred in January 2005, when the European-built Huygens probe descended to the surface of Saturn's moon Titan. Shortly after the images were received on Earth, raw JPEG versions were inadvertently posted to a public University of Arizona website. By the time that ESA released three small images from Huygens, amateurs had already produced and posted gorgeous mosaics.

A Two-Way Street

Providing open access to images has created an international community of space enthusiasts who eagerly consume the data. Their work helps a much broader public visualize the strange worlds being explored by our robotic emissaries.

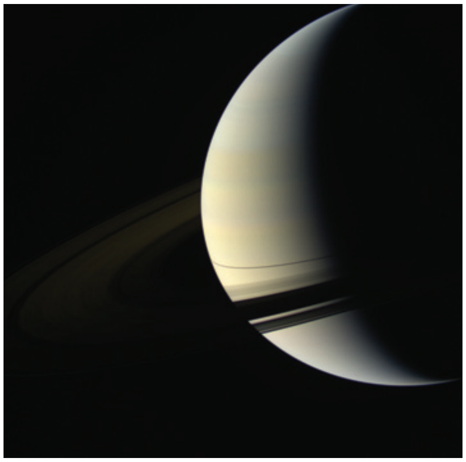


NASA / JPL / SSI

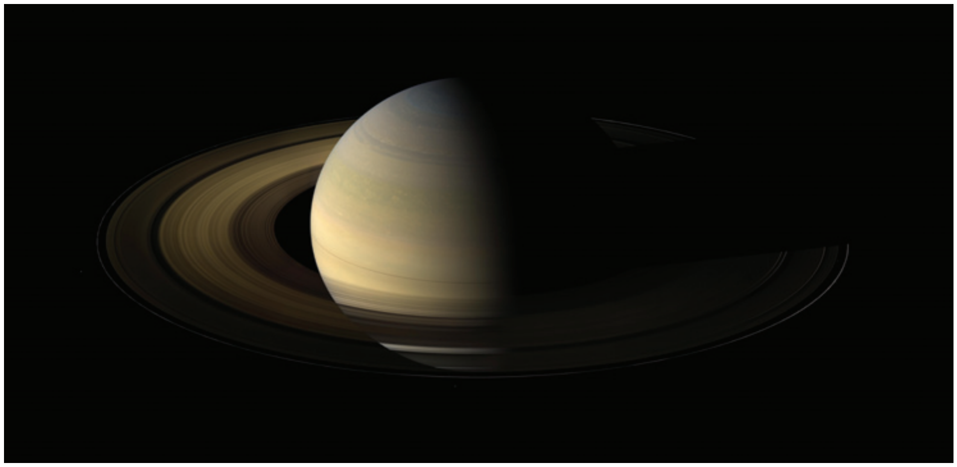
Modern interplanetary spacecraft return so many images to Earth that there are plenty of gems waiting to be discovered by the armchair space explorer. This example from the Cassini archive shows Rhea, Saturn's second largest moon, passing behind Dione, its fourth largest. Dione appears bigger because it's much closer to the spacecraft.

On a few occasions, amateurs have also been able to contribute to space missions. The most notable example happened as NASA's New Horizons mission prepared for its gravity-assist flyby of Jupiter.

The goal of New Horizons' Jupiter encounter, which took place only a year after its launch, was to speed the spacecraft onward to Pluto. Of course, the science team hoped to use the flyby to test out their instruments and systems and



DATA: NASA / JPL / SSI (2)



Both of these views were created from images taken by Cassini when Saturn's rings were nearly edge-on to the Sun. In the version at right, the Cassini imaging team brightened the rings by a factor of 20 to 60 to make them more spectacular. The author's more naturalistic rendition (*left*) shows how faint the rings really are when sunlight is just glancing over their surface. The difference in Saturn's phase is due to the fact that Cassini took the underlying photos at different points in its orbit.

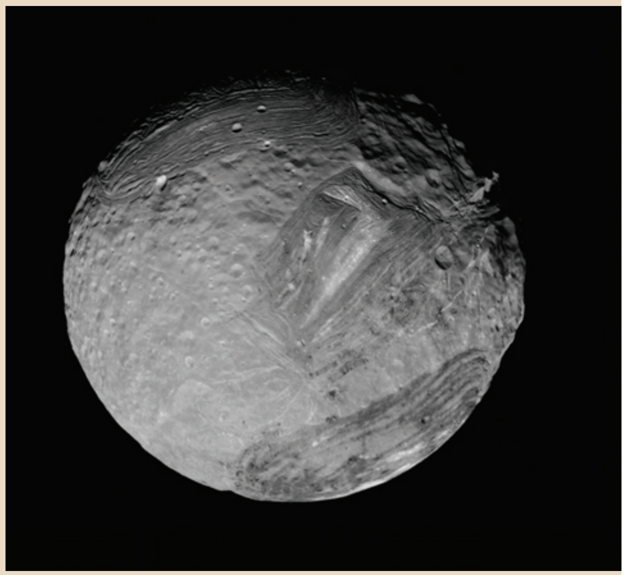
do some valuable science. But the tight schedule and limited budget allowed very little time to examine the flyby geometry for "Kodak moments," opportunities to take photographs that might be useful for public outreach.

In February 2006, New Horizons imaging team member John Spencer posted a note to unmannedspaceflight.com inviting forum participants to search for potential Kodak moments. Within 24 hours, forum member Richard Hendricks had posted a list of possible shots, two of which were eventually captured by New Horizons during its flyby. The successful experiment in amateur-professional collaboration inspired Spencer to issue a similar call for Kodak-moment opportunities during New Horizons' 2015 Pluto encounter.

Despite such successful interactions, NASA and ESA have not yet taken advantage of the skill and enthusiasm of amateurs by outsourcing any of their production of graphics for public consumption. But individual researchers have taken note of the work of amateurs. Scientists do their own processing work to analyze their data. But when it's time to present their research, they want to put their best foot forward. At conference after conference, I've seen researchers incorporate amateur-processed images into their slide presentations, because amateurs create some of the most evocative views of worlds never seen up close by human eyes. ✦

Planetary Society web editor ***Emily Lakdawalla*** *blogs daily about planetary exploration missions at planetary.org/blog.*

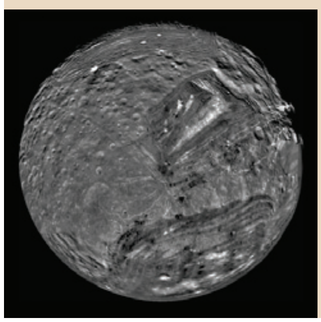
Two Different Interpretations of Identical Data



DATA: NASA / JPL (2)

These mosaics were created from the same data set: eight images captured by Voyager 2 near its closest approach to Uranus's moon Miranda on January 24, 1986. The spacecraft was traveling very fast with respect to Miranda, so the images vary in scale, and the moon appears to rotate from one image to the next. So significant warping of the images was required to assemble the mosaics.

The version produced by the Voyager science team (*below*) is an orthographic map projection, in which the images were processed to be accurate with respect to latitude and longitude, and to remove the effects of solar phase angle on brightness of the surface. The result is scientifically precise but lifeless.



The version above was produced by Ted Stryk, who stretched the component frames using a rubber-sheet method. Although his version is less geometrically accurate, it does a far better job of portraying Miranda as an only quasi-round world whose mountains and canyons produce noticeable bumps and grooves on its limb.