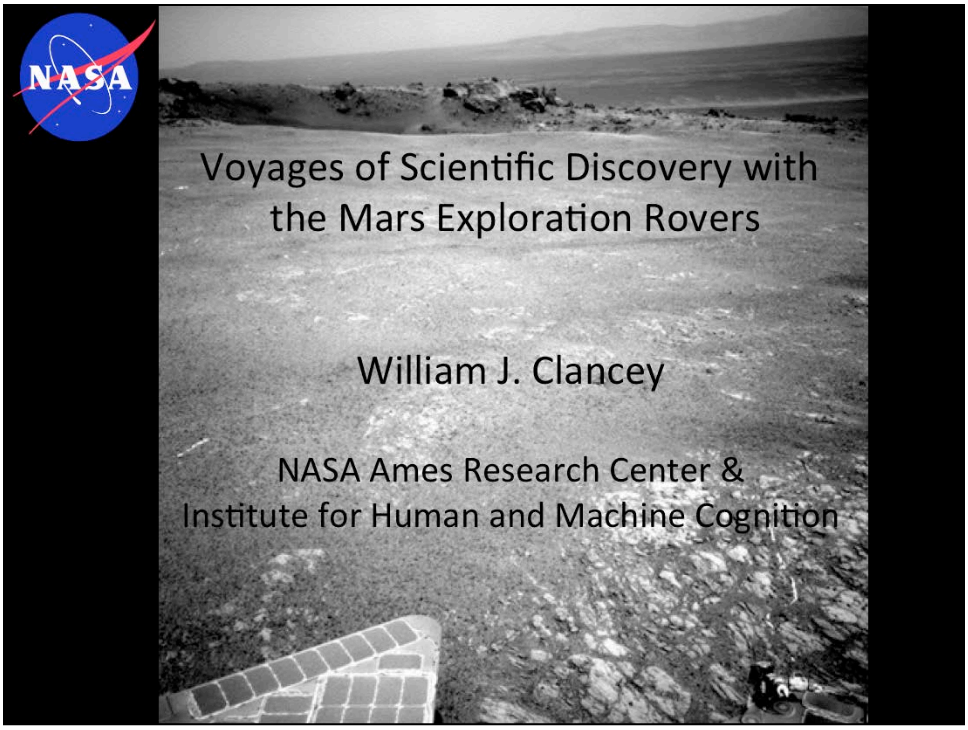
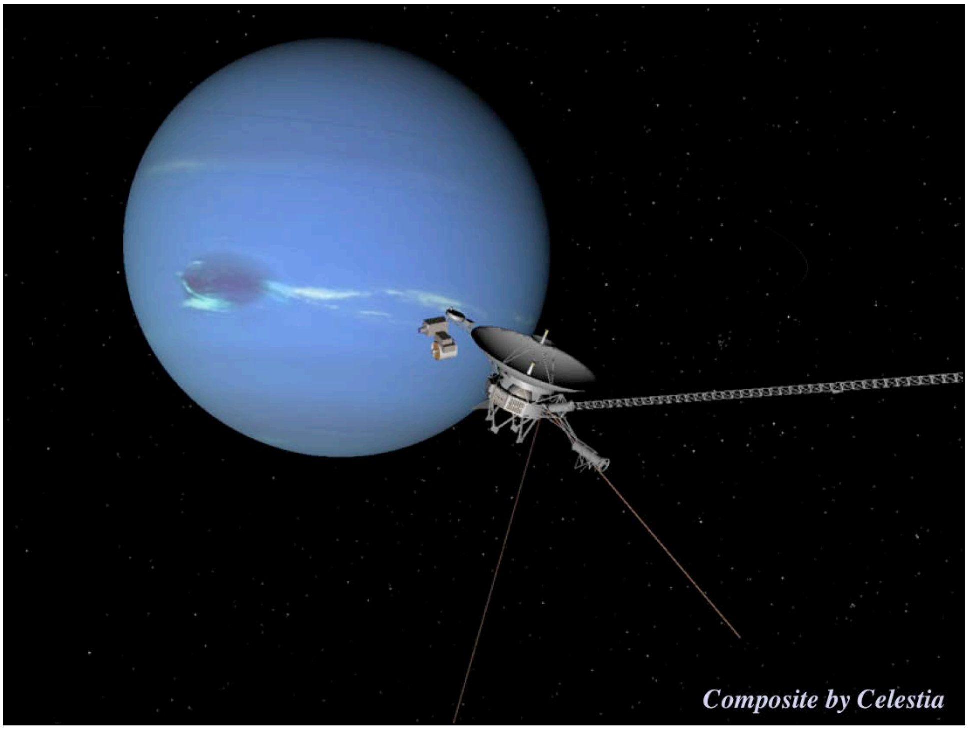


My presentation this evening is about the Mars Exploration Rovers, twin robotic laboratories that began operating 8 years ago on Mars, one of which is still being used to explore the Martian surface.

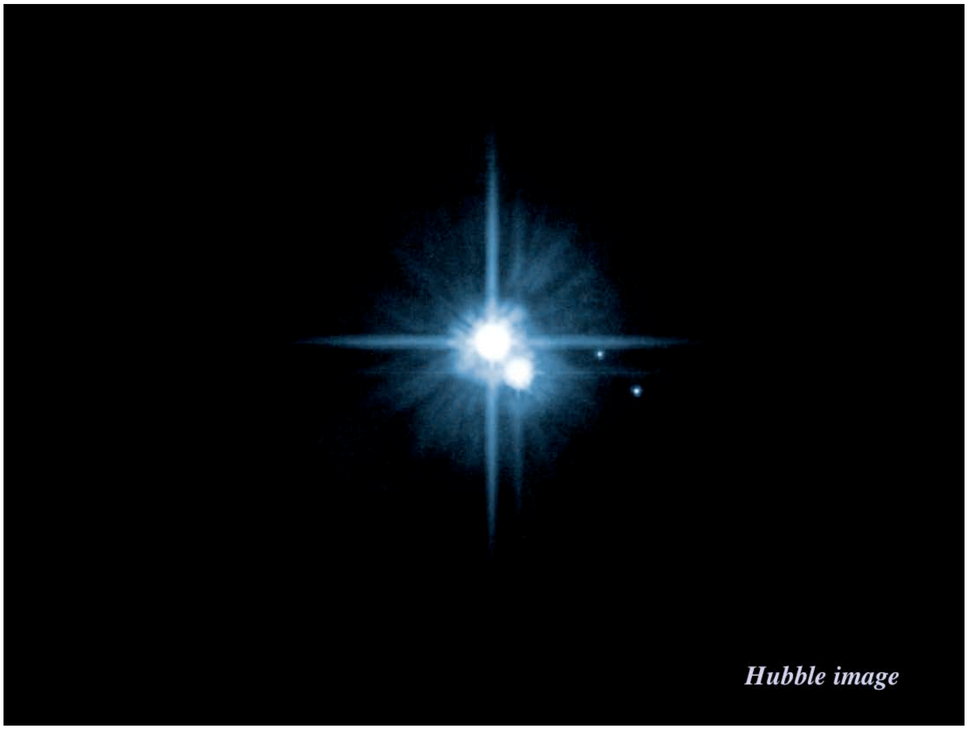
My story is about how people relate to these robotic systems. The Mars Exploration Rover mission, also known as MER (M-E-R), challenges how we usually think about the role of robots in space exploration.

It provides a new way of understanding how computer tools and social organization can be orchestrated to extend human capabilities.



For over 40 years we have been exploring other planets and their moons with robotic spacecraft. Whether flying by beautiful blue Neptune like Voyager in the 1970s, orbiting Saturn like Cassini, or roving on Mars like MER– these spacecraft must be computer-controlled because the distances are too far for us to control them directly from Earth.

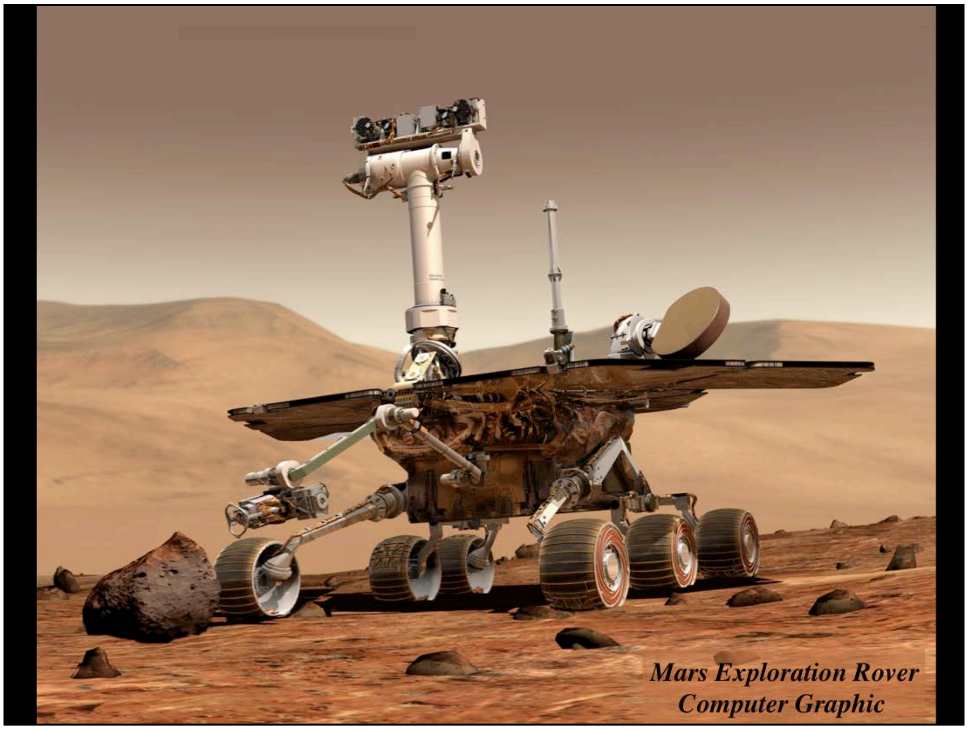
We can joystick a rover on the Earth's moon; it takes about 1 1/2 seconds for the signal to be received. But at the speed of light Mars is at least 5 minutes away and sometimes 20. Radio time to Jupiter is on average about 45 minutes, Saturn is twice that.



When the New Horizons spacecraft reaches Pluto and its moon Charon {"karen"} in 2015 after a nine year flight, it will take about four hours before we know whether the mission was a success.

Given the great distances we can't go to these places in person anytime soon. So to carry out a scientific study, we must repeatedly reprogram and redirect the spacecraft—specifying where to go and how the various instruments are used.

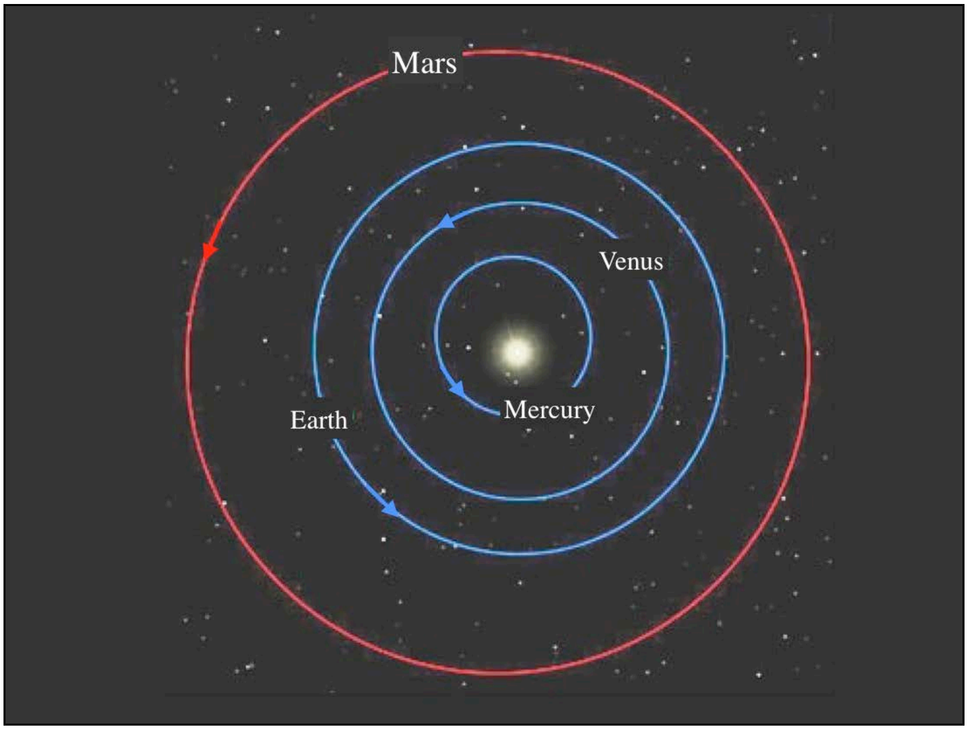
Science teams, working together for 5 or 10 years or more, interpret the data that's returned, and discuss with engineers what's interesting and possible to do next.



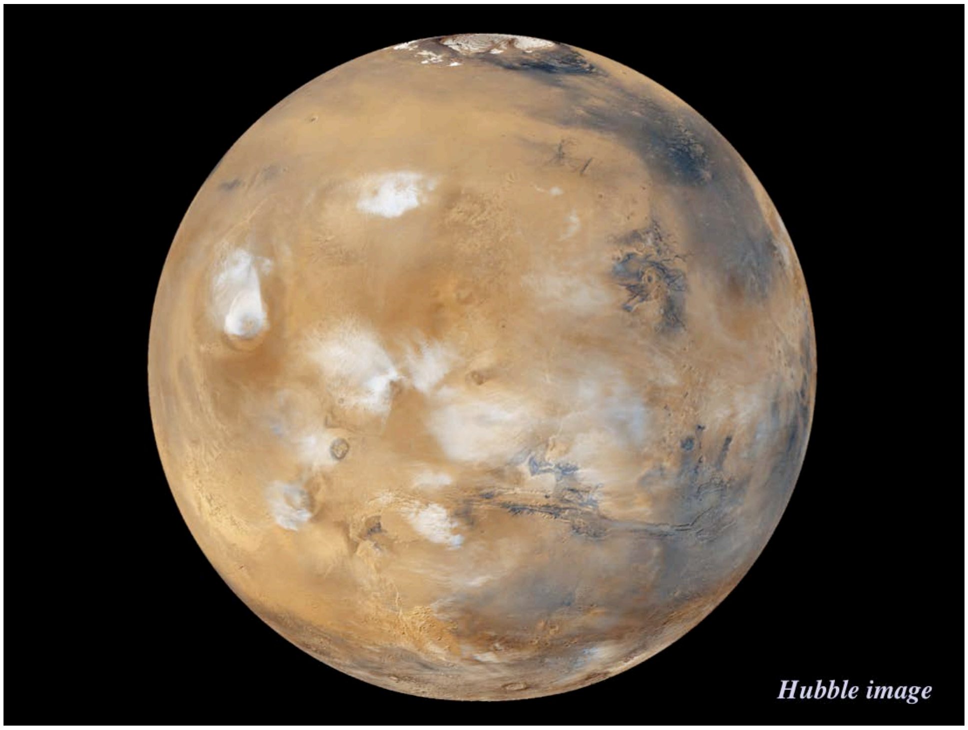
So at its heart, the story of planetary exploration today is about the relation of people and robotic spacecraft—machines that are actually complex laboratories capable of operating in extreme cold with little power, packaged to handle the vibrations of launch, and work for years without repair.

Sending these scientific instruments throughout the solar system is one of the great successes of the computer age and will surely mark our place in the history of science and exploration.

But these missions also show that we understand how to design machines and organize people so everything fits, and that's my story today about the Mars Exploration Rovers — how the design of the spacecraft, the organization of people, the software tools, and the work schedule make it possible for scientists to work on Mars.

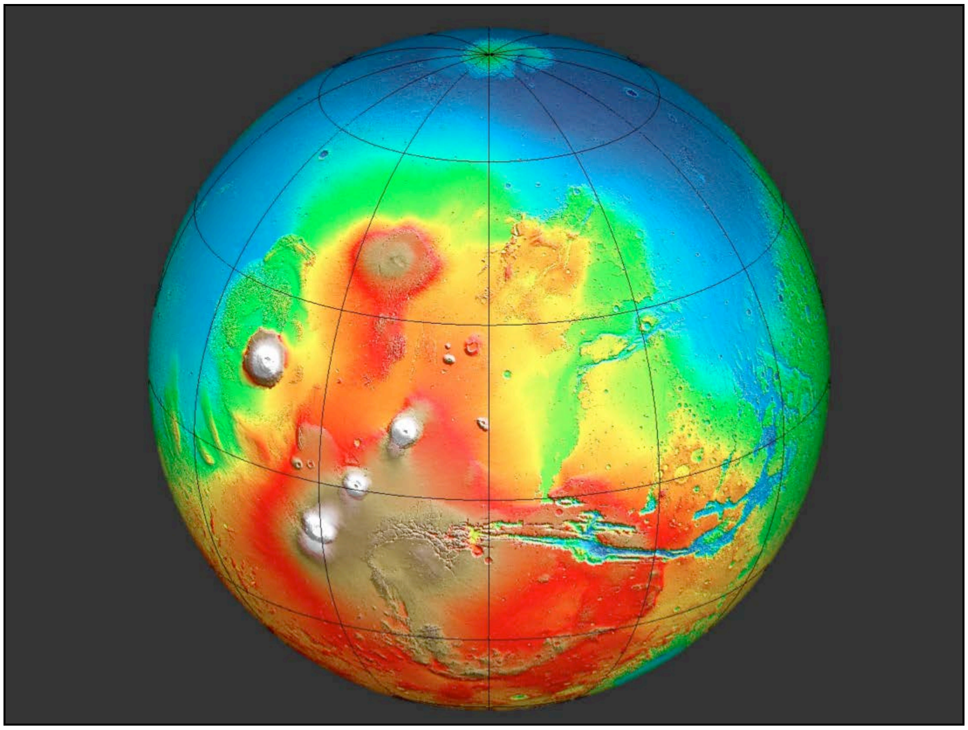


In the scale of the Universe, Mars is right next door – about 9 months travel using conventional chemical rockets.



Mars is about half the diameter of the Earth but lacks oceans and so has roughly the same surface area as the Earth – that's a lot of landscape to explore.

The climate is often colder than the Antarctic with great extremes during the day. But on a summer afternoon on the Mars equator, you could survive wearing something like a lightweight scuba suit and helmet.

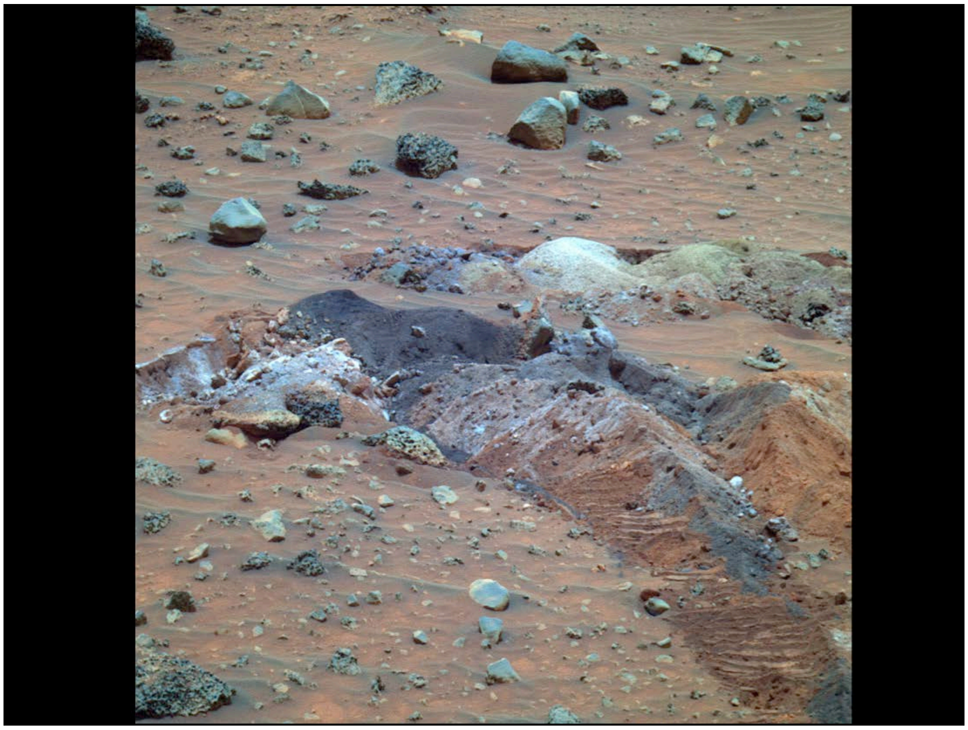


Actually a scuba suit might have been appropriate 3 or 4 billion years ago. We believe Mars was more like the Earth then — wet and with a thicker atmosphere.

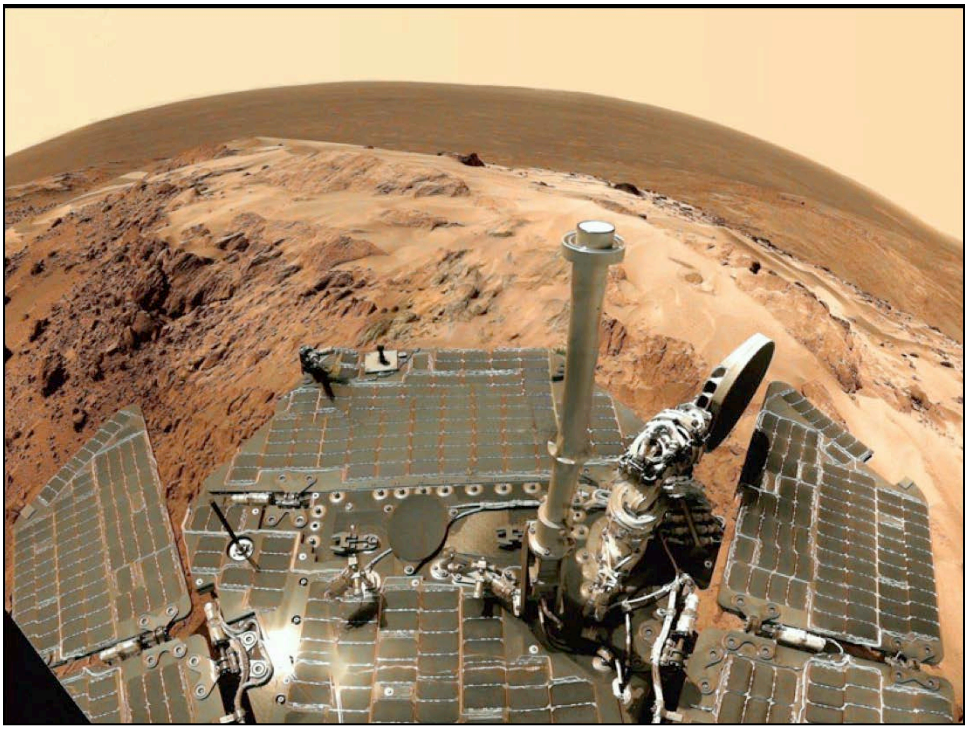
One striking elevation map created from orbit shows the lower areas colored blue, and suggests that large parts of the northern hemisphere might have been covered in seas; and there is evidence for ancient shorelines.

So what happened? Did life form on Mars? Why was its atmosphere lost? Are microorganisms living today below the surface? If life formed there, did it form separately from Earth— or are we related?

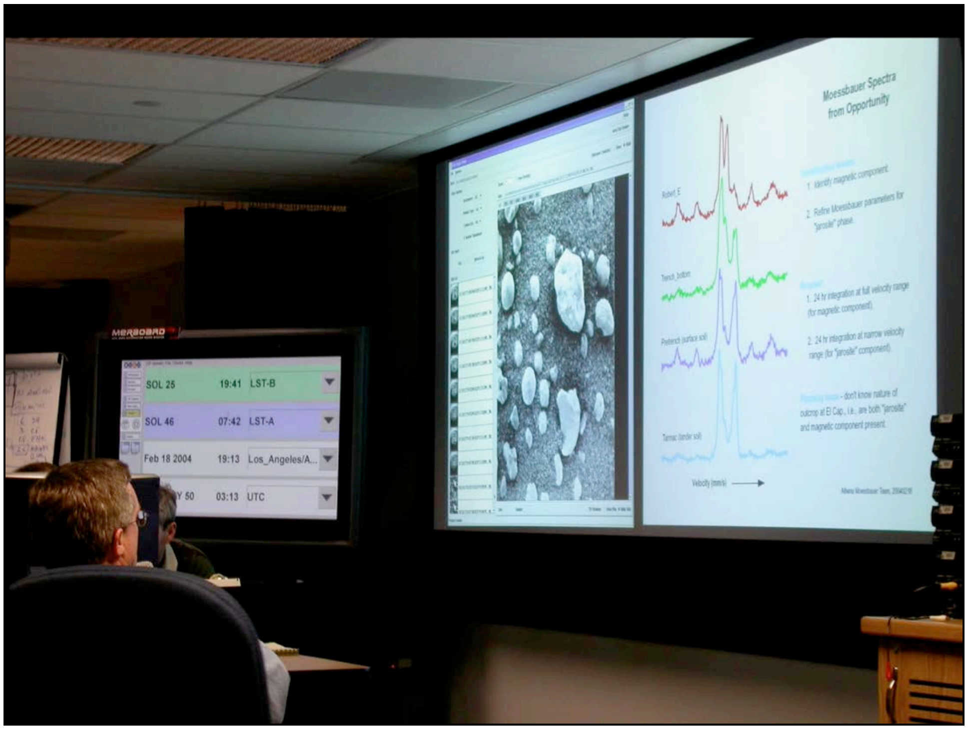
These are big questions and this is why many of us are excited about Mars.



As I’ve said, we can’t directly control the spacecraft on Mars because of the time delay in seeing and affecting what is happening, but by acting through programs that control the rovers and their instruments people have been working on Mars for over 8 years….



Two teams of scientists and engineers, operating the twin rovers called Spirit and Opportunity, have driven together over 25 miles of sand dunes, in and out of a dozen craters, and climbed hills hundreds of feet high to analyze the layers of deposits…and they have also stopped to admire the views and take photographs.



The scientists have scraped rock surfaces, micro-photographed their texture, and analyzed their molecular composition.

In February 2004 a month after landing, I had the privilege to observe mission operations at the Jet Propulsion Lab in Pasadena.

The two rover teams had twin facilities on different floors, and they lived and worked in the time zone of their assigned rover.

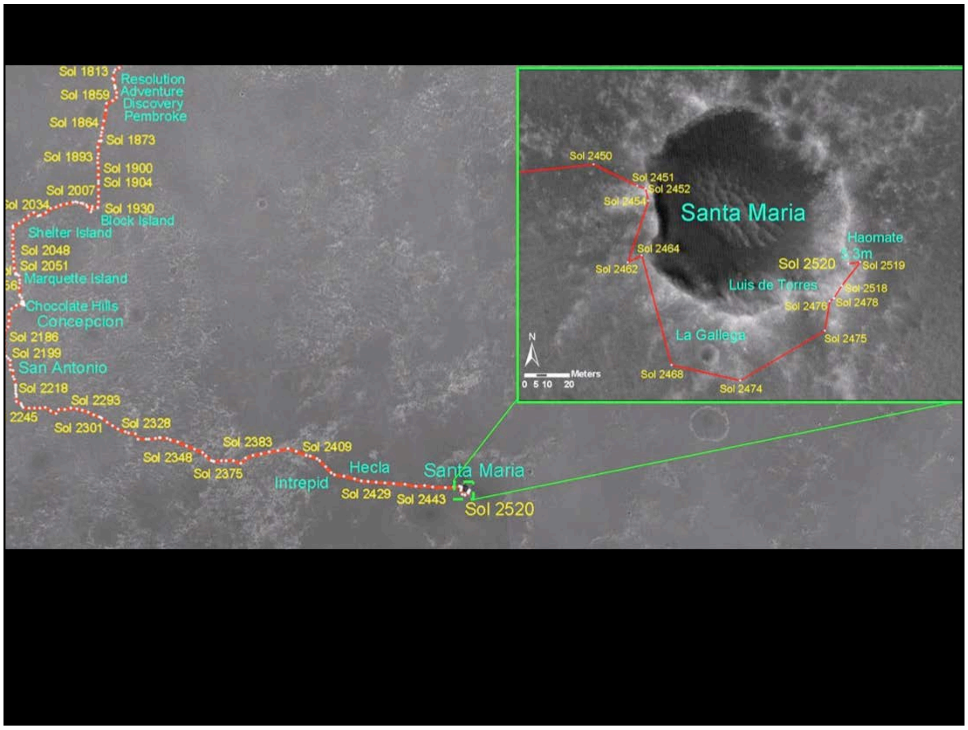
Because the Martian day is longer than Earth's, that means they reported for work about 40 minutes later every day.

The main science meeting room was darkened so they could orient to what they called “Mars local time.”

Each team had about 75 scientists and student researchers, organized into science theme groups -- Mineralogy and Geochemistry, Soils and Rocks, Geology, Atmosphere.

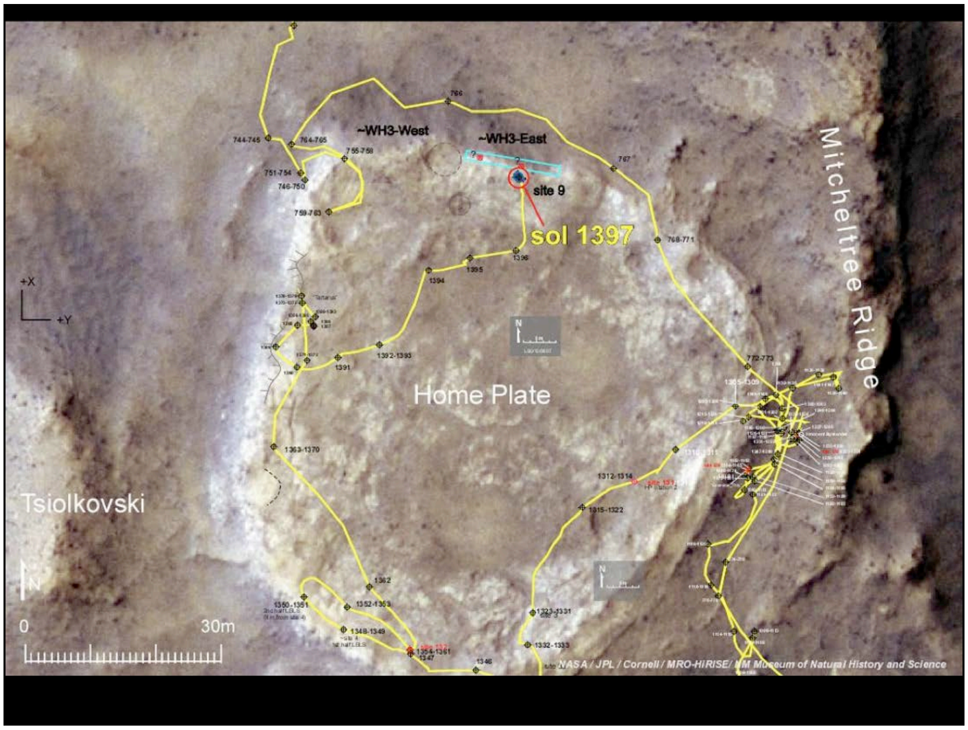
They were arranged at their own tables and gave presentations interpreting what they were learning and what they'd like to do tomorrow on Mars.

The long-term planning group sitting off to one side reviewed the overall mission engineering objectives—measures of distance, number of images, and instrument analyses—and how these goals affected tomorrow’s plan.



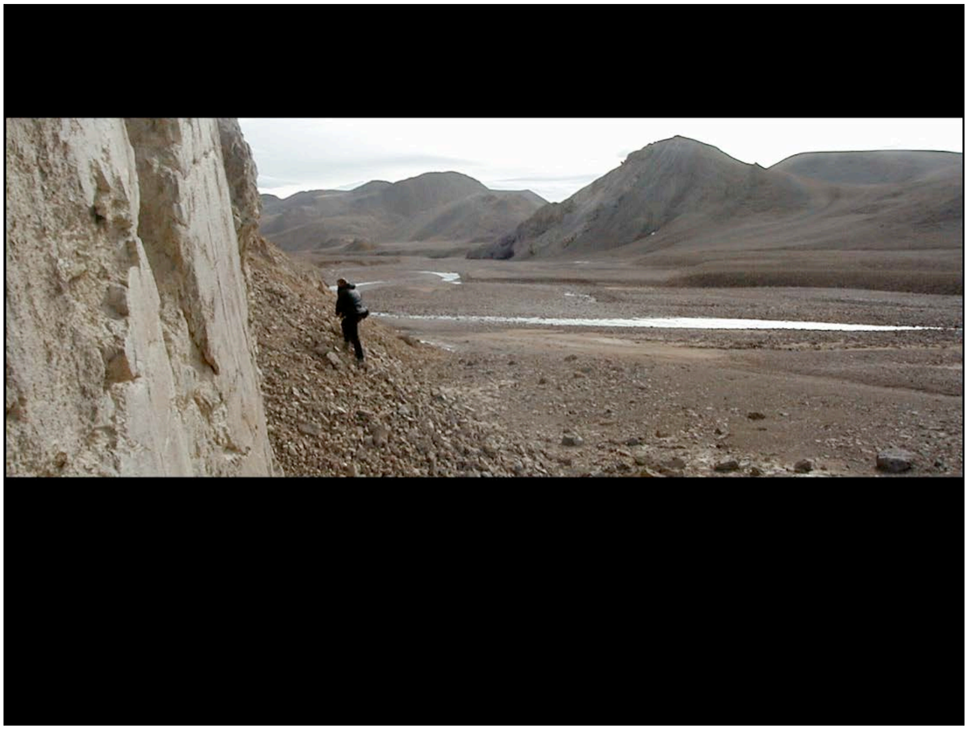
In the words of Steve Squyres, the Principal Investigator of the MER mission, this has been the first overland expedition on another planet.

Applying the rover's tools at chosen spots along the martian landscape, we have learned how water has altered the chemistry of soils and rocks, and found places similar to where life thrives on Earth.



Home Plate for example, an area behind the Columbia Hills about 100 meters across, might be a remnant of large hot springs like those we find in Yellowstone Park.

This is how planetary field science proceeds, by recognizing minerals, formations, and processes that are familiar to what we understand on our home planet. The success of comparative planetology on Mars is partly why it's such an exciting place to study. We're on another planet, but it looks and feels a bit like home.



Just as the MER scientists make analogies with Earth, my study of field science on Mars starts by comparing it to how field science is done on Earth.

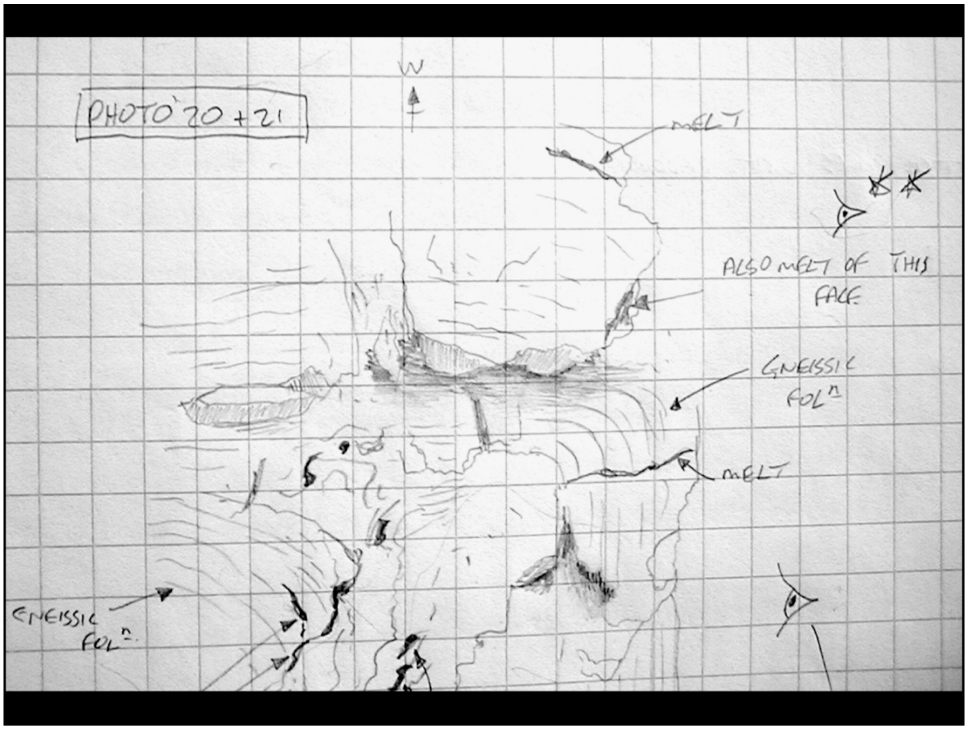
Since the late 1990s I had been joining Mars scientists on an expedition in the Canadian Arctic, a nearly lifeless landscape called Haughton Crater on Devon Island.

The scientists chose this place because it is Mars-like, allowing them to understand how and where life exists in extreme conditions.

And the expedition itself reveals how people might live and work on Mars, which is of interest to mission planners.

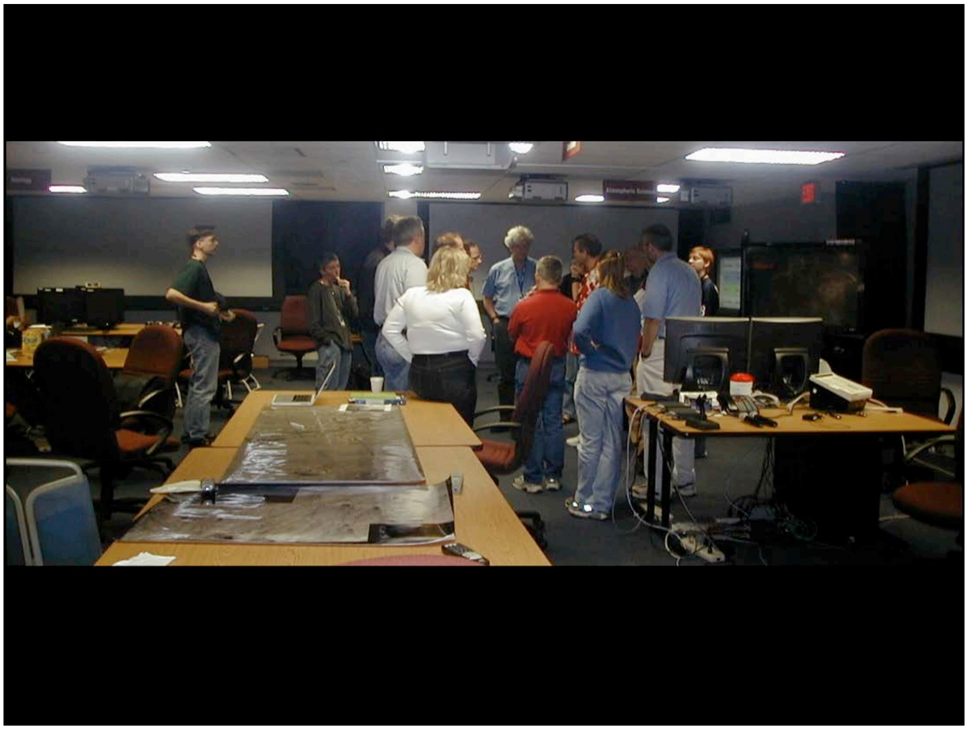
So on Devon Island I followed scientists in the field to understand how they explored; how they decided where to go, and what tools they used…

I documented how they collected and organized samples to be analyzed with instruments in laboratories back on Earth…



I studied what they diagrammed and described in their notebooks, and how this related to their published work.

I observed especially how they tended to work alone or in small groups.

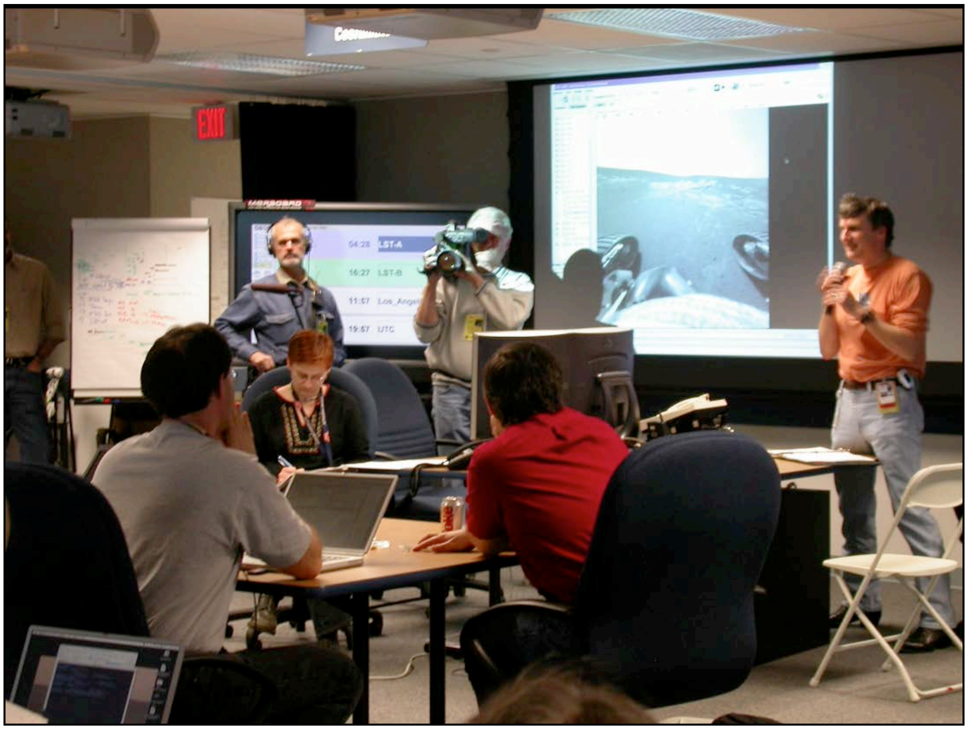


Observing the scientists in Pasadena, I was taken by the contrast immediately: The scientists are indoors, in a dark room, part of a large team, doing everything by consensus.

People from different disciplines are required to work together -- geologists who in the Arctic would race to the nearest outcrop on a hill to survey the landscape, were working with mineralogists who wanted the rover to stop and take a new sample every few meters, and among them were laboratory scientists who had never done field work before.

So working through a rover remotely creates a new way of doing field science.

This new practice changes the scientists, and leads them to relate to their tools, the rovers, in unexpected ways.



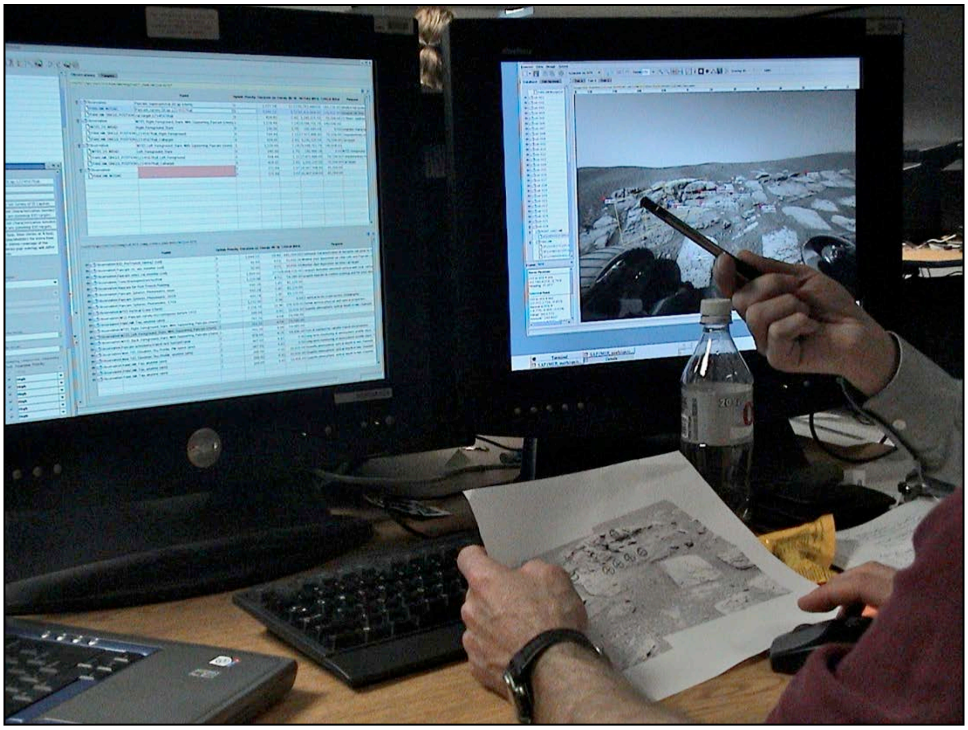
How could the scientists work together under these conditions? How could they accept the anonymity of the mission team where their names would never be associated in the public press with any of the decisions of what rock to analyze, how long to stay, what the data means?

How could people used to seeing, touching, and roving at will study a landscape through a programmed laboratory?

How was it possible at all to do field science on another planet while remaining here on Earth—let alone keep people engaged for eight years?

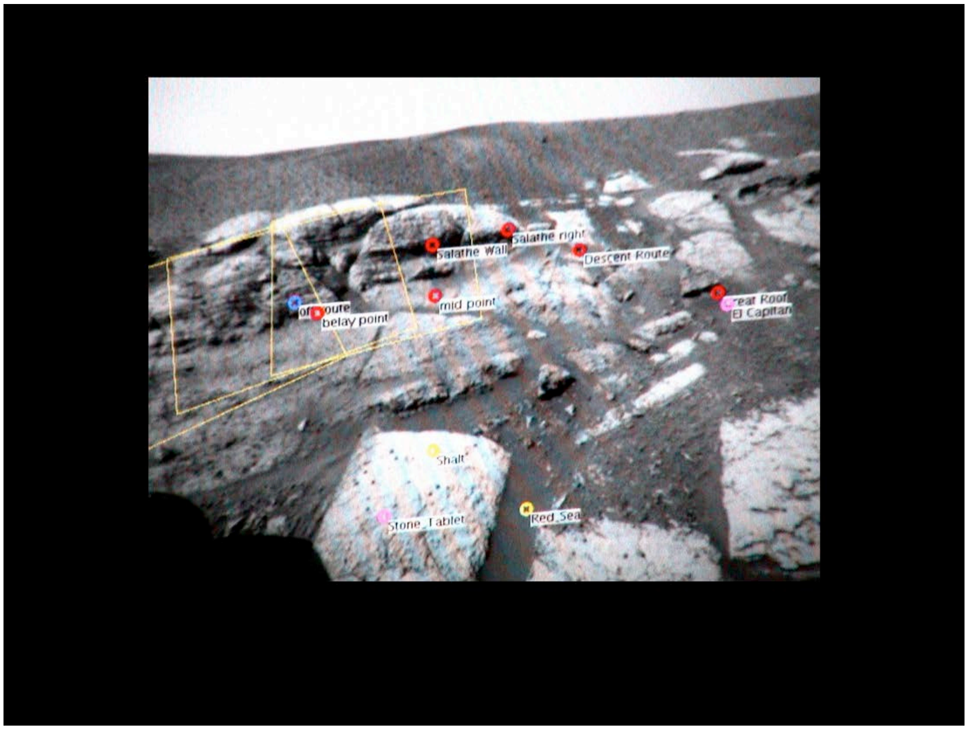
The key is that, although the scientists can't directly see and control what is happening, the design of the rover instruments and computer software makes it possible for them to be virtually present on Mars. Through the combination of stereo and spectral images, and being able to move about, scuff the soil, and scrape rocks, they experience being there.

For example, Steve Squyres described their landing – "We realized we had landed in a crater, probably Eagle Crater, and that's where we were. And then we noticed, 800 meters away—maybe we can make it—there's Endurance Crater …Wouldn't it be great to actually get there!" Squyres's descriptions are all first person – "We had landed… We noticed… Maybe we can make it…" In this imaginative projection the scientists become the rover. And this experience of being on Mars is essential to the success of the mission –it enables them to actually do field science.



To know what rocks and soils are nearby, and what they can reach, or how long it might take to get somewhere, they use a combination of 3-D images, computer graphics, and simulations, often overlaying them.

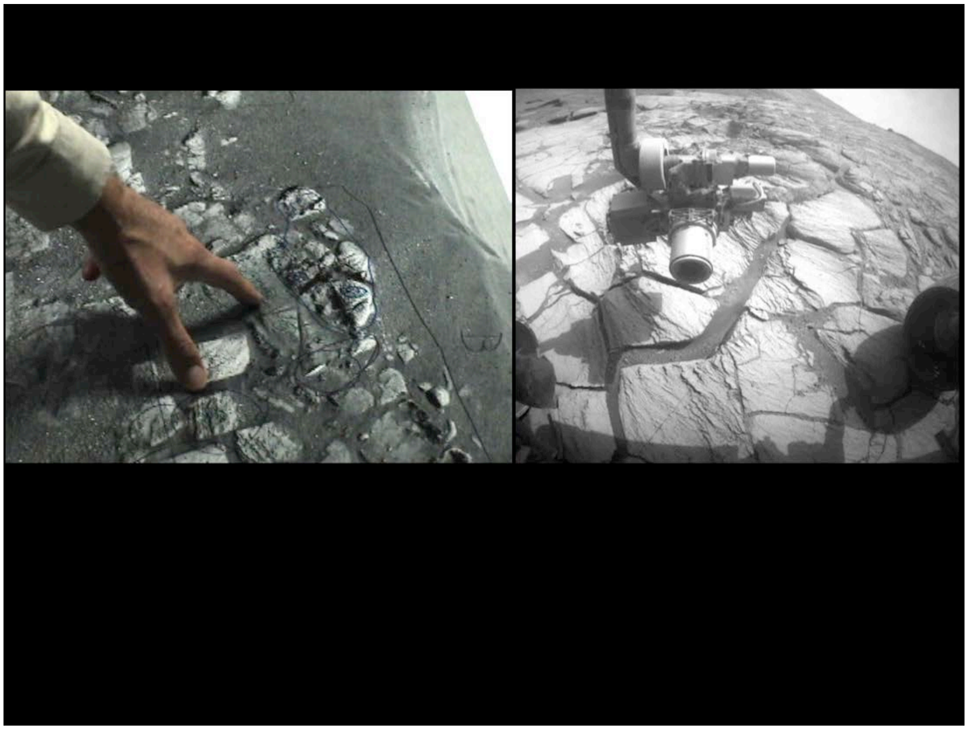
These visualizations allow them to point to places, give them names, and control precisely where new photographs are taken and where the instruments are placed.



So for example, they can draw a yellow bounding box to specify where a camera should zoom in for a more detailed image.

Each photograph can be used like a map of an area on Mars because its location relative to the rover is precisely registered in the planning program. As we move in from panoramas used for navigating to images of outcrops and rocks, we can see and mark up details.

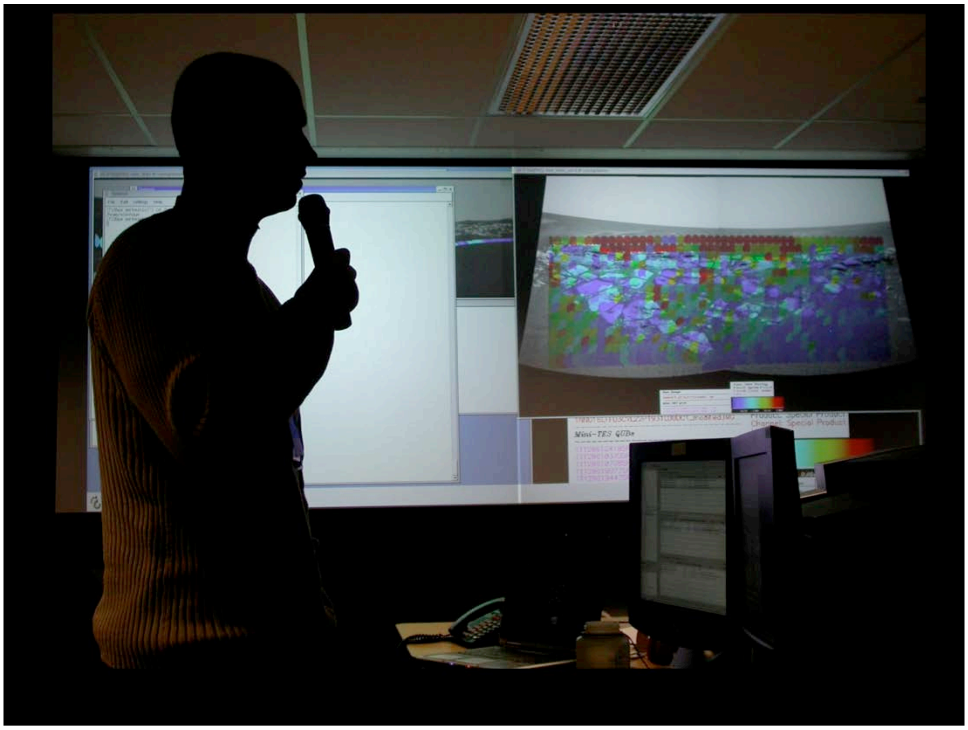
Even small rocks and patches of soil might be named and become targets for an atomic spectral analysis or a microphotograph.



Combining these planning tools with their imagination, the scientists can work as if they were on Mars.

Jim Rice, a geologist on the mission said: “I put myself out there in the scene, the rover, with two boots on the ground, trying to figure out where to go and what to do, how to make that what we’re observing with the instruments. Day in day out, it was always the perspective of being on the surface and trying to draw on your own field experience in places that might be similar.

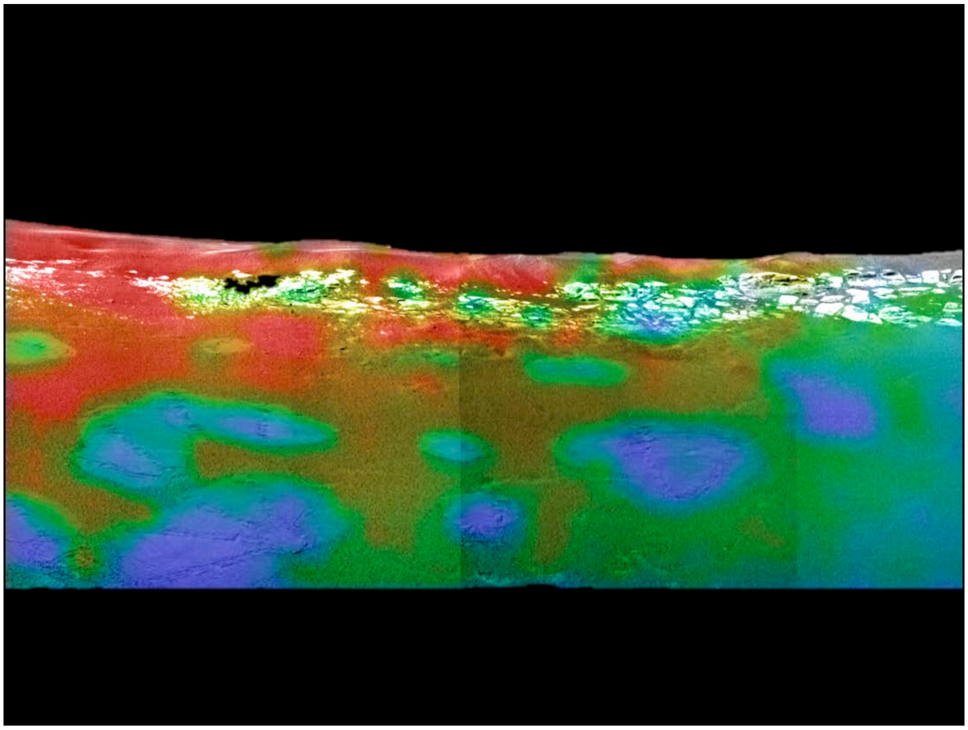
David Des Marais, an astrobiologist, described it this way: “The first few months of the mission, they had these huge charts on the wall, engineering drawings of the rover, with all of the dimensions. We’d have some geometric question, “Well can we see this; can we reach this? Is this rock going to be in shade or is it in the sun?” We’d go stand and stare at those charts. “And over time we stopped doing it so much because we began to gain a sense of the body. That’s projecting yourself into the rover. It’s just an amazing capability of the human mind—that you can sort of retool yourself.



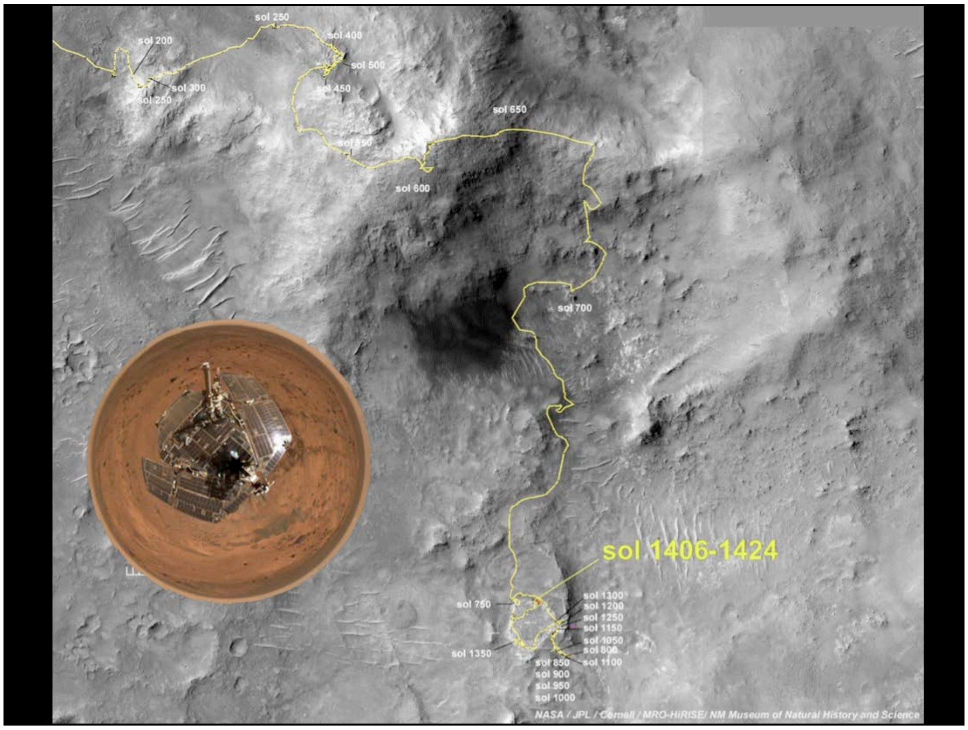
Acting through the robots they control, the scientists look around, manipulate materials, and move over the landscape.

They might pretend to be the rover, crouching down and gesturing with an arm to better imagine what's reachable.

And through the eyeglasses of special cameras, they can directly see iron minerals in the rocks…



…they are transformed in a way to a kind of cyborg on Mars.



Now that's all pretty different from doing field science on Earth. But this is an odd kind of expedition for another reason. Usually scientists go off in different directions at different times using their own tools.

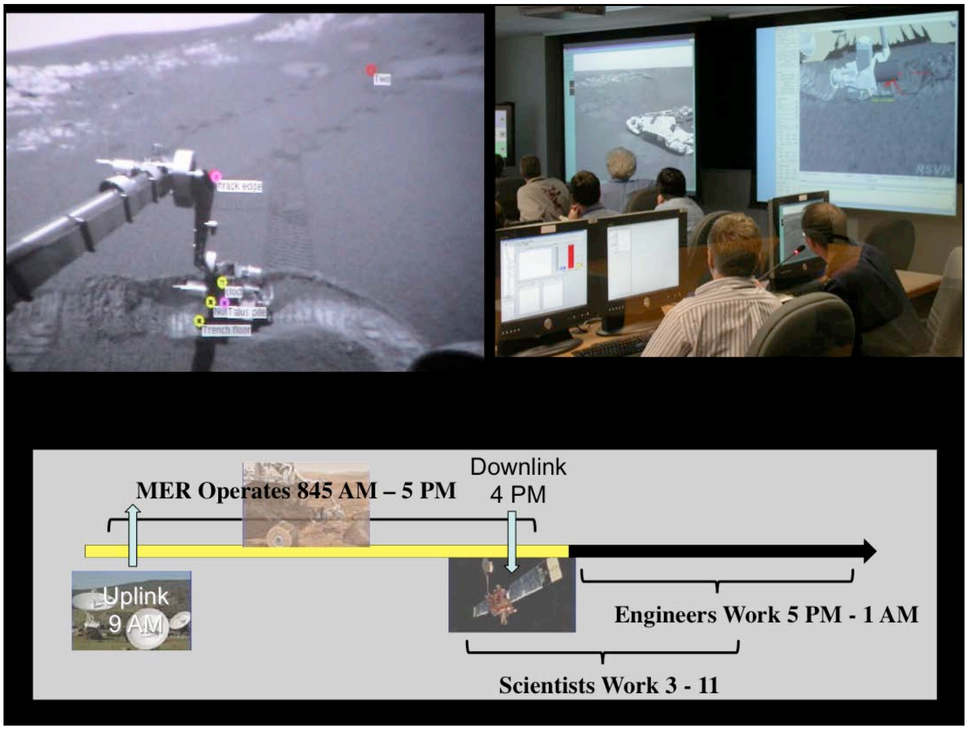
For MER the entire team is all there together, 150 scientists and engineers, balancing together as it were, like on a huge skateboard, creeping over the sand, and up and down hills and craters, meters at a time.

I have also thought of it as being like on a ship in an early voyage of discovery on Earth—the scientists and sailing crew all having to travel together, to negotiate how long to stay, and where to go next, and what to do at each site.

This requires a well-coordinated understanding of roles, schedules, resources, and long-term plans, with a clear chain of command.

If you visited the science and engineering coordination meeting during the prime mission, the first 90 days of landing on Mars in 2004, you would see the scientists up front, on the bridge as it were, with huge displays of the martian surface that lay before them.

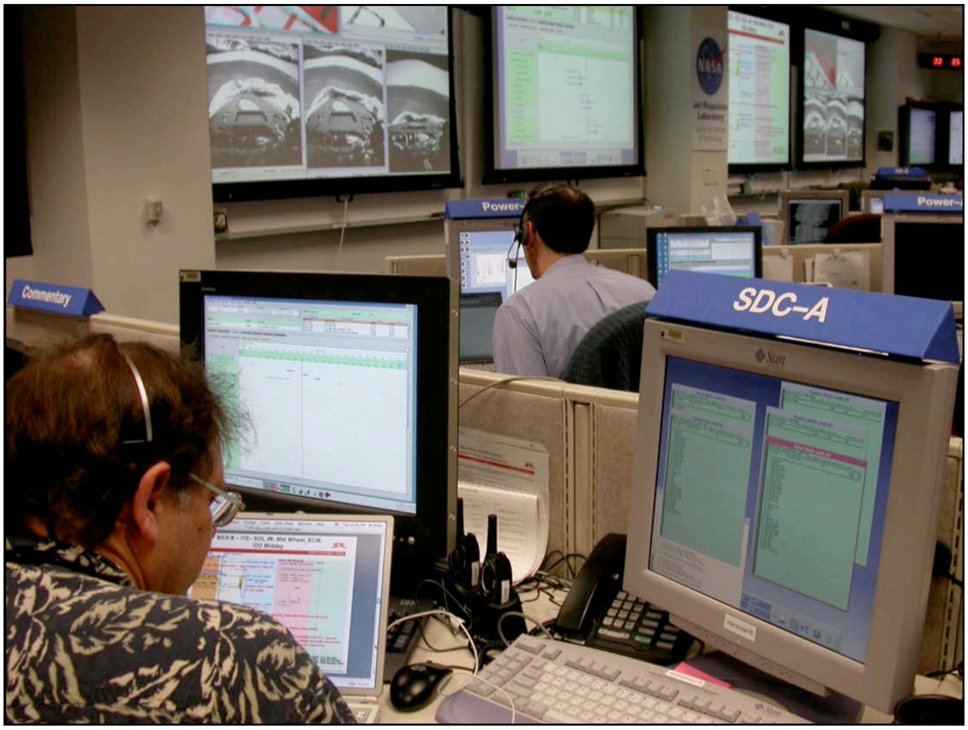
Behind the scientists, as if below decks, were the engineers, arrayed behind big square monitors showing the ship's power, memory, and an evolving timeline plan for tomorrow's work.



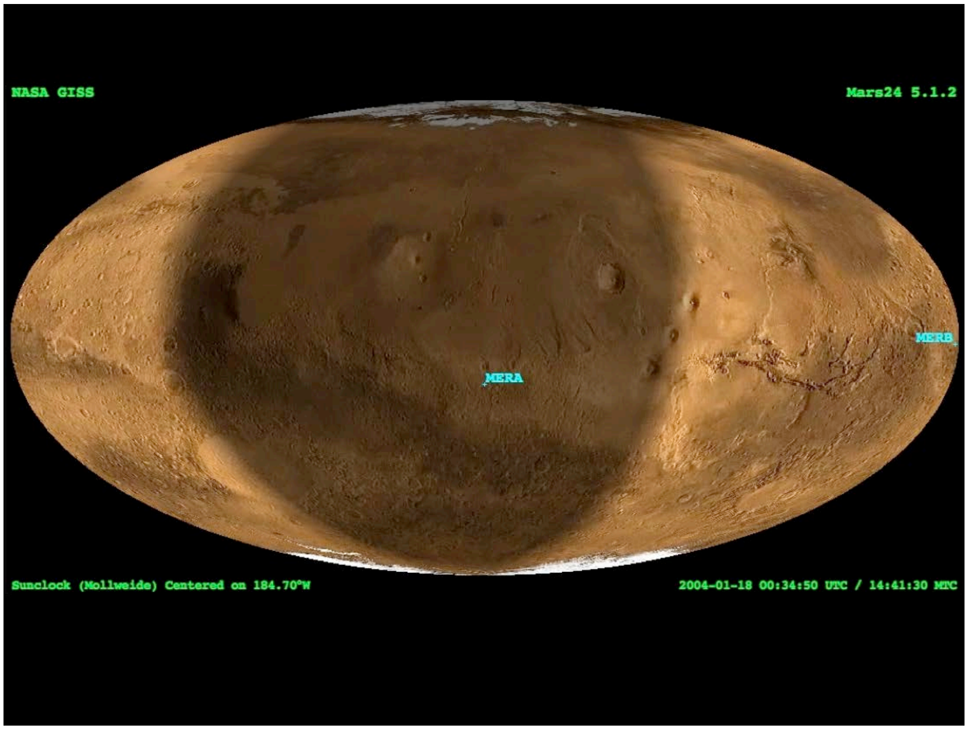
This coordination meeting would occur about 6 PM local Mars time every day. The scientists arrived at work about 3 hours earlier, mid-afternoon rover time, ready to receive photographs and instrument analyses, the result of the rover's work during the day.

The MERs are solar powered, so they work on roughly a 9 - 5 schedule, local Mars time. Every morning each rover would receive a new program for the day's work. So between dinner time on Mars and sunrise the scientists and engineers must finalize a plan—followed by a second shift of engineers who refine and test the program before it is sent to Mars.

If that weren't enough, keep in mind we were simultaneously operating two rovers on Mars for over five years. Spirit and Opportunity were in fact two missions, operating in parallel -- they had their own meeting rooms for science operations at JPL, their own engineering programming teams, 6 PM coordination meetings, and their own cache of free ice cream.



But the teams shared a single mission control center -- where the engineers attend to monitors like those you might find in Houston's mission control, their computers connected to banks of satellites and earth stations that communicate with the rovers.



This common engineering activity required the two missions to be coordinated in a special way. If you look at the map of Mars with the landing sites of the two rovers at Meridiani Planum and Gusev crater, you'll notice that we landed the rovers about 180 degrees apart near the equator.

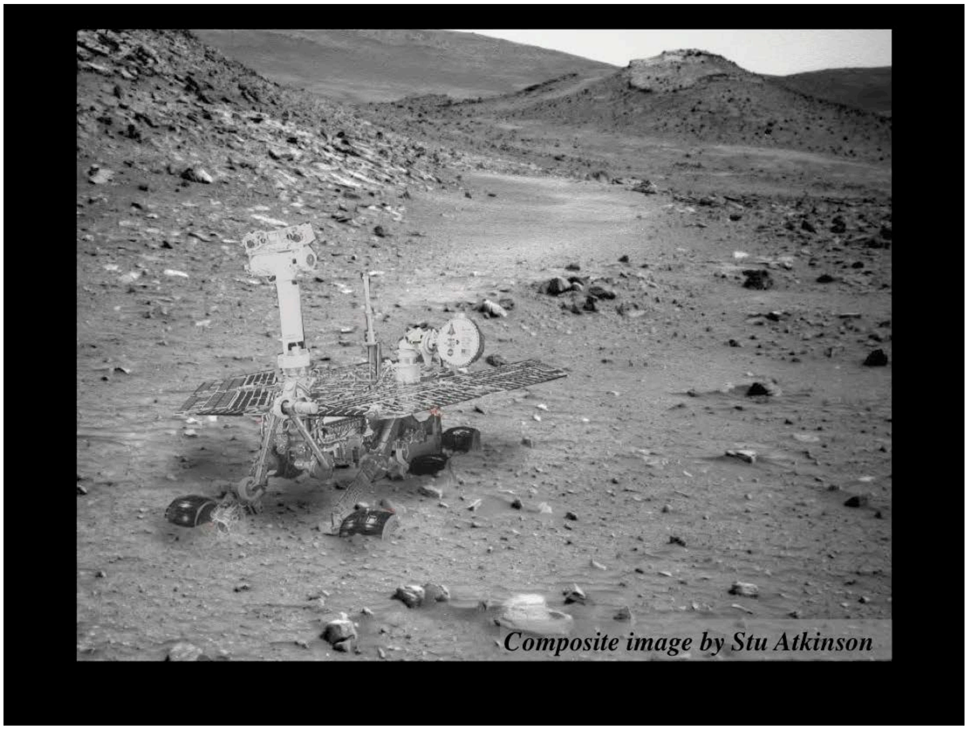
Most people will realize that the sun angle will be most favorable for solar power near the equator, but few realize how the geography of the mission relates to the problem of commanding the rovers every day.

Placing Spirit & Opportunity on opposite sides of Mars allows a single command center and management organization operating around the clock to focus on one rover at a time – controlling them is separated by a half day on Mars. This illustrates why understanding and designing the mission comprehensively as a total system is so important -- the choice of landing sites affects the scheduling of facilities and operations.

So I've described the logistics, the tools, and the mental projections involved in working on Mars. But there's another angle to how people talk and think about the rover that I've found fascinating and also very strange– it's how the rover becomes the hero of the story in official reports on the web, in the press, and even in the scientists' own publications.

What I've learned is that anthropomorphizing the rover is both practical and poetic, it facilitates the scientists' work, helping them to work together as a team, and it provides a way to express their feelings. NASA's 2001 Press release announcing the MER project, epitomizes the personification of the robots—"In 2003, NASA plans to launch a relative of the now-famous 1997 Mars Pathfinder rover. This larger cousin is expected to reach the surface of the Red Planet in January, 2004…. This new robotic explorer will be able to trek up to 100 meters across the surface each Martian day…. Scott Hubbard, Mars Program Director at NASA Headquarters, said, "This mission will give us the first ever robotic field geologist on Mars…"

The metaphors in this poetic narrative (such as referring to the earlier mission as MER's "cousin") simplify for the public's understanding and also serve as a kind of cultural cheerleading (in praise of America's "new robotic explorer").

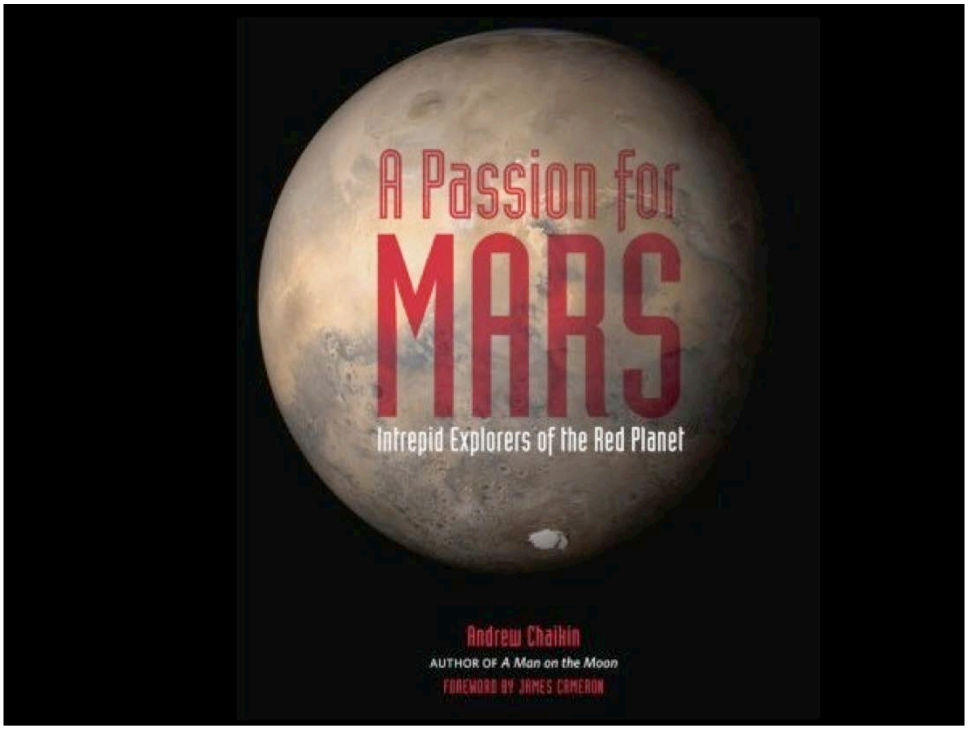


Years later the tone was distinctly sentimental when the Associated Press reported Spirit's demise:

"Spirit, the scrappy robot geologist that captivated the world with its antics on Mars before getting stuck in a sand trap, is about to meet its end after six productive years." The melodrama of the rover is told here in the genre of a lost person—Spirit is said to be "incommunicado"—and it's personified like characters in a Disney animation: "As far as sibling rivalry went, Opportunity was the overachiever while Spirit was every bit the drama queen underdog."

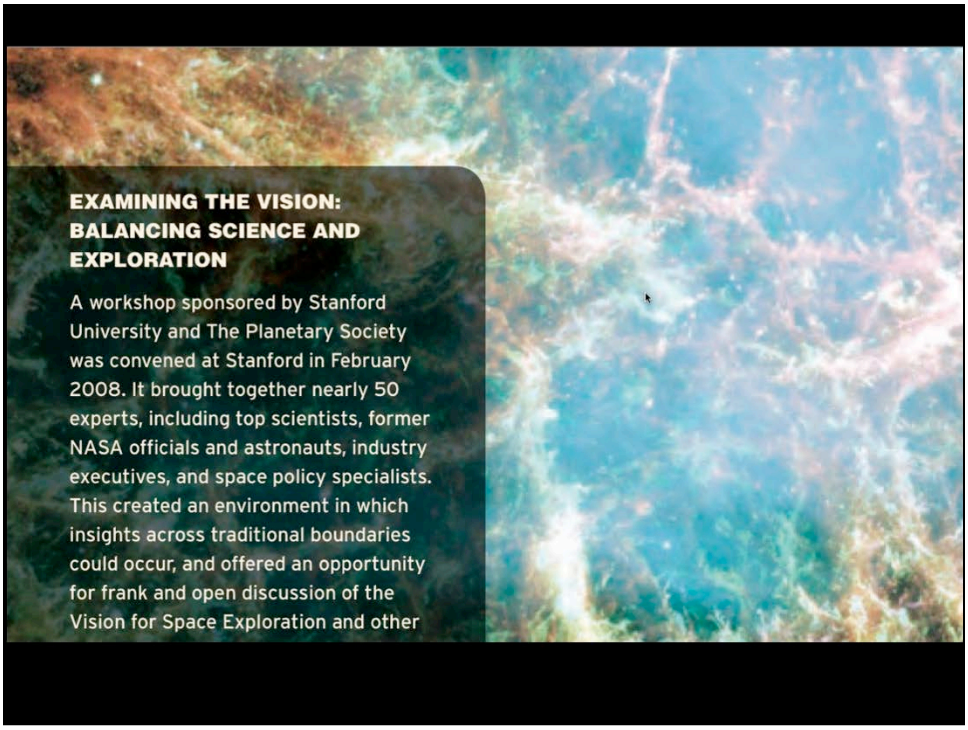
Surprisingly, lead scientists are quoted as speaking in the same matter-of-fact way: "The mission's deputy investigator, Ray Arvidson of Washington University, said he will remember Spirit as a fighter. 'It wouldn't quit, just like the little engine that chugged up the hill.'

Sometimes this poetry appears a bit overdone, but then we find quite serious descriptions of the rover's character and its accomplishments, like a moral in a children's bedtime story: "The plucky rover will be remembered for demystifying Mars to the masses…. This is a story of perseverance." Talking about the rovers in this way, in the third person, makes it possible for the scientists to tell us about themselves, how they feel about the rovers, and the challenges they encountered—a personal emotional presentation you won't find in the journals Science or Nature.



The metaphor of the robotic explorer actually appears in the first books about planetary spacecraft in the 1970s, and it has become a journalistic cliché.

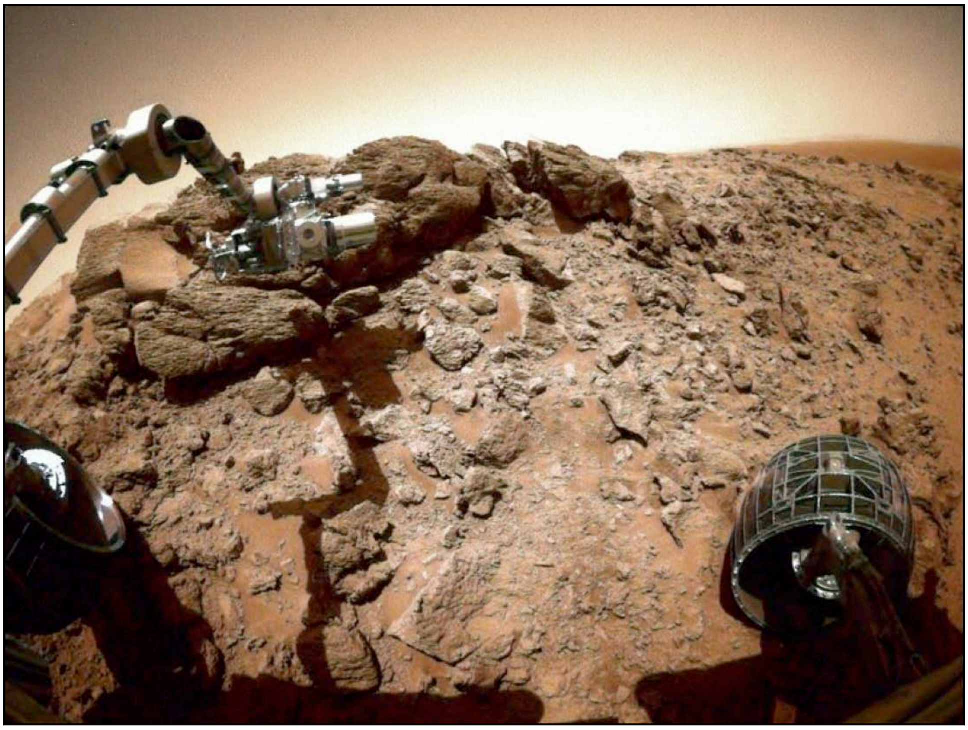
A few years ago Andrew Chaikin subtitled his book "Intrepid explorers of the Red Planet." The book is about the scientists' passion for Mars. But in Chaikin's poetic wrapping the intrepid explorers are the spacecraft.



Over the past decade, the cliché became a conceptually confused debate in the space exploration community between the advocates of science (meaning robotic spacecraft) and exploration (meaning human spaceflight). Partly this was a debate about control for money. But a genuine question remains about the relative roles of people and robots, as distances beyond Mars make daily reprogramming more difficult and the robots become more able to identify what's worth studying.

Some have summarized the dichotomy as "human explorers vs. robot explorers." At a Stanford University symposium, "Humans and Robots in Exploration" in 2008, one topic was – "When does the human become the tool of choice for solar system exploration?" By this phrasing, people and robots are both tools… and then they ask "what is the right mix?" Of course viewing people and robots as interchangeable "tools" from the start is absurd.

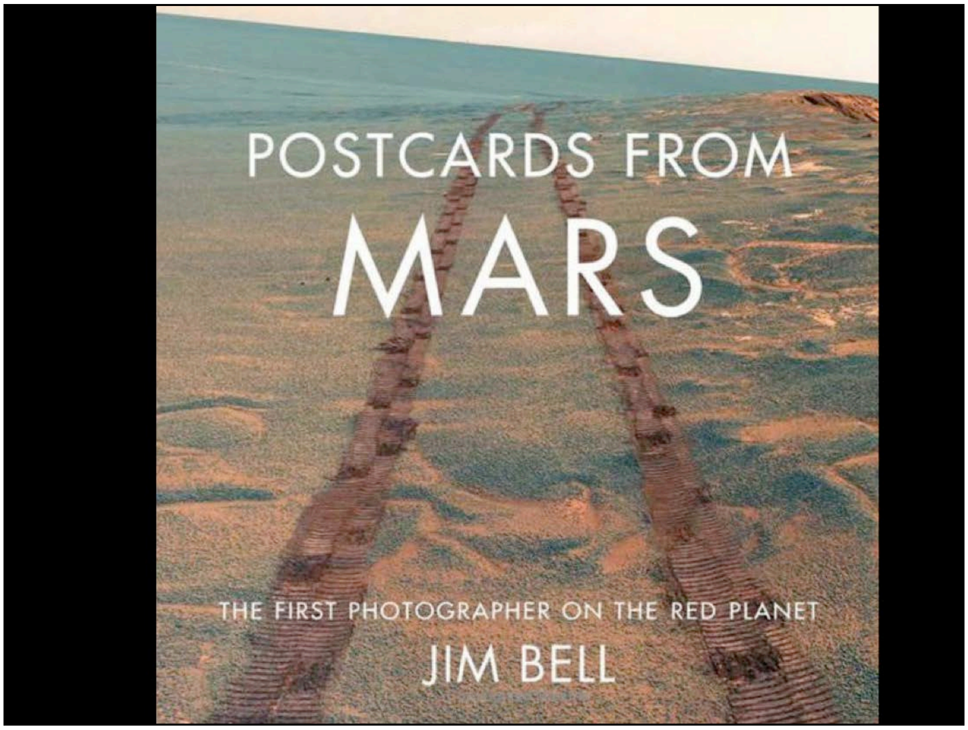
I believe some of the difficulties in talking about people and robots arise because a new working relationship has developed. Spacecraft that fly by a planet carry out a canned program and send the data back in a one-time package. But mobile laboratories with sensors and manipulators that are programmed everyday for years provide a qualitatively different kind of experience for scientists.



This new way of working, which MER epitomizes, can be difficult to think about because it is a relation among people, technology, and processes —not a property or capability that can be ascribed to people or robots independently, which is why the term "robotic geologist" is so misleading.

The relation of people and robots in practical work has been difficult even for the scientists on the project to describe. MER scientists have said they could do in a day what took the rover many months. But they're thinking mostly about the long drives— astronauts would leave the rovers in the dust.
But there's no shortcut for the hours required to do a spectral analysis or a pixel-by-pixel infrared panorama. Nobody's used instruments like these in the field before.

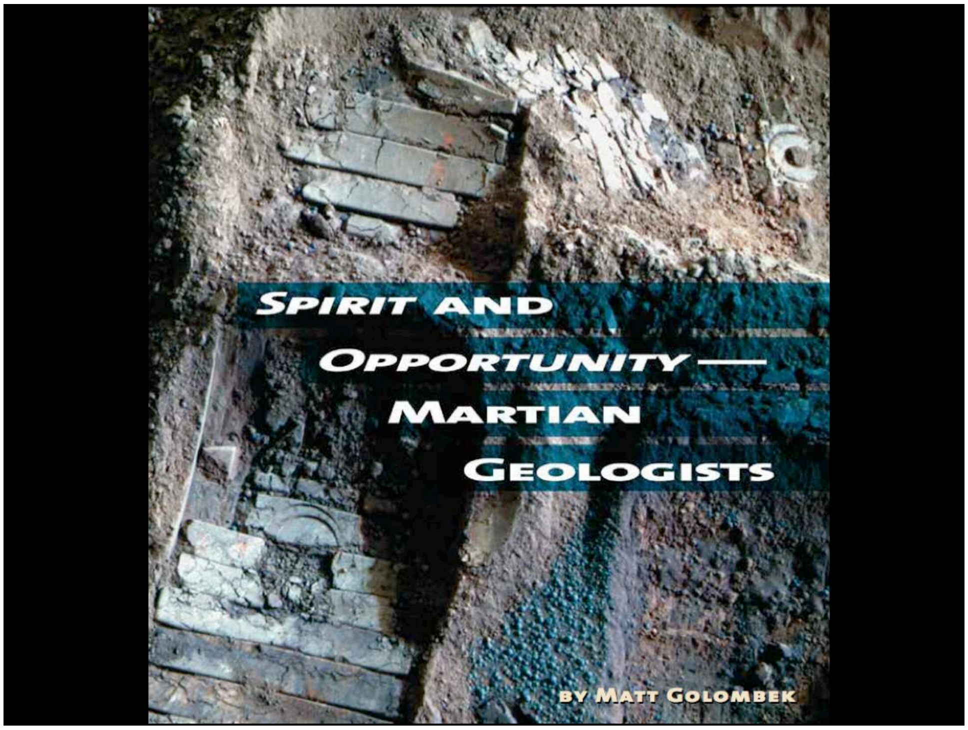
How the rover's automation and human actions are dependent on each other can be difficult to explain—because we don't think about it in practice. In terms of phenomenology, the rover is "seen through," the rover is embodied in our activity, it becomes transparent like a hammer, a bicycle, or even an automobile. We hit, we ride, we go places—we don't have to think about the machinery, it becomes part of us. The rover's arm reaching out is the MER scientist touching a rock on Mars.



Jim Bell's book shows the difficulty of talking about this embodiment. The title is, Postcards from Mars: The First Photographer on the Red Planet – as the Panorama camera lead he's referring to himself. He writes that the rovers "have allowed us to be, in a sense, the first 'photographers' on the Red Planet." He put scare quotes around "photographers," but I would have put the quotes around "on the Red planet" — because Bell and his colleagues really took the pictures but were not actually there.

How shall we describe this? Who sent the postcards? I believe some of this poetry is revealing that joint action is difficult to think about and describe. The phone cameras many of you are carrying in your pockets provide a good example of how viewing robots as being free agents and giving them credit for doing the work can easily arise.

Cameras today are all computerized, so when you press the button computations determine the exposure and other settings, and they might even decide that you are taking a portrait, focus accordingly, and compensate for backlighting. Still you say "I took this photograph." Now separate the button press and the creation of the photograph by something between 30 and 240 million miles and add an overnight delay – now you want to say, "Spirit took this photograph today." All the people and technology in between drop out. It's a narrative short-hand. Philosophically, it raises a question of agency that's at the heart of the humans vs. robots dichotomy.

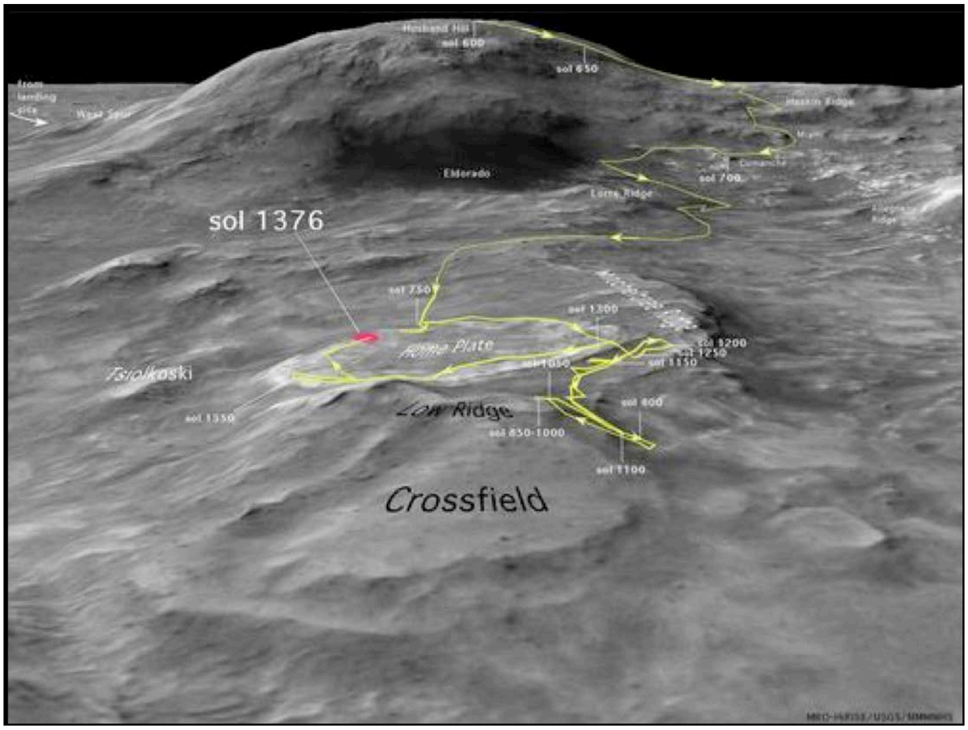


Ascribing agency to the rovers appears throughout the scientists' writings. For example, in The Planetary Report in 2007 Matt Golombek, a lead MER scientist, provided a superbly readable, technical summary of the science—the title is "Spirit and Opportunity—Martian Geologists."

In a clear presentation about ancient processes that formed and altered rock and sand materials near the MER landing sites, Golombek alternates poetic attributions about the rover's actions with the scientists' observations and conclusions:

"After exploring Endurance crater, Opportunity drove south to investigate the heat shield it used during landing. Next to the heat shield, we noticed the only rock seen for kilometers on the plains. Opportunity's investigation of this rock revealed it as a nickel iron meteorite, a very exciting finding, as it was our first discovery of a meteorite on another planet. (Since then, Spirit has discovered two others.)

It appears that Spirit caught on pretty quickly to how to recognize meteorites doesn't it?

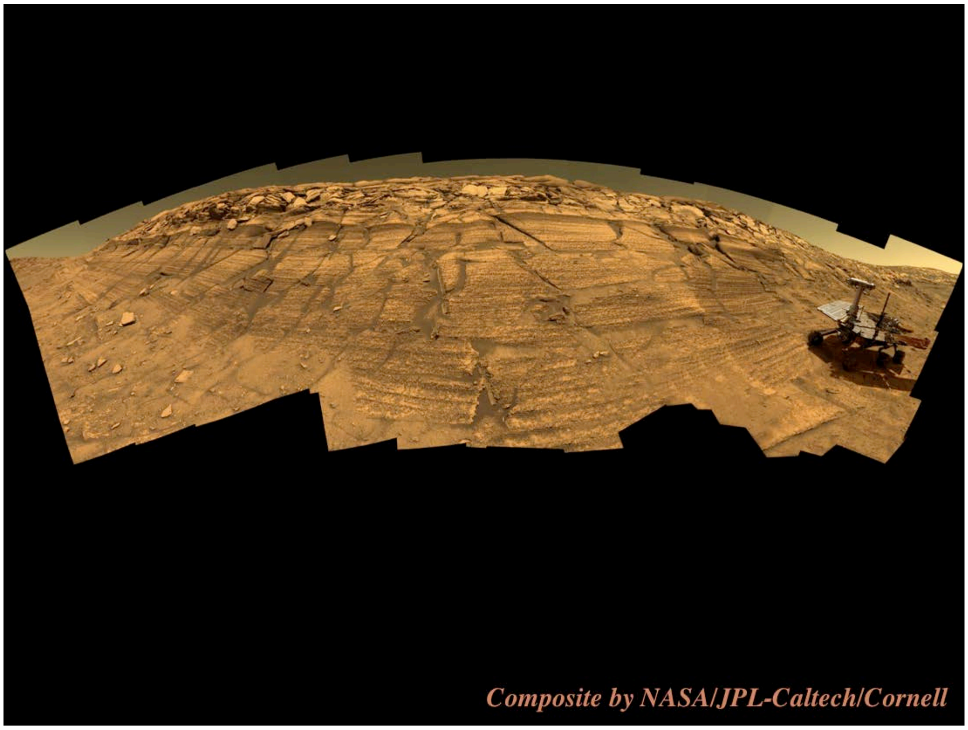


When I first heard the term “robotic geologist” I thought the phrase was just hype, unfair to the people who were actually doing the work, and turned the mission’s story into a kind of puppet show, or something like the Wizard of Oz -- “pay no attention to the scientists behind the curtain.” I worried this would confuse the public and was obscuring the real story about how people are able to work on Mars.

People might begin to wonder, Why should we send scientists to Mars if we already have a robotic geologist working there?

I’ve already mentioned how viewing the rover as a third person, out there on Mars, provides a way for the scientists to talk about themselves, but over time I’ve come to realize that this perspective also has many practical benefits.

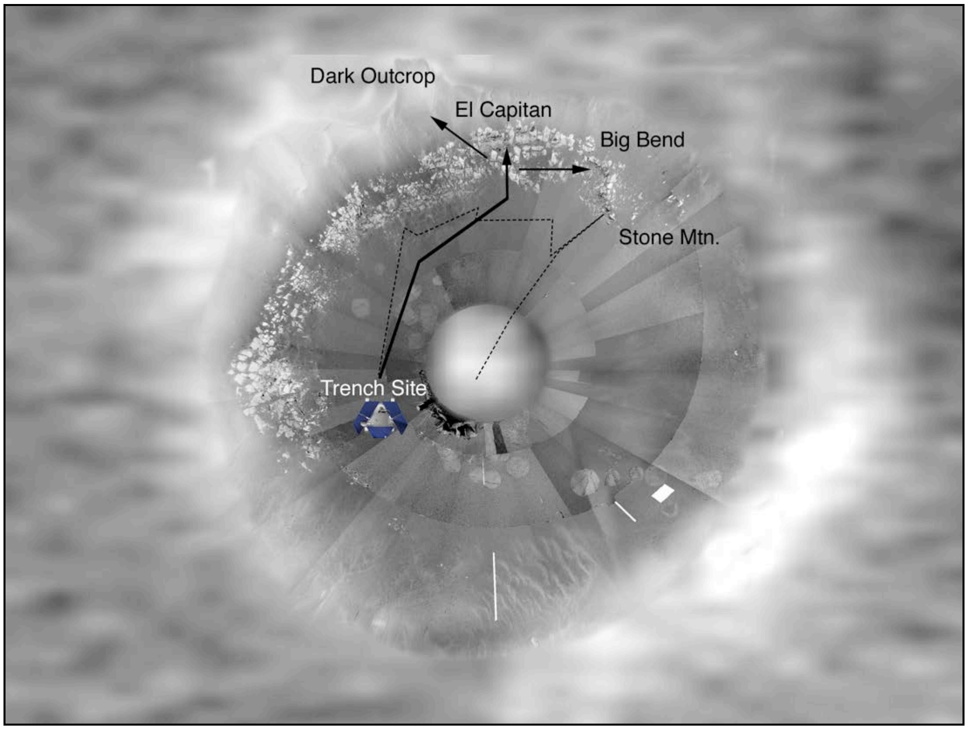
As an obvious example, superimposing the rover’s route on orbital images provides a bird’s-eye-view of the regions that have been explored. We hover over the landscape, seeing MER from orbit.



The third-person view of the rover is also expressed vividly in computer composites that show the rover working alone on Mars.

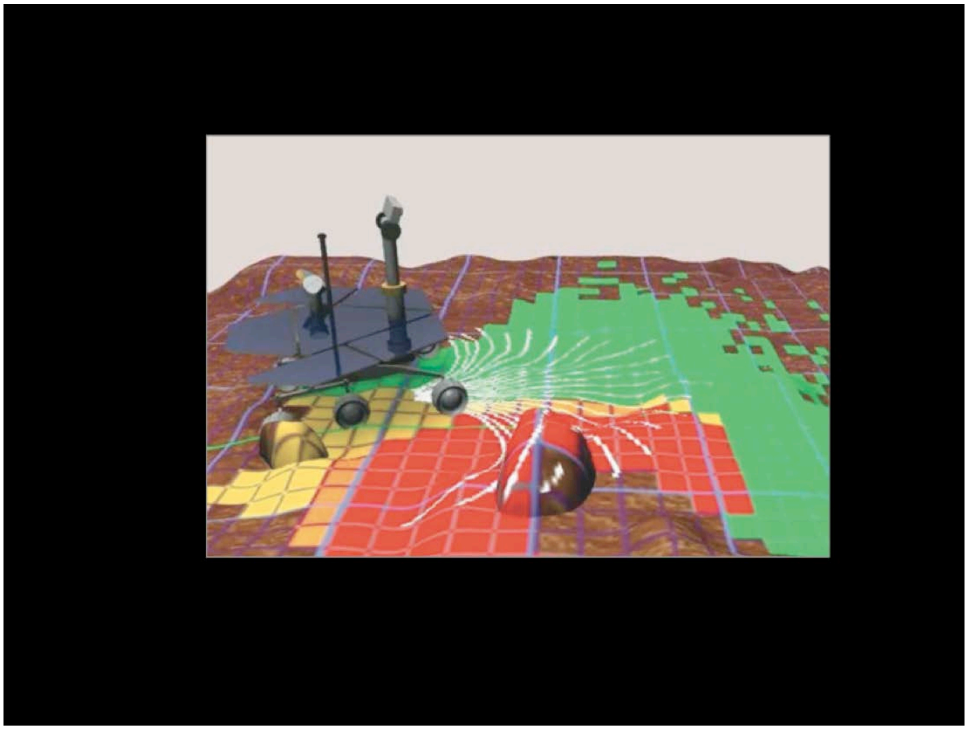
It makes you wonder, who took this photo? Does this express a wish to be present and to make tangible the images the scientists & engineers have in their minds? Or is it another practical projection, another way of understanding the rover's orientation and context, which facilitates doing the work?

Here we see the interplay of art, imagination, and science— motivating and enabling each other.



Other less dramatic computer graphics composed with Mars images are used routinely to orient the planning and programming of routes and targets.

Such third-person views provide an important way of locating the rover, and then by projection, locating yourself in the work on Mars.

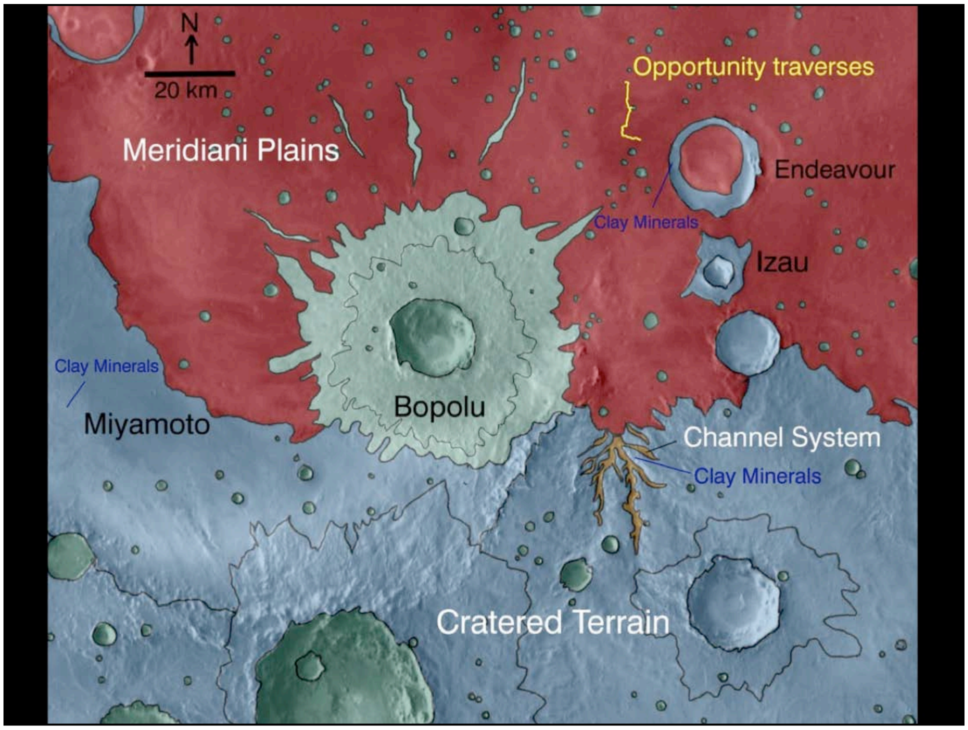


There’s yet another way of relating to the rover, the 2nd person perspective.

When the lead MER rover driver said he viewed the rover as a partner, telling me, “the rover and I work as a team” -- he didn't mean it was the same as working with a JPL colleague.

Instead, he was using the best words he could find, relating to the rover as a peer, to express how he delegated work to the rover, so it planned portions of the route that he didn't have sufficient data or time to analyze and program himself.

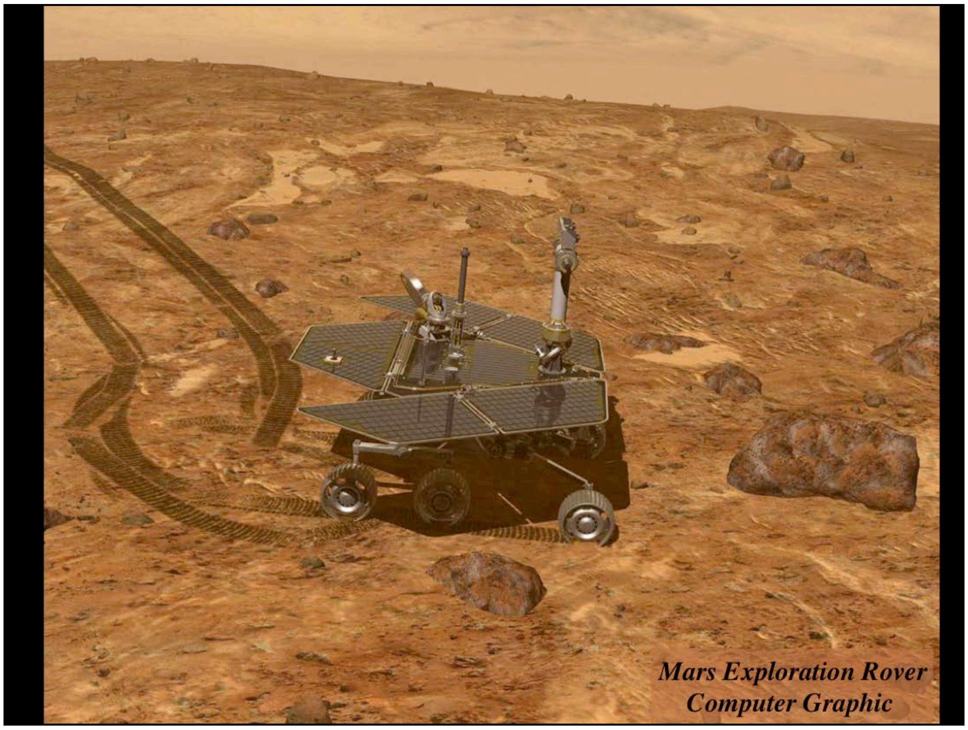
He relates to the rover in terms of “what I do” and “what you do.” For him this second person I–you relation is practical. The rover is an agent you can rely on.



Talking about Spirit and Opportunity as investigating, driving, and so on, has probably also taken hold because it fits so well the convention in scientific writing of depersonalizing contributions—reports focus on the goals, methods, and data—the emphasis is on Mars not the scientists or how they do their work.

Individual scientists are also properly wary of taking the limelight, when everyone knows that they work as a team.

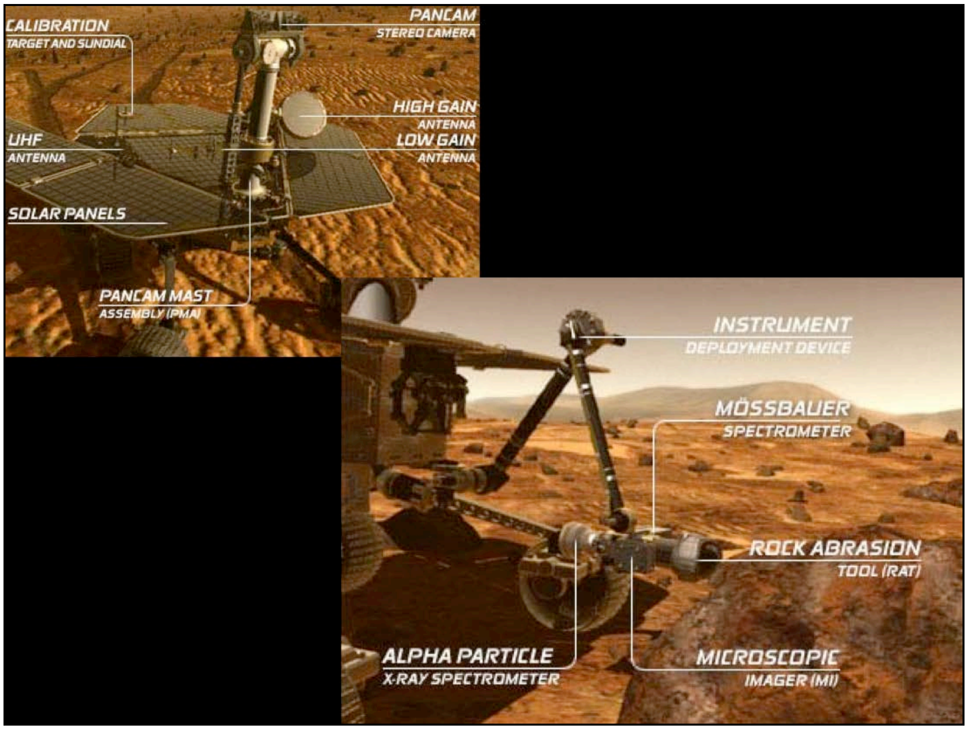
And in this respect, I was especially surprised to learn how the "robotic geologist" metaphor had been pivotal in designing the rover itself and promoting teamwork.



A central concept in the original MER mission proposal is that the “Robotic geologist” is a physical surrogate for the science team.

Unlike the boxy spacecraft we send to orbit or fly by planets, MER was deliberately designed to personify a scientist —about human height, with stereo-vision, mobile, with an arm holding a hammer and hand lens and other sensors.

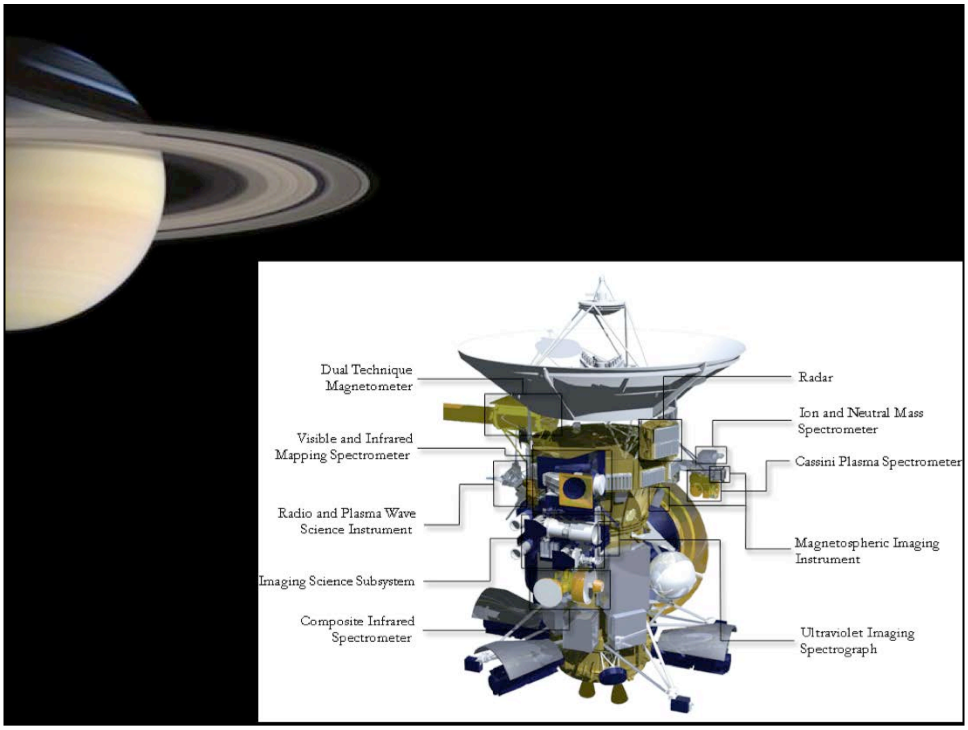
Combining the disciplinary teams in one persona, MER realized the vision of “One instrument, one team.”



The team's ability to identify with the rover is fundamental to MER's design, as Steve Squyres explained:

"The whole idea behind MER is that these tools work together. Look at the silica discovery… The mobility system [by which he means the rover's wheels] …trenches up some soil. We notice it with the Pancam wide-angle camera, we hit with mini-TES to check for iron; it looks interesting, and we go over and we figure out its molecular composition with APXS. Everything works together."

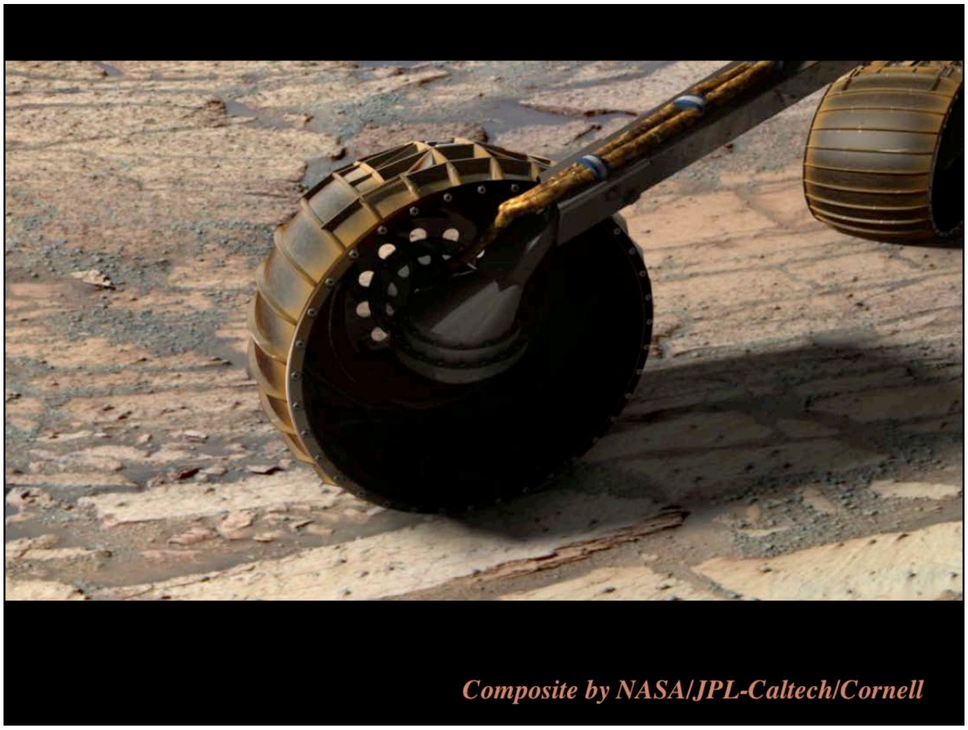
Having instruments that work together encourages the instrument teams to work together. This was Squyres vision, which he called "science systems engineering." He said, "You've got these sensors and each of them provides complementary bits of knowledge. You're going to use the payload to fullest advantage, if people look at it as being entirely at their disposal....If you were out there in the field, doing geology with your field partner, you might be arguing about what this rock means or what that rock means, but you're not going to argue about, "Well, should we use the rock hammer or should we use the compass? We don't have pancam guys arguing with mini-TES guys, but rather geologists arguing with chemists about exploration…"



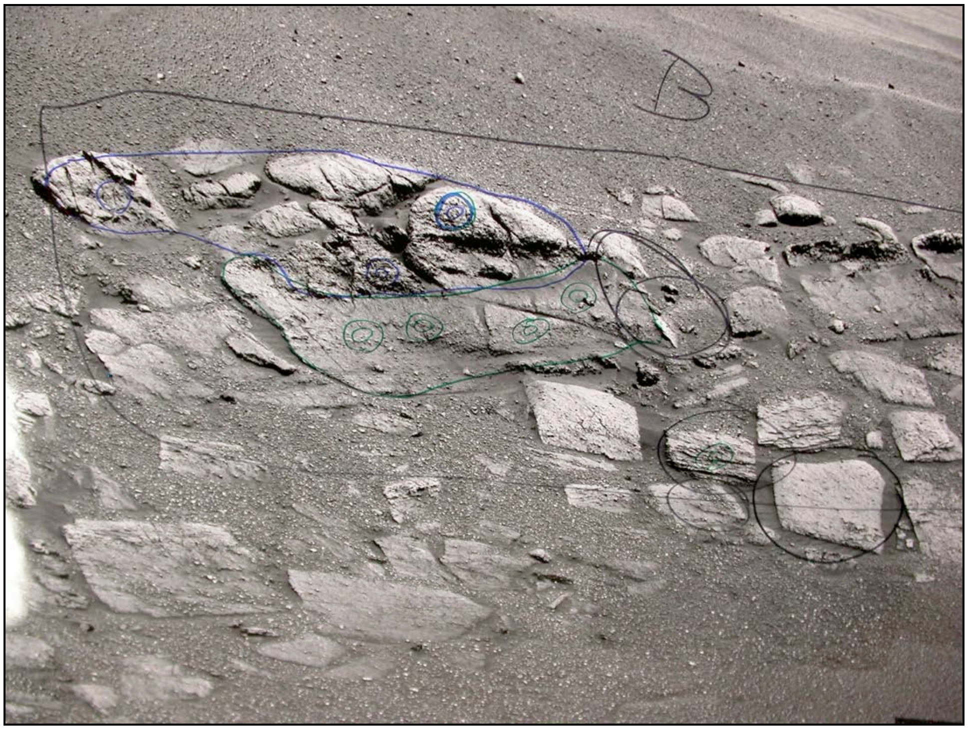
This design and organization starkly contrasts with almost every other planetary mission.

For example, the Cassini spacecraft now orbiting Saturn has 12 instrument teams each with its own principal investigator.

These are matrixed with discipline teams having different turfs—studying the planet, its rings, Titan, and icy moons. It's at best a consortium sharing a single platform, jockeying for control and resources.



The scale and reality of being two boots on the ground enables and requires a completely different technical design and social organization.

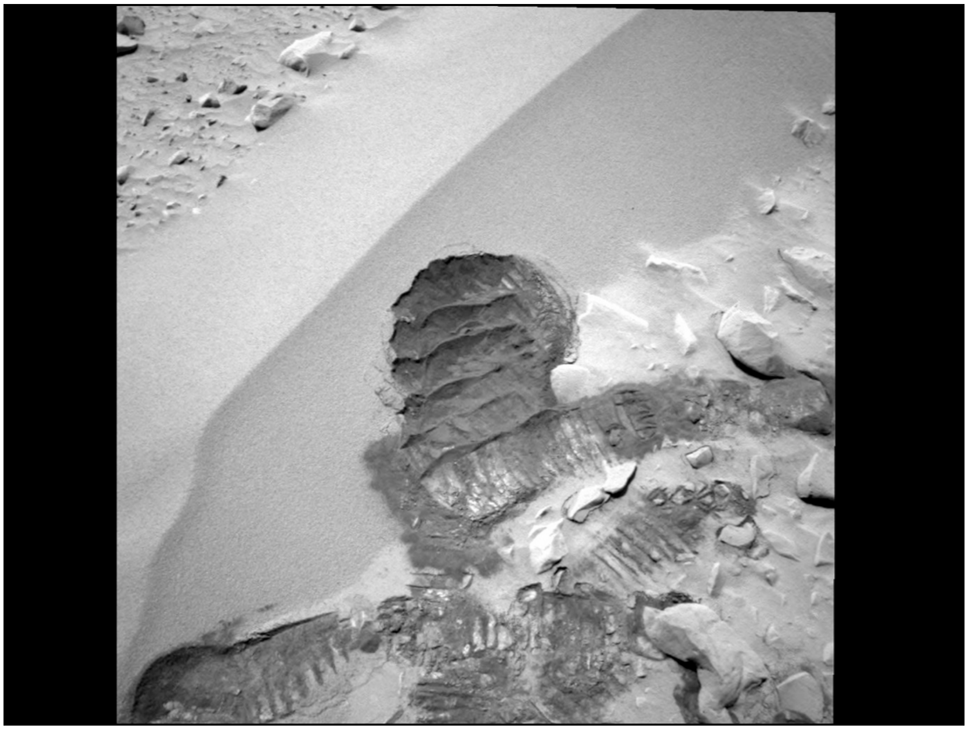


Rather than features at a planetary scale, MER's instrument targets are palpable and directly manipulated. Viewing the rover as a geologist surrogate makes sense.

Typically a robot is viewed as an automated machine acting without human intervention. But the vision of the "robotic geologist" was broad and multidimensional. Instead of replacing the scientists, the “robotic geologist” was conceived as a collaboration tool, a way of getting the disciplinary teams to work together. Combined with the virtual reality planning tools and commanding every day that enabled frequent individual contributions, the MER exploration system helped scientists to forge a new kind of collaboration, which made them agents on Mars, working through a mobile, programmable laboratory.

So although many speak about people and robots in space as if there is a choice— human explorers or robot explorers —our relationship to these computer-controlled devices is more complicated. Envisioning the field science, the scientists become the rover, a 1st person view; they are on Mars. Programming the rover's drive, an engineer may view the work as a joint accomplishment; for him the rover is a partner, a 2nd person view.

Working as an ensemble, acting together through the rover’s hardware & software systems, everything turns inside out in the 3rd person perspective. The rover becomes the team, and they can write about its exploits proudly. I would paraphrase the Associated Press story about Spirit’s demise by saying, “This intrepid team of scientific explorers will be remembered for demystifying Mars to the masses”; “This is a story of perseverance.”

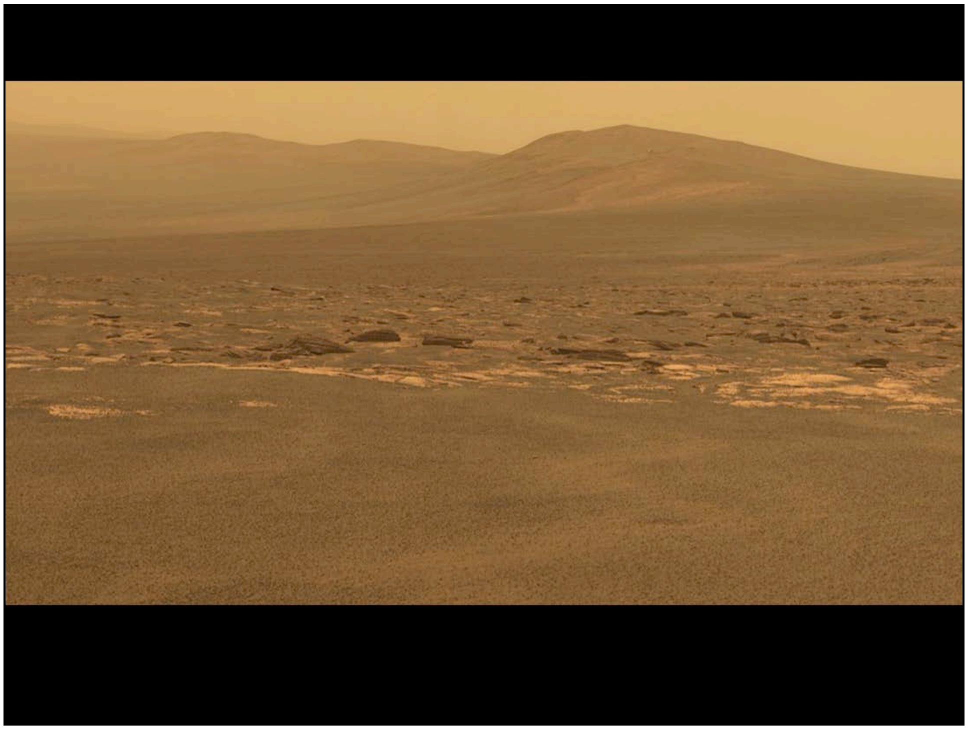


The MER scientists and engineers have invented a new practice of planetary field science. These are their footprints on Mars.

In the “robot geologist” metaphor the team tolerates and in some ways revels in their anonymity. The more fantastic the historic exploits of Spirit and Opportunity, the more proud you can feel to play even a small part in the mission.

This projecting of personal ambition onto the group’s effort and accomplishments is no small part of our power and joy as human beings.

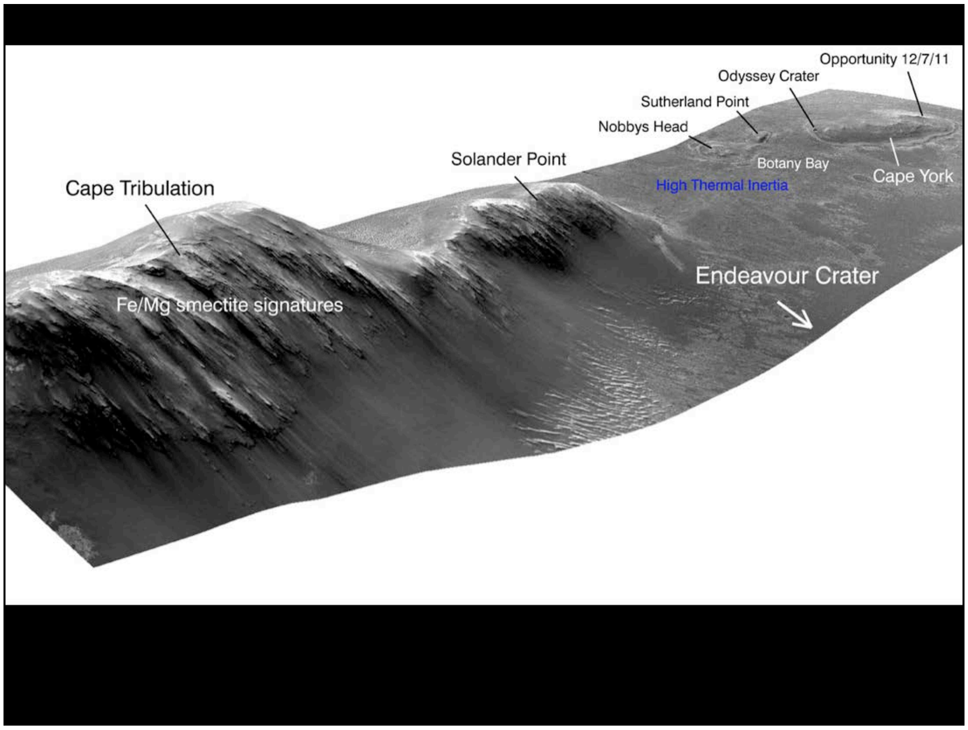
And so the accomplishments of MER are intricately based on relating technology to both the psychological and social nature of people. It is a textbook example of how to design a complex system of people and machines.



The MER mission objective was to travel about a third of a mile in a 90 day mission, taking perhaps dozens of photographs, and learning something about the history of water on Mars.

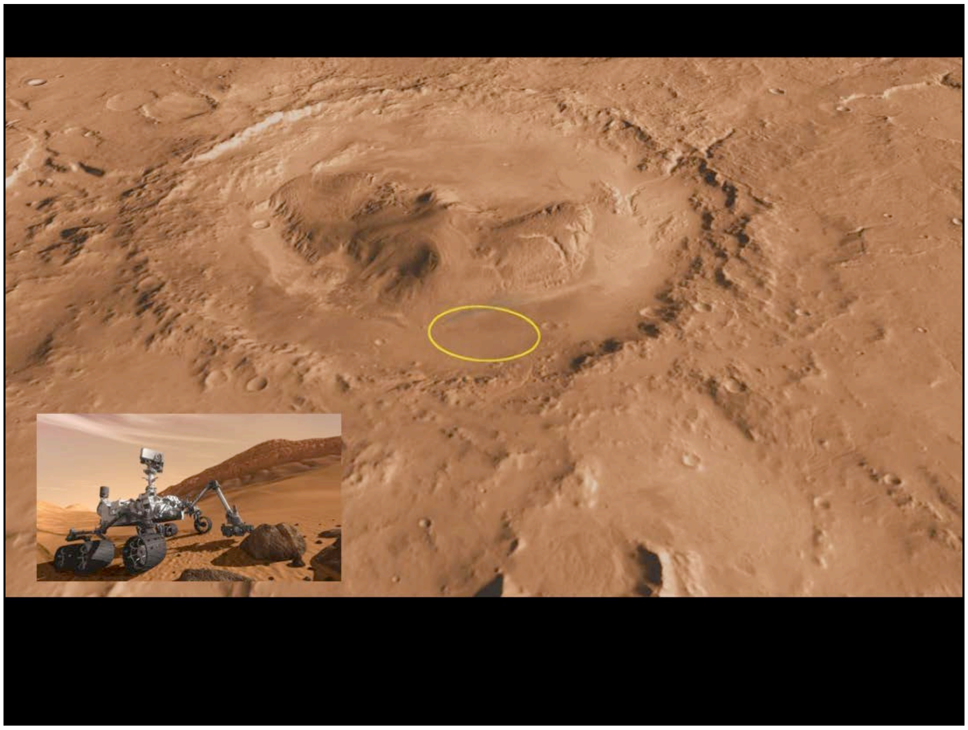
In an extended mission over an unimaginable eight years we have traveled over 25 miles and taken almost 300,000 images and spectral scans. The science itself could fill a textbook.

Now with a somewhat elderly craft, we have arrived with Opportunity at a deep crater 14 miles wide called Endeavor with clay soils and new layers to investigate.



Using high-resolution images and scans from orbit, we've identified interesting mineralogy; and after the Martian winter, we will set a course for Solander Point.

Opportunity will almost certainly spend its last days or years here.

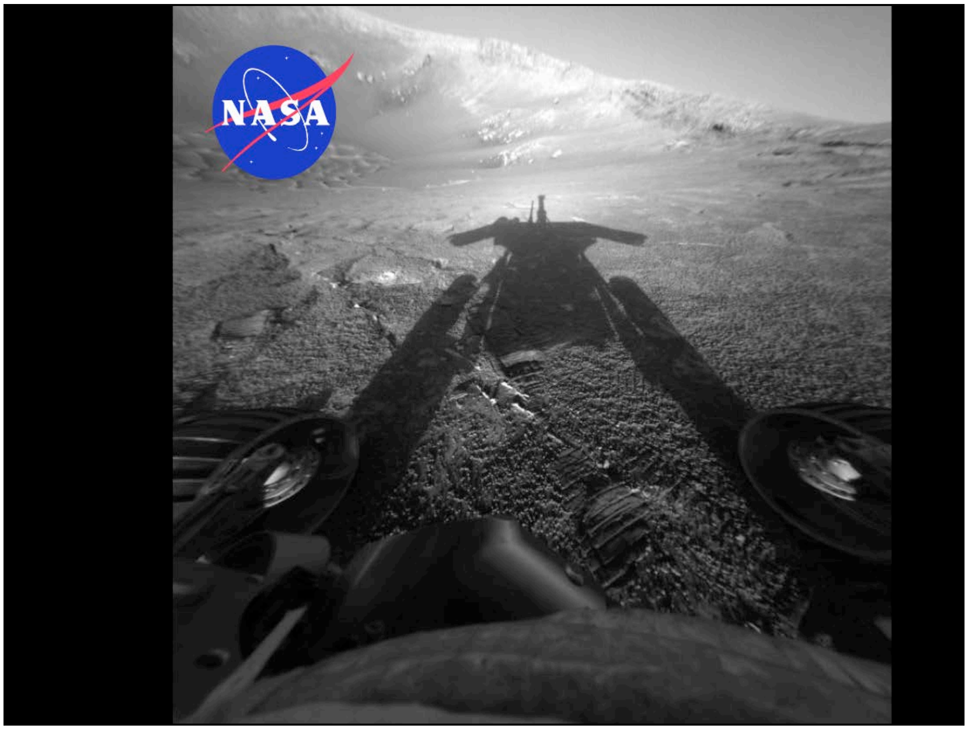


The next Mars rover — a relative of MER — is on her way to land in Gale Crater in early August. If we are successful we will climb and explore its central mound over several years. It’s actually a mountain, towering 3 miles high over the landing site on the floor of the crater and has been built up for perhaps 2 billion years.

NASA calls this rover "The Mars Science Laboratory” or MSL— it’s loaded with new instruments and weighs about a metric ton, five times MER.

Perhaps with the name “science laboratory” instead of “robotic geologist” the MER experience has clarified the true nature of these spacecraft, as tools for the scientists, and perhaps this time they will place themselves more publicly in the driver’s seat.

But you can be sure there will be more poetry. Like Spirit and Opportunity, MSL has been personified by a nickname. They call her “Curiosity,” and you can guess how that will play out.



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