Steven W. Squyres

TO ANSWER A SIMPLE QUESTION

Conducting an Experiment on Mars

The classic scientific method says this: we go with a hypothesis; we devise an experiment to test the hypothesis; we get the results; we reevaluate the hypothesis; and we do a new experiment. This works well in a lab. It even works sometimes in traditional field sciences, such as field geology or biology. But when we do an experiment on another planet, immediately we run into a host of challenges.

First, the missions are extraordinarily expensive. Our Mars rover mission from end to end, right now, costs $850 million. When it costs almost a billion dollars to conduct a science experiment, there are many factors such as political or practical issues that govern what one can afford to do—many people are looking over one's shoulder. When entrusted with this kind of money, a researcher has to be much more conservative than if going on a field trip to do geology some place. So we design our experiment very carefully.

Another factor is we don't get a chance to do it over. This is a very big deal. We don't get a chance, once we have answered our first set of questions, to design a new experiment. It took $850 million and 17 years to make this journey to Mars. We can't say, next time we're going to do this or that—the process is too lengthy. When we design our experiment, we make it as flexible as we possibly can.

The hypothesis we were testing on Mars is a very straightforward one to state. Did Mars once have environmental conditions on its surface that would have been suitable for life? We wanted to answer that single question. A simple question.

In all of recorded history before our mission, there had only been three successful landings on the surface of Mars. In no case did these missions involve mobility that got any farther than 10 meters away from the landing site. People hadn't seen much of Mars. We were also going to two places that are quite different from any place anybody had ever been on Mars. So we designed an experiment to answer that question for an environment we knew very little about, with no capability whatsoever to redesign the experiment if, once we got there, we found that we weren't in the right place or we didn't bring the right stuff. This means that we design as much flexibility into the experiment as possible, and when we get to Mars, we

do the best we can with it. There's a certain amount of, let's hope for the best!

Pioneering with the Tried and True

As in any kind of science, we build on what has been done previously. All of the instrumental techniques that we used on our vehicles are ones that had been proven in some other realm. All of our spectrometers had either been flown into space before or were techniques that had been demonstrated to get good results in the lab. Our cameras are based on very well-proven technologies. We knew that we needed to move around on the surface, and we based the rovers on the very successful Sojourner, a mini-rover that flew on the Mars Pathfinder mission. We took as our building blocks, things that had worked previously, but we combined them in ways that no one had ever tried before. It's necessary when building a system for space flight to use techniques that have extraordinary high reliability. People tend to think of planetary spacecrafts as being extraordinarily high tech. However, the technology that flies on vehicles is, for the most part, tried and true, very well established, and quite a bit behind the times. The computer on our rovers was a smoking hot machine in 1983. It's a 20-year-old processor with proven reliability.

WHEN IT COSTS ALMOST A BILLION DOLLARS TO CONDUCT A SCIENCE EXPERIMENT, THERE ARE MANY FACTORS SUCH AS POLITICAL OR PRACTICAL ISSUES THAT GOVERN WHAT ONE CAN AFFORD TO DO.

Serendipity and Discovery

Once on the surface of Mars, serendipity plays a big part in what we find, but we must be prepared. Serendipity can lead to very important scientific discovery, but we have to consciously plan to do our operations in a way that allows for it. We can plan for good luck. We take the tools that will reveal unexpected new circumstances—we can't make serendipitous discoveries if we're blind to the things that might reveal those discoveries. If we don't take the right pictures, we're not going to stumble across something interesting in our pictures. We need a planning process and an operations process that can be responsive to new and unexpected discoveries. We need an operating system that will provide information. We're gaining knowledge about the environment around us, so if something turns up, we want to see it. If we plan exactly what the rovers are going to do every day for the next two weeks, and we have a rigid timeline that we expect to adhere to, that timeline can take us blowing right by some serendipitous discovery. We recently made a very important, fascinating, and purely serendipitous discovery.

We were trying to climb up a very steep hill with the rover, Spirit, in a place where we'd never been. In an unsuccessful attempt to climb up the hill with the rover driving backwards, we turned up a lot of soil right in front of the rover. We took a picture of the soil, and it looked peculiar. It was brighter than most soil we'd seen. I looked at the pictures again, and this soil looked different. These were low-resolution black-and-white pictures, but they were good enough to show that there was something odd here. So, rather than going on to our next drive, we said, "Stop! Wait a minute!" We took a moment to reach out our rover's arm and make a very quick measurement—a half-hour measurement of the elemental composition of the soil—to see what chemical elements were there before driving away from it. We got the data, and it turns out that this stuff had more sulfate salt in it than anything we'd seen at this landing site! We'd never seen anything remotely like it. Suddenly we said, "Hold everything. We've found something totally new; we're going to change our plans completely," and we turned on a dime. We changed our planning process. We said, "We're not going to climb up the hill right now; we're going to stop right where we are and spend five days with the rover exploring this soil and its composition in detail to find out what this means. Sulfur markers are deposited by water. This is telling us something important." We had the pictures, and we had the ability to change our plans immediately.

"Stop! Wait a minute!" We took a moment to reach out our rover's arm and make a very quick measurement.

Can't Do It without a Crew

The science that we're doing on Mars requires knowledge across an incredible breadth of field. To conduct our explorations on Mars, we need to be knowledgeable about geochemistry, mineralogy, geology, atmospheric sciences, physical properties of rocks and soils, long-term Martian history, astrobiology—all of these fields. No one person could possibly have all the knowledge necessary to do this kind of research. It requires putting together a team of colleagues with this breadth of knowledge, inventing a way of operating the vehicle, and doing our science in such a way that all of that knowledge is brought to bear. It's very much a team sport. A big part of our training and our preparation for operating rovers on Mars was based on finding ways to work together as a team.

We have graduate students and undergraduates who are like full colleagues on this project, and they make major contributions to this process. They can run the vehicle. A graduate student at SUNY–Stony Brook led the science team for Spirit in planning three sols—three Martian days of operation on Mars' surface—

NASA/KSC/JPL

The Mars Exploration Rover Crew

while I attended a meeting in Washington, D.C. Students have been in positions of incredible responsibility on this mission.

As Good as It Gets

I've had several highlights in my scientific career. Working with the Voyager imaging team on flybys of Jupiter and Saturn when I was a 22-year old graduate student was a major highlight. That hooked me on this business. Working on the Magellan Mission to Venus—looking at the very first high-resolution pictures of the surface of Venus—and trying to understand how that planet has evolved was a pivotal point. But without question, the highest point of my career has been the rovers. Yep! That would be it: the discovery with the rover, Opportunity, that there was once a wet, habitable environment at the surface of Mars. Finding evidence for an ancient, shallow, salty sea on Mars—that's as good as it gets.

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How Common Is Life in the Universe?

Everything we do on Mars is motivated by the thought that Mars once could have been an abode for life. In order to determine whether or not life took hold on Mars, we have to go there, and we have to look for evidence of either past or present life. When we ask ourselves, where do we look? We must look in the areas of old environments: places that are or have been suitable for life in the past. Our mission was not looking for life. Our mission was aimed at seeing: Did those environments exist? Was there a place life could have taken hold? What we found in the location of the rover, Opportunity, was that there was a place on Mars where the environment was wet and would have been suitable for some form of life. Moreover, the kinds of minerals that have been deposited there are the kinds that have been good at preserving evidence of simple microbial life for billions of years. These rocks would be extraordinarily interesting to bring back to Earth and search for evidence of life.

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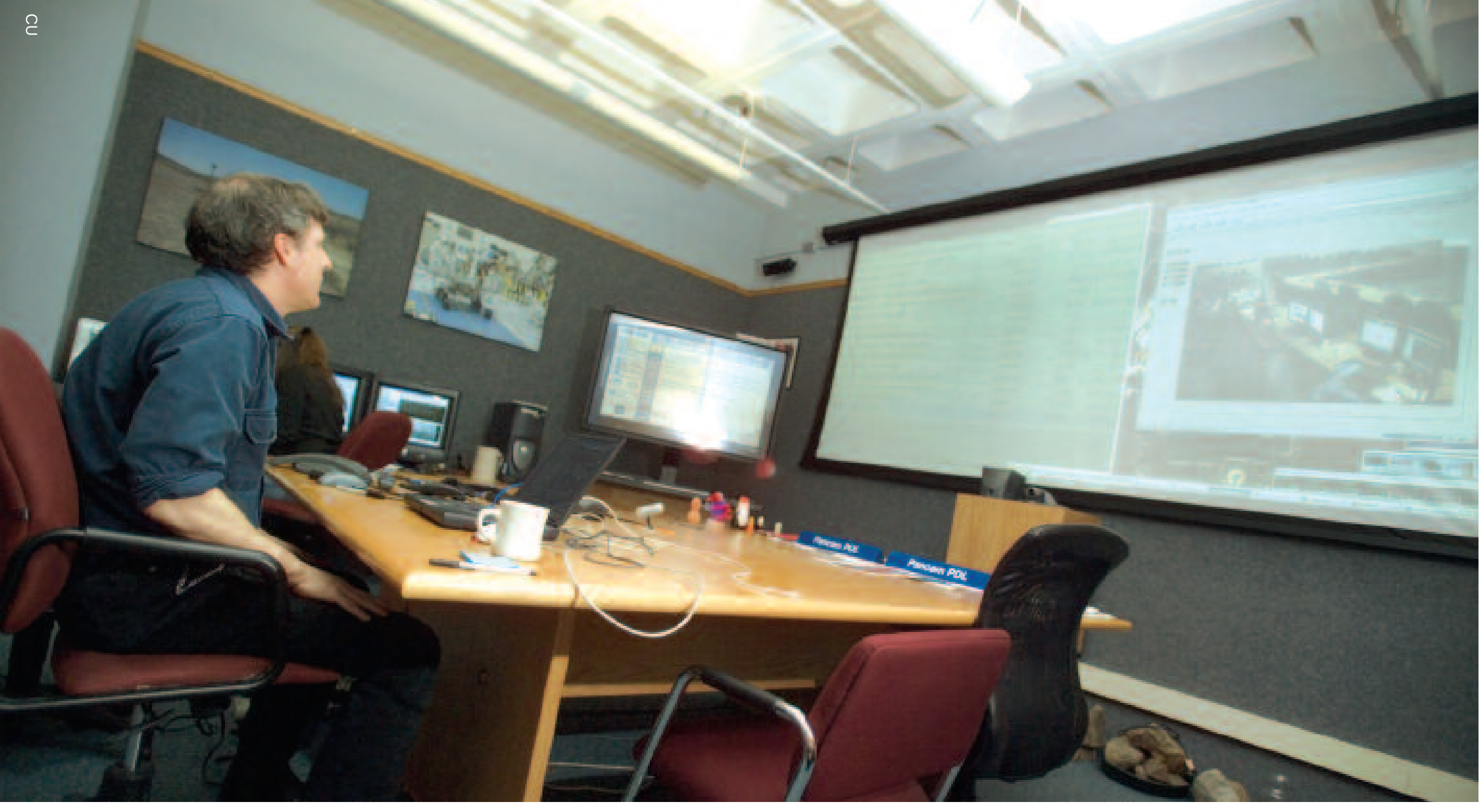
The search for life elsewhere, other than on Earth, appeals very deeply to the human need to understand where we came from and if we are alone in the universe. We have one example of life in this universe. It's us, here on Earth. That's it! We don't know if life is common throughout the universe or if it is a singular occurrence. If we were to find that life somehow independently took hold in two different worlds, just in this *one* solar system, then extending that knowledge to the multiplicity of solar systems that are out there does not require a great leap of logic, faith, or anything else. Two examples are a lot more than one in this particular realm! That's a very important aspect of the Mars project.

Another facet is related to how life originated. We would like to find evidence in the geological record on Earth for the miracle of life's origin. The problem is that it took place so long ago, and Earth has been so geologically active for all of its history, that the evidence of that event is destroyed. It's gone forever; it doesn't exist on Earth. On Mars, on the other hand, half the planet is covered with rocks that are four billion years old. If (it's a big "if") life did take hold on Mars, then the evidence for how that occurred could still be preserved on the planet.



Mars, because it's been less active, might hold the key to understanding the origin of life. Now, if you ask me how the knowledge of whether or not we are alone in the universe and how life originated benefits humanity, my answer is it doesn't put roofs over people's heads, it doesn't pave the potholes, and it doesn't provide for society's basic needs in the way that a lot of applied research does. But in a society like ours that has the capacity to provide for the fundamental needs of its citizens, enriching the human spirit—supporting the arts, supporting basic research with no practical or immediate payoff because it might lead to something interesting, or supporting fundamental exploration of places where humans have never been before to see what's there—is valuable. The question of how life arises and how common is it throughout the universe is one of the most profound questions confronting people today.

FINDING EVIDENCE FOR AN ANCIENT, SHALLOW, SALTY SEA ON MARS—THAT'S AS GOOD AS IT GETS.

When I Figure "It" Out, It Feels Good

Science is just figuring things out, and I love to figure things out. That's part of what motivates me. When there's a question that's bugging me and I figure it out, it just feels good. Another thing that always excites me is going some place that no one has ever been before. It's the exploration: seeing some view that no human eyes have ever seen before. That's cool. In a mission like this, we can do that and share it with the whole world instantaneously, which is fun.

I enjoy the creative process. I can remember when the technology functioning on Mars today was just drawings on my white board. To take them from a concept in my head to drawings, to hardware that doesn't work, to hardware that does work, to hardware that's on top of a rock, to hardware that's on Mars is a creative process that I deeply enjoy. It's very satisfying.

To Go Where No One Has Been Before

When I was in high school, I knew I wanted to be a scientist, but I liked climbing mountains. So, I thought, well, I'll do geology because that's a way to do science in the mountains. I came to Cornell to be an undergraduate geology major. I took three years of geology and enjoyed it very much, but after doing it for a while, I found that the geologists who had been studying this planet for the last 200 years had done a good job of figuring stuff out. This doesn't mean that there isn't a lot yet to be done. There's plenty. But to me, geology on Earth felt like going into details. I was interested in finding a place, a big blank canvas, a place where nobody had been before and where the fundamentals of geology were a complete mystery.

In the second semester of my junior year, I had a hole in my schedule. I was in the Space Sciences building showing a friend around campus, when she noticed a little three-by-five-inch card tacked on a bulletin board. This was in 1977, right after the Viking Mission had arrived to Mars. The card was announcing that a member of the Viking science team, Joseph Veverka, who is now the chairman of the astronomy department, was teaching a graduate course on Mars. That sounded like fun, so I signed up for the course. Because it was a graduate course, we were expected to do original research for a term paper. Three to four weeks into the semester, I started thinking about my paper. The whole grade for the course was based on it. Joe

Our mission was aimed at seeing: Did those environments exist? Was there a place life could have taken hold?

gave me a key to what was called the Mars Room at that time, which was on the second floor in Clark Hall. All of the pictures from the Viking Orbiters were kept there. This was before the internet, the CD room. There were big rolls of photographic paper, and they were cut up and put into binders.

There was a stretch of time when we had hardware, but no ride to Mars.

I remember vividly: I went there one afternoon thinking, I'll sit down and flip through the pictures in the notebook for 10 or 15 minutes to look for an idea for my term paper. I'd never looked at pictures of Mars before. I was in that room for four hours, and I walked out of there knowing exactly what I wanted to do with the rest of my life. That was it. This was the blank canvas I'd been looking for. It was a complete world. I didn't understand what I was seeing in the pictures, but that was the beauty of it. Nobody understood this stuff. This held an immediate appeal for me. Now what it meant was that getting out into the field in my boots, the mountaineering part of things that had drawn me to geology, was something I couldn't do anymore, because I wouldn't be able to go to Mars myself. That was a sacrifice. But the appeal of solar system exploration was great enough that it was the right thing for me.

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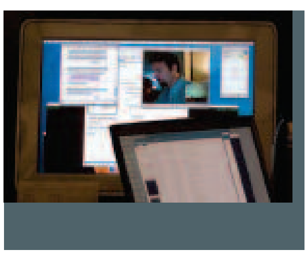

Patience Required

The greatest frustrations in the space exploration business have to do with the very long time scales. From the time I decided I wanted to be a principal investigator on a mission to Mars to the time we actually had hardware on the Martian surface was 17 years. It was 10 years of writing proposals: one after another, getting rejected, and finally writing one that was good enough to be selected. But space exploration is a tough business, and a lot of things go wrong. During the development of our mission there were a couple of missions in front of us—two missions launched in 1998 that failed at Mars. One of them burned up in the atmosphere and the other one crashed on the surface. That caused NASA to rethink their Mars program and cancel our mission. There was a stretch of time when we had hardware, but no ride to Mars. That was frustrating. The mission that we've now flown, the Mars Exploration Rover Mission, rose from the ashes of that particular disaster. Talk to any scientist, and there will be a tale like this. We were impatient to get to Mars, to find out what's there, but patience is required.

My Family, My Rovers

I was working on the Mars project before my children were born. I've been doing this for their entire lives, and they are ages 16 and 14 now. My wife and two daughters have been phenomenally, miraculously supportive of everything I've done. I spend as much time with them as I possibly can. I don't have a life outside my family and my rovers. The rovers take up a huge amount of my time, and my family is of paramount importance to me. It's tough. There is no time for anything else, and it's been that way for quite a while.

WHEN I WAS IN HIGH SCHOOL, I KNEW I WANTED TO BE A SCIENTIST, BUT I LIKED CLIMBING MOUNTAINS. SO, I THOUGHT, WELL, I'LL DO GEOLOGY BECAUSE THAT'S A WAY TO DO SCIENCE IN THE MOUNTAINS.

I enjoy taking my daughters and my wife out for dinner to just spend time with them. My younger daughter likes Thai, so I may take her to a restaurant like A Taste of Thai. My older daughter likes French cuisine. My wife and I were able to spend a few days on Saint Lucia in the Caribbean, which was an essential, overdue break.

The first eight months after we landed on Mars was a tough time for the family. We landed in January 2004 and, for eight months, I was living in Pasadena in a tiny apartment; for the first four months of that, I was working on Mars time, which means that I was living on a day that was 24 hours and 39 minutes. The schedule would shift continuously with respect to Earth time. Sometimes I'd be working in the middle of the night, and then I'd take a trip home. I would come home for three or four days each month.

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Johnson Museum

I WAS IN THAT ROOM FOR FOUR HOURS, AND I WALKED OUT OF THERE KNOWING EXACTLY WHAT I WANTED TO DO WITH THE REST OF MY LIFE. THAT WAS IT. THIS WAS THE BLANK CANVAS I'D BEEN LOOKING FOR.

My wife and each of my daughters would come out to spend time with me in Pasadena, which was like an extended "take your daughter to work." That was fun. But for eight months I was living alone in California. That was really, really tough. It's been wonderful to be able to come back to Ithaca and conduct flight operations here. Spend the day driving rovers on Mars, and then go home for dinner. That's really nice!

Today's Kids Will Put People on Mars

This mission provides us with a good vehicle for getting kids at all levels—elementary school, middle school, high school, and undergraduates—intrigued by the sciences and careers in these fields, especially the young ages. A lot of math and science can seem esoteric to a young kid in school.

We have tried in many ways: going into classrooms ourselves, conducting teacher workshops and giving teachers curriculum materials that they can use to hook kids, producing websites, and having students come and actually work with us. We've done this at all levels: some which have national and international scope, some in which we've dealt with people on a one-to-one basis, and everything in between. It's important that we use this extremely visible, exciting mission as a way to promote careers in science and engineering to young kids, because they're the ones who are going put people on Mars someday and send missions to other places we can't yet go.

Share the Thrill

We sent a couple of robots to Mars. We're looking at rocks there. The rocks tell a story about what it was like long ago. If the rocks are made of one thing, it means this; if the rocks are made of something else, it means something different. We can explain that, and we can share the adventure with the public. It's very easy for a scientist to focus on the immediate problem. That's what we do—we're trying to solve scientific problems, and it's very easy to zero in on solving our particular problems and not think about how to share the information with the public. When we're doing science that is funded by the public—especially with a hefty price tag, like our mission—we have an obligation to let people know what they're getting for their $850 million. We're on a fantastic adventure at Mars, so let's take everybody along! The research we're doing gets complex and esoteric, if one digs deeply into the details, but the fundamentals of what we're doing are not hard to explain.

What's wonderful about a mission like ours is that it gets people's attention. Everybody wants to know: Are the rovers going to crash? Are they going to die? What's going to happen? How long will they go? Because the mission has so much visibility through the internet, the news media, and public lectures explaining what we're doing in straightforward language that anybody can understand, we are sharing the adventure. Many people think of science as this very tedious process or very highly intellectualized subject that most people can't understand. We give people another sense of what science is really like.

A geologist is like a detective at the scene of a crime, looking at clues and trying to figure things out. It's something anybody can identify with, if it's explained right. Sharing the adventure as it happens might sound like this: "Wonder what's going to be over that hill? What is that rock over there? Oh, look! It's a meteorite? Wow!" This scenario actually happens to us! We want to share it with people as it happens and give them that thrill of discovery—that gee whiz feeling, we just figured it out—that scientists live for.

Life after Mars

We initially thought the mission would be about three months. I thought, if things went well, we might still be operating the rovers after four or five months, or even six months. After 14 months, we were driving hard every day, and sometimes we were pushing the rovers and ourselves harder than we were earlier in the mission. They're still going strong. This has absolutely consumed us for a very long time, and now we're really tired. Fatigue and attrition have become significant.

We're going to keep pushing these vehicles and ourselves until the last rover dies—the last bit of data on the very last Martian soil. We have an obligation to the people who built the vehicles, and we have an obligation first and foremost to the people who paid for them to get everything out of them. Now, if Mars stops being interesting, that'll be easy. I guess it will be time to stop, and we'll finally say, all right, let's give up! Until that happens, we have to push them to the very end, and that's my sole focus. After that, I'm going to take a long rest. It's going to be a long, long rest. I'm involved in other Mars projects, and I'm looking forward to them. I can have a lot of fun and a lot less responsibility.

Everybody wants to know: Are the rovers going to crash? Are they going to die? What's going to happen? How long will they go?

One Project Takes All

The Mars rover mission takes at least 60 hours a week. I do have other projects on my slate, but I'm making limited time contributions to them. I will be interpreting the science with the team responsible for taking very high-resolution pictures of Mars for the Mars Reconnaissance Orbiter, launched this past August. I'm on the Cassini Imaging Team and a couple of science teams for the Mars Surface Lab Mission that will launch in 2009. I'm also on the imaging team for the Mars Express Mission, an orbiter at Mars, and the Gamma Ray Spectrometer Team for the Mars Odyssey Mission that is in orbit around Mars. With the experience that I've gained from our mission, I'm looking forward to contributing to these projects.

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Peopled Missions to Mars?

Putting people on Mars has been 20 years in the future for the last 20 years. I think it's 20 to 30 years away. It's a very difficult thing to do. It can't happen soon enough for me—and God knows I love my robots. I'm as big a proponent of robotic exploration as you'll ever find, but even I feel that the best, the most effective, and the most inspiring exploration is going to be done by humans. So I want to get on with it! Hope I live to see it.

Nothing Is Going to Top This

My greatest aspiration has already been fulfilled. It has been my aspiration for the last 17 years of my career. It is this mission [the Mars Exploration Rover Mission]. It has been successful at a level far beyond what I could have possibly dreamed. There may be a few more missions for me, but nothing is going to top this.

More about Squyres

The Goldwin Smith Professor of Astronomy provides an inside look how the Mars Exploration Rover Mission came together in his newly published book, *Roving Mars: Spirit, Opportunity, and the Exploration of the Red Planet* (Hyperion, 2005). A mission that would have been successful had it operated for 90 sols per rover is still going strong after more than 700 sols per rover (02.21.2006).

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