

The Pathfinder lander, surrounded by deflated airbags, as viewed by the Sojourner rover's camera.

Pathfinder - a retrospective

By Geoffrey A. Landis

Mars is one of the most interesting planets in the solar system, featuring enormous canyons, giant volcanoes, and indications that, early in its history, it might have had rivers and perhaps even oceans. It's such an interesting planet, in fact, that I wrote a book about it: *Mars Crossing*, my first novel. Five years ago, in July of 1997, the Pathfinder mission landed on Mars, bringing with it the microwave-oven sized Sojourner rover to wander around on the surface and analyse rocks. Among the experiments on the mission was an experiment I designed to analyse dust deposition. Pathfinder is only the first of an armada of spacecraft which will examine Mars from the pole to the equator in the next decade, culminating (someday, we hope!) with a mission to bring humans to Mars.

Mars

Mars is the next planet out from the Sun, so it gets a little bit less sunlight than we do, and so it is a cool planet. Mars is a bit smaller than the Earth. The first thing you notice when you look at it is that it's a very red planet -actually more of a muddy orange colour, but it's much redder than the Earth, which is why they call it the red planet.

The fact that we think of it as being a small planet is a little bit misleading. In fact, the land area of Mars is greater than the entire land area of the planet Earth. It's really a big place. There's a lot to explore on the planet Mars.

You can see Mars from the Earth, and even from here, about fifty million kilometres at the closest, with a telescope we can see a lot of

things about Mars. It has clear dark and light features; you can see it has a polar cap. Like the Earth, Mars has an axis that's tilted, and therefore it has seasons, winter and summer, and the polar caps grow in the winter and shrink in the summer. It also has clouds, so you can tell that it has an atmosphere.

But to really get a good look at Mars, you need a spacecraft. You need to get up close, and now we can see really interesting things about Mars. The first thing that spacecraft learned when they visited Mars in 1964 was that it has a lot of craters. It's a lot like the Moon. It's been heavily bombarded, which is reasonable because it's closer to the asteroid belt than we are, so you do get asteroids that hit the planet Mars. From these first spacecraft to visit Mars we also learned that its atmosphere is very thin - less than 1 percent as thick as Earth's atmosphere.

After the first spacecraft, which just flew past the planet, we put spacecraft into orbit. Viking looked at it more carefully and saw that Mars has what appears to be dry riverbeds. These look like dry rivers. So Mars once had water. Today, Mars is a very cold and dry world, so what happened to the water? Where is it now? As we know, water is very important. It's important for life - all of us drink it. We also know that as soon as the planet Earth has a surface cool enough that water could condense on it, life formed on Earth. That was a few billion years ago. But once, perhaps several billion years ago, Mars also had water. So it seems very probable that it might once have had life.

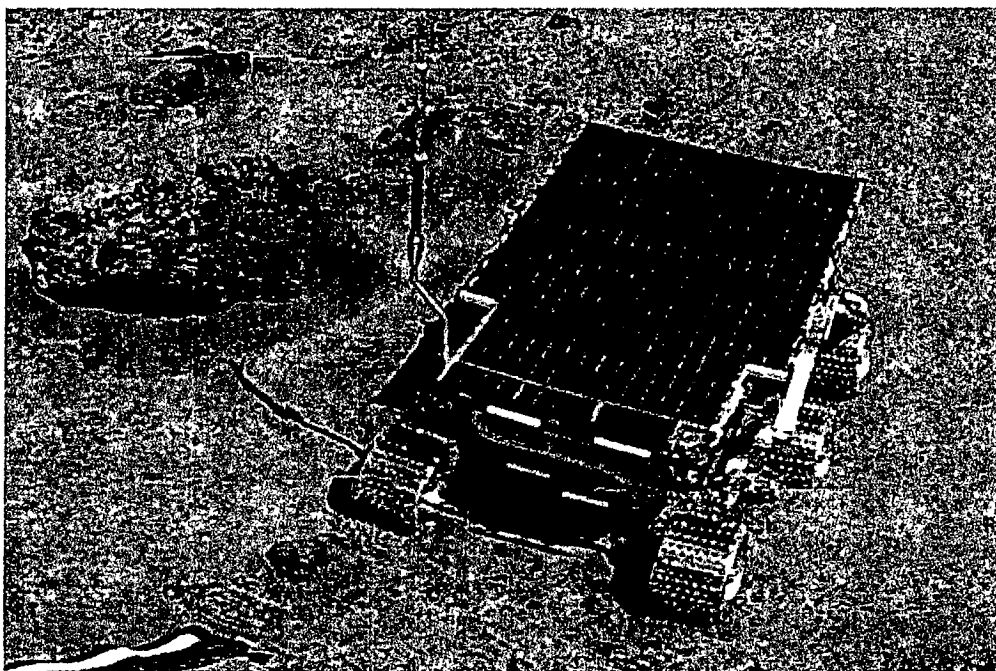
For a long time scientists have guessed that

underneath the soil on Mars, there is water in the form of permafrost, and recently the Mars Odyssey mission has verified this, showing that at high latitudes in the top meter of the soil there is a large amount of ice. If the ice saturates the soil all the way down, this could indicate the presence of water in the soil equivalent to a global ocean five hundreds of meters deep. And water is important. you can drink it, you can grow plants in it, and most importantly you can split it up and make hydrogen and oxygen. You can breathe the oxygen, and the hydrogen and oxygen are rocket fuel. So in many ways, Mars is in fact a very hospitable planet. It's got all the stuff we need.

Mars is the planet of extremes. It has the largest canyon the solar system, the Valles Marineris, a canyon that extends almost a third of the way across Mars. They named it Valles Marineris, the "Canyon of the Mariner", because it was discovered by the Mariner spacecraft. This is a canyon four thousand kilometres long, and in places nearly ten kilometres deep. (In my novel, my characters spend much of their time exploring and climbing through Valles Marineris.)

Mars has the largest mountains in the solar system as well. Olympus Mons, the largest, rises up twenty-five kilometres. It's a volcano so tall that the top of it is in vacuum and outside the atmosphere. It is far taller than Mount Everest.

Mars also has two moons. Unlike our moon, the moons of Mars are very irregular. In fact, they are often referred to as potato-shaped. They're small -the larger one, Phobos, is only about fifteen miles across.



Dust deposition on the Sojourner rover.

The Sojourner rover and the rock "Yogi," viewed by the Pathfinder lander. (This image is a mosaic of several dozen individual frames taken by the Pathfinder "IMP" camera; close inspection reveals many seams where individual frames do not perfectly overlap.)

Mission and landing on Mars

But I would like to talk a little bit about the mission that I was involved in, Pathfinder.

This is a view of the Pathfinder as it lands on Mars. Pathfinder was a very interesting mission. Its purpose in fact was to do more than just land on Mars. It was to test out a new way of landing on Mars, using airbags. It launched at about two in the morning. It was actually a very beautiful night when it launched. It had a little crescent moon, and you could see Mars in the background. It was a very impressive launch.

Pathfinder was a solar-powered spacecraft. Before Pathfinder nobody had used solar power on Mars before; Pathfinder was a first. Analysing the operation of solar power systems on Mars was a project that I worked on, and I am very proud that some of my work helped in the design of the power system for this spacecraft.

It's quite a challenge to pick a landing site on another planet. The scientists say, we want to go someplace really exciting. We want mountains, and we want giant boulders, and we want crevices and cliffs and channels. The mission planners, say great, but they want a site that is absolutely flat with no features on it whatsoever. So the scientists say no, no, we want mountains. But the mission planners say absolutely no, no, absolutely flat. So the scientists picked an area that is a very interesting area on Mars, Ares Valles. It's an outflow channel; there had been a giant flood and it washed down a canyon and picked up rocks and deposited them in the

channel bed. The scientists said, "Wow, this is great, there should be lots of neat rocks for us to look at." And the mission planners liked it because they said, we can set down in this area, which has a spot that looks very flat with no features. So everybody was happy.

The day before landing, we had our final science meeting before touchdown, and there was nothing we could do. We took the big map of Mars, and everybody got a little red dot of paper, and wrote their name on a dot, and stuck it onto the map, showing where we thought it would land. And then the person who guessed best won. My guess was pretty good, but not good enough, so I didn't win.

Then it did land. It comes down in a parachute, and then the airbags inflated. It bounced on the surface, and it bounced a lot, as high as a five-story building, and at least eighteen times. That was just as many as they counted; it probably bounced more than that.

Then it opened up, like a flower unfolds, and the blue solar petals on the inside were revealed, and we got to see the Sojourner rover.

The Sojourner rover really was the real star of the show. This is the first time that anybody has operated a wheeled vehicle on another planet, and I'm pleased to tell you that it set a world speed record for the fastest vehicle ever to go on the world of Mars. The speed record was a little bit under half a meter per minute - that's about one-fiftieth of a mile per hour - but that is faster than anybody has ever gone on Mars before. It

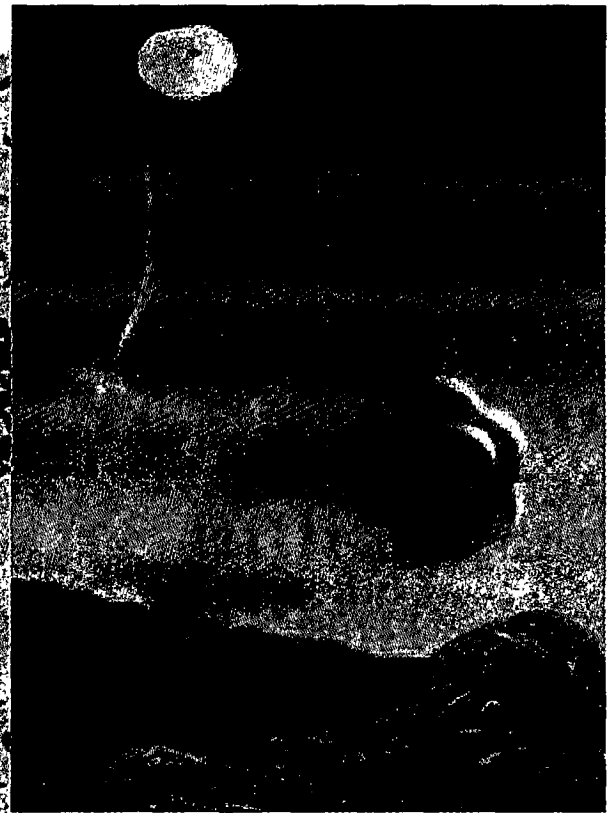
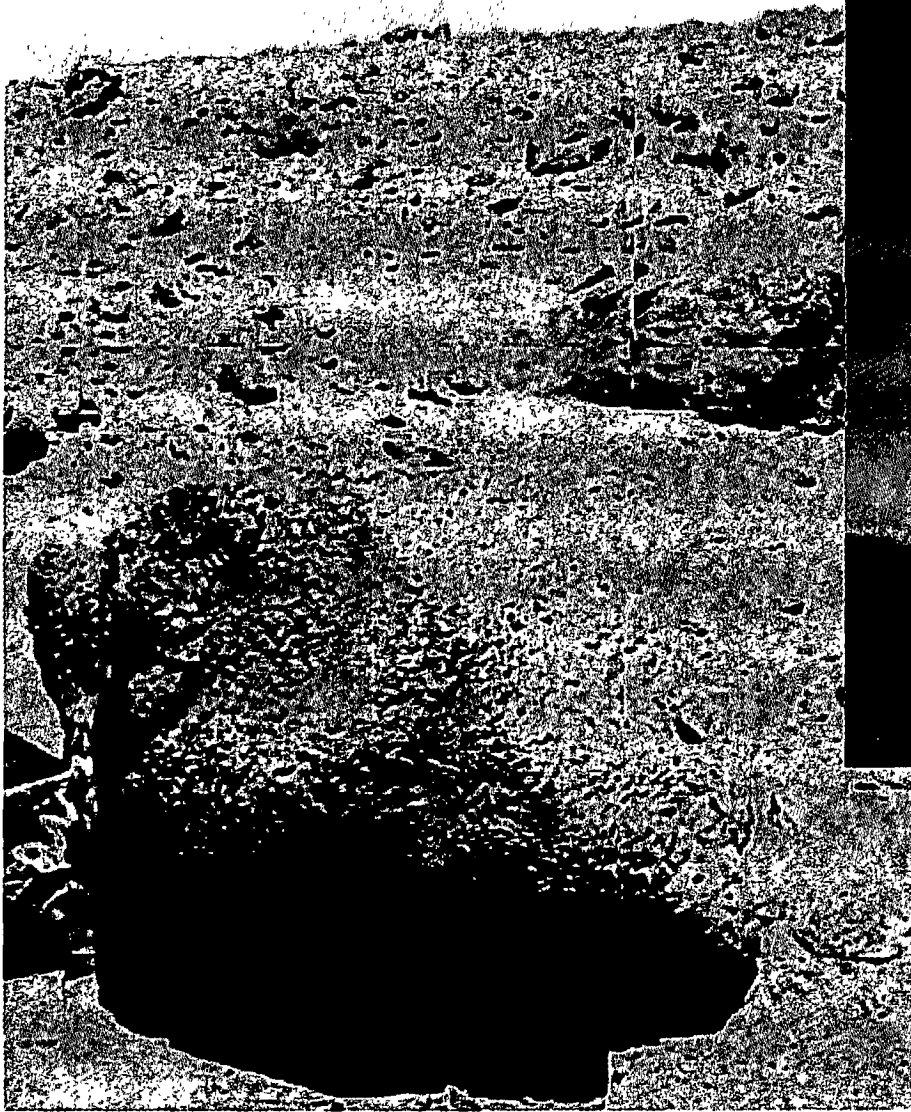


has six wheels that enable it to run over different kinds of terrain, and walk over rocks.

The suspension is articulated to allow it to crawl over very large rocks. If a car had the same sort of wheel systems, it could drive over something a rock a meter and a half tall, as tall as a dining room table. So it gives it a good amount of ability to go over very rough terrain.

To pick a name for the Pathfinder rover, they held a contest for schoolchildren. The name was chosen by Valerie Ambrose, a schoolgirl from Connecticut. "Sojourner" means "wanderer," and the Sojourner rover wanders around on Mars, so it's a very appropriate name.

Once we got the deflated airbags retracted and the petals opened, we had the first view of the surface from the landing site. It was very exciting for the geologists, who were just jumping up and down and cheering. "Wow, this is great. We've picked the world's greatest site. It



Pathfinder's airbag bounced down onto the Martian surface.

has clear areas; it has rocks, it has mountains. How could we have picked better?" They were just very lucky.

The Sojourner rover is stowed on one of the petals covered with solar panels. To drive off the petal and onto the surface, they have to deploy rolled-up ramps. These ramps to get the rover to the surface are spring-loaded, so they deploy with an enthusiastic bang.

While the geologists were saying what a great landing site it was, though the mission engineers were really chewing their fingernails because they looked at the same picture and what they saw is airbags. After deflating, they're supposed to be retracted out of the way by a little motor. But the engineers saw that part of the deflated airbag was over the edge of the petal with the Sojourner rover on it. They worried, if we fire the pyros to release the spring-loaded ramp, the ramp might hit the airbags, and

bounce back and smash against the rover. So they worried that it was a problem, they couldn't deploy the ramp, and if they didn't deploy the ramp, they couldn't get the rover off. So they took the petal and raised it back up to about 45 degrees, and then they ran the airbag retraction motor some more, and then they dropped the petal back down again and checked it again. The airbags were away from the edge of the petal, and they could deploy the ramp. Everybody was quite relieved. It was almost sunset on Mars by then, so they send the command for the rover to roll down the ramp and get all six wheels on soil, but we didn't actually find out that it had worked until the next day.

Dust collection on solar arrays

My involvement with the project came because I was working in collaboration with the photovoltaic research branch of NASA Lewis

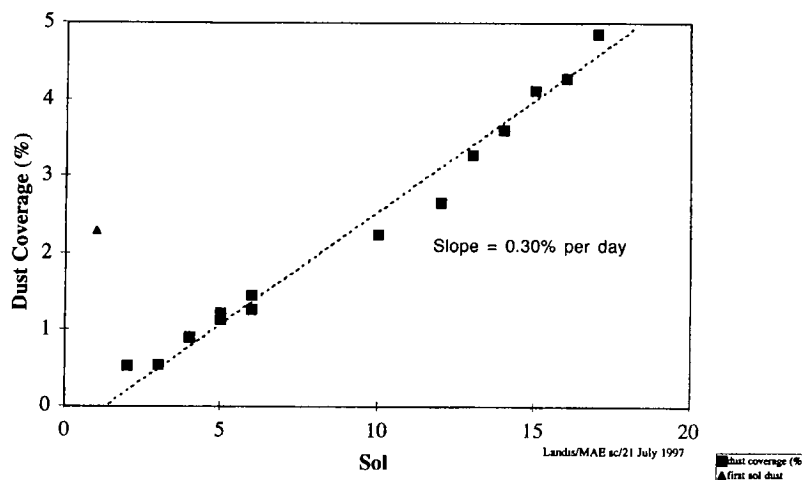
Research Center (since renamed NASA Glenn). We do research on more efficient solar cells, and understanding how they work in space. We had done a lot of calculations about whether you could in fact make a solar-powered spacecraft work on the planet Mars (it was our computer model that they used in designing the power system for Pathfinder), and looked at a lot of data from the Viking missions to understand the solar intensity on Mars. Mars, in fact, has a quite dusty atmosphere, including some times when it has thick dust storms. What does all that dust in the atmosphere do? If there's a dust storm, does it get too dark to run a solar power system?

Since Pathfinder wasn't landing in the dust-storm season, we calculated that there would be enough sunlight to run the Pathfinder spacecraft, even in the worst case.

But that's not the only problem. If this dust is in the atmosphere, is it going to settle down on the nice clean solar arrays? We calculated that this wouldn't be a major problem, but we really wanted to measure it to find out how much the deposited dust would degrade the solar arrays, so we could include this effect when we design future missions.

So I proposed a little instrument to put on the corner of the Sojourner rover to measure the dust. It was a very simple instrument: a solar cell with

Dust Deposition on Rover



a glass cover on top of it. Dust settles onto the glass. When we commanded it, the cover swung away for a moment, and we measured the sunlight without the glass cover. We can see how much dust has degraded the performance by how much more power we get from the solar cell without the dusty cover in front of it. A very simple measurement.

Here is some data. (I should mention here that a sol is a Martian solar day, a little longer than an Earth day - we always use the word sol when we're talking, so as to not get confused about whether we are talking about Mars or Earth days.) I might mention that 6 percent is the reflection from the glass so that if there is no dust on it, it should read 6 percent. Here on the first day of the mission, it's 8 percent. We're covered with 2 percent dust and we haven't even been on Mars for an hour yet. Well, what happened? Then the second day, that dust went away. It dropped down to almost nothing, and then one can see a slow rise in the amount of dust.

What happened? Well, after we landed on Mars, the first thing we did was to retract the airbags. We were scraping these big pieces of cloth over the surface, and so we raised up clouds of dust, and they got on top of my dust monitor system (in fact, they saturated one of my sensors, the QCM - which is why I'm not talking about it here.). What did we do next? We lifted up the petal and then we plunked it back down again. So, the dust that we raised up, fell off. So it took us a while to figure out why we had this dust here and it was gone the next day. But, that's what happened, it fell off when we picked up the petal and dropped it down again.

So we're very happy, we got good data from Mars. If we look over a little longer period of time, here's about the first three weeks, here's

that first day, and then it drops down, and then we're accumulating about a one percent loss in performance due to dust every three days. So I can say that there is some power lost due to dust, but it is not too bad. For a long mission, we will have to remove the dust from the solar arrays, or else stop it from depositing in the first place. After about a month, the dust cover jammed (maybe a little bit of grit got into the pivot), and after that our data wasn't terribly good. We're not sure whether the dust coverage saturates, or keeps on building up. We need another mission!

Martian rocks

We had a lot of fun on the mission. Most of the scientists on the mission were geologists, and geologists love to talk about rocks. They decided to name all the rocks that they can see, so that when they talk about rocks, they remember which one is which. So the first thing they did when they got the pictures down was to make a mural of the surface of Mars as seen by the lander camera. They stuck the mural on the wall of the conference room and said anybody could name a rock. So if you have a name for a rock, you just write it on a little yellow piece of paper, and stick it on to the picture. If everybody likes it, they'll leave it up, and if they don't like it, somebody else will name the rock.

So I looked at one rock, and said, hey, that rock looks like the head a bear. Take a look, you can see his nose, you can see his eyes, you can see his little ears there. It's a little bear and he's facing away from you. I said, "Let's name him Yogi Bear." Yogi Bear is a cartoon character in America who was very popular when I was a child.

For a long time I was worried that I was the

only one that thought it looked like a bear. But then a fax came to us from the artists who draw the cartoon Yogi Bear, and they see it looks like a bear, too.

The Sojourner rover also had cameras on it, and viewed from the Sojourner - it still looks like a bear. So, I think that was a pretty good name for a rock. It looks like a bear from either direction.

You can also see some other very interesting rocks from the rover. You can see how pitted these rocks are. The little pits are filled with sand. Some rocks are vesicular and there are some very angular rocks over here. The geologists are very happy to look at all these different rocks, with a lot of different theories about wind pitting and what the rocks are made of, and where they came from. They are very happy geologists in Pasadena.

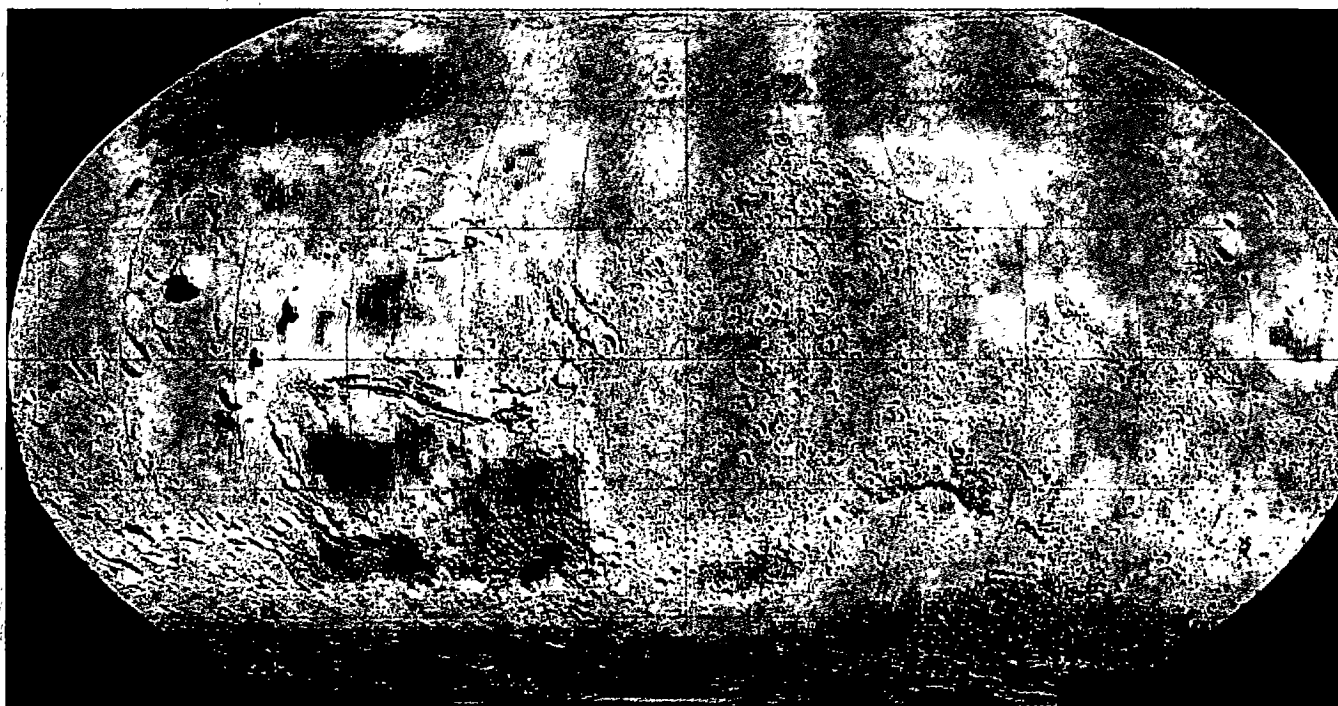
Pathfinder mission had other instruments on it as well, including the APXS ("Alpha Proton X-ray Spectrometer") that could actually sniff the rocks and find out what they are made out of. It was a very capable instrument.

After eighty-two sols on Mars, the mission finally failed. What happened was that the battery on the lander - the base station - failed, and so it was unable to keep the electronics warm at night. Mars gets pretty cold at night (about minus 90 C) and thermal cycling is probably what killed the electronics - we don't actually know for sure what happened, except that a day or two after the main battery failed, it went to sleep at night and we didn't hear from it in the morning.

The Sojourner rover actually had a tiny isotope heat source to keep the electronics warm, and when the base station failed, it probably kept on working, although it wouldn't get any more commands from Earth. The Sojourner had a program that told it, if it doesn't hear from us, it should stop moving, and wait for the engineers on Earth to solve the problem. But if it didn't hear from Earth after seven days, maybe the problem was that its receiver wasn't working, and its transmitter still worked. So after seven days with no communication from Earth, it was designed to start up again and just circle around, taking pictures and analysing rocks. I like to picture it as still circling around - although it's going to be going mighty slowly, since the solar arrays are going to be quite covered with dust.

Future missions to Mars

Pathfinder is not the end of Mars exploration. We have a whole armada of spacecraft going to the red planet. The Mars Global Surveyor is in orbit around Mars right now and has a mapping camera that shows very detailed close-up pictures



Scientists recently discovered enormous quantities of water ice lying just under the surface of Mars using instruments on NASA's 2001 Mars Odyssey spacecraft. Using Odyssey's gamma ray spectrometer instrument suite, scientists detected hydrogen, which indicated the presence of water ice in the upper metre (three feet) of soil in a large region surrounding the planet's south pole. This global map shows soil enriched by hydrogen, indicated by the deep blue colours, which show a low intensity of epithermal neutrons. Progressively smaller amounts of hydrogen are shown in the colours light blue, green, yellow and red. The deep blue areas in the polar regions are believed to contain up to 50 percent water ice in the upper metre of the soil. Light blue regions near the equator contain slightly enhanced near-surface hydrogen, which is most likely chemically or physically bound because water ice is not stable near the equator. The view shown here is a map of measurements made during the first three months of mapping using the neutron spectrometer instrument, part of the gamma ray spectrometer instrument suite.

of the surface of Mars from orbit.

I worked on another mission, which was intended to launch in 2001, called the 2001 Surveyor lander. Unfortunately in 1999 two missions that I did not work on both failed, and because those two missions failed, the 2001 lander mission was cancelled. We were all very disappointed.

Another mission did launch to Mars in 2001, an orbiter, the Mars "Odyssey" mission. The Odyssey spacecraft is in orbit around Mars right now, and taking measurements of Mars from orbit.

Many future missions are now being planned. The next mission to land on Mars is the Mars Exploration Rovers, two rovers each one much larger than the Sojourner rover, to launch in the summer of next year. (I have been selected to be one of the participating scientists on this mission, and I am extremely excited about the mission). At the same time, the British are heading to Mars with a small lander named the Beagle-2, a spacecraft which "hitchhike" to Mars with the ESA "Mars Express" orbiter. In 2005, the "Mars Reconnaissance Orbiter" is going to fly a high-resolution orbital camera, and in 2007, NASA will select one of several proposed "Scout" missions.

Some of the people that I work with would like to fly an airplane in the atmosphere of Mars. This is a challenging endeavour, because the atmosphere is so thin. Some people have suggested flying a balloon, and other people have suggested landing a spacecraft on the ice of the polar cap, and melting down through the ice to see the layers under the ice. Another group that I'm working with is proposing a long-range rover to drive across the fascinating layered terrain around the polar cap. It will be exciting to see one of these missions fly.

We would like to actually get samples back to Earth in a future mission, probably in the year 2015, which is only thirteen years from now, and blast them all home so we can take a look at them and look for fossils and for other interesting things.

All of these robotic flights are precursors to the most important future exploration: a mission to Mars with people on board. But right now there is no mission planned, so this is more science fiction than science.

In my science fiction novel, *Mars Crossing*, I picture such an expedition to Mars - in fact, several expeditions. The difficult part of sending people to Mars is not how to send them to Mars -

the difficult part is bringing them home. (And most of my novel is about how the characters work at coming home) In the novel, the expeditions to Mars manufacture rocket fuel from resources found on Mars to bring the expedition home. One of the expeditions lands on the polar cap, and makes rocket fuel out of the carbon dioxide and water ice in the cap, and the other expeditions lands near the equator, and manufactures fuel out of the atmospheric carbon dioxide. I think that this is very realistic, and that when we do send humans to Mars, that this is the logical way to do it - we should make the rocket fuel on Mars, instead of bringing it from Earth. Of course, in my story, the characters have tremendous difficulties, and are in great danger. I hope that in the real world, they will not have so many problems! The best expedition is one that is not very exciting. But perhaps this is one of the functions of science fiction, to show what the problems might be.

I do think that people will go to Mars. It is our sister planet, and we should go explore it. The universe is very big, and the Earth is only a small part of it. It is time for us to move out, and see what's out there.

Let's go!