



Voyages of Discovery with the Mars Exploration Rovers

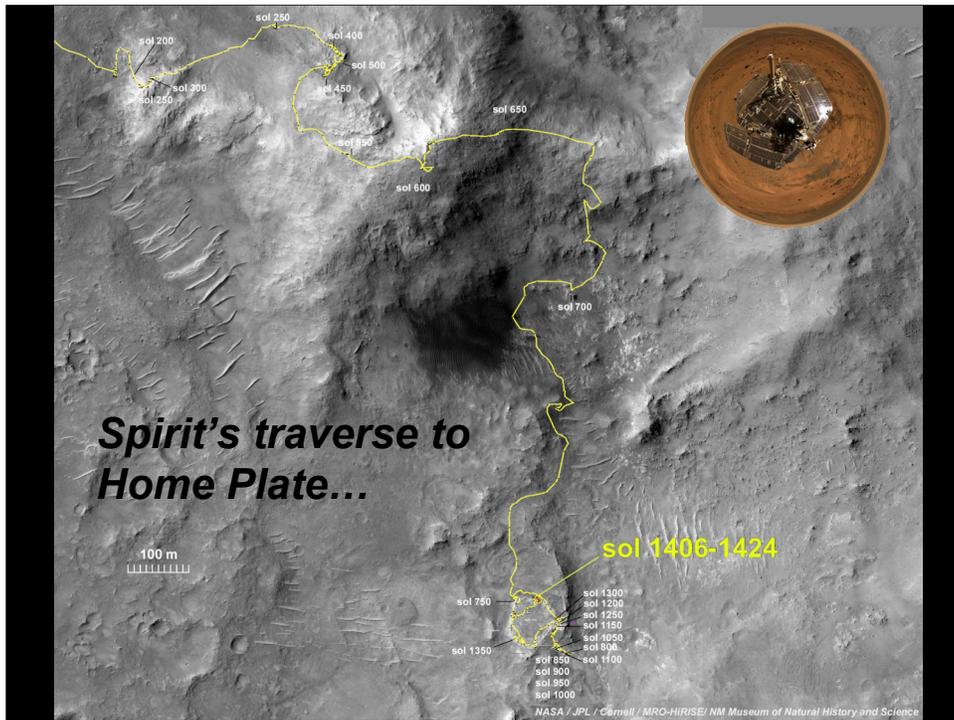
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I'm pleased to open the CONTACT 2008 conference with a tale that is scientific, visual, anthropological, philosophical, and a bit poetic.

This is the story of a new kind of exploration system. With MER we are beginning to answer the question -- how can people and robots work together to explore a planetary surface? It's a complex system that has been craftily engineered --- the instruments, the software tools, the organization, the scheduling.... What Squyres has called "One instrument, One Team."

I had the privilege of observing and documenting the scientists' work at JPL during the nominal mission in February 2004, a particularly exciting time when we were examining the outcrop in Eagle Crater. I later interviewed seven scientists, including Steve Squyres, plus two lead JPL engineers, and written a monograph partly funded by NASA's History Division. What I have learned is that MER is a new exploration system that changes the practice of field science. Working with a rover is full of paradoxes and surprises. And it's this new perspective I'm going to share with you today.

The overarching metaphor I suggest for grasping what working with a rover on Mars is the idea of a "Voyage of Discovery." In particular, I've found some interesting parallels to Cook's voyages to the Pacific in the late 18th century. So let's begin there.



Here we see Spirit's path in Gusev Crater -- over the Columbia Hills and to the Home Plate area where we found almost pure silica.

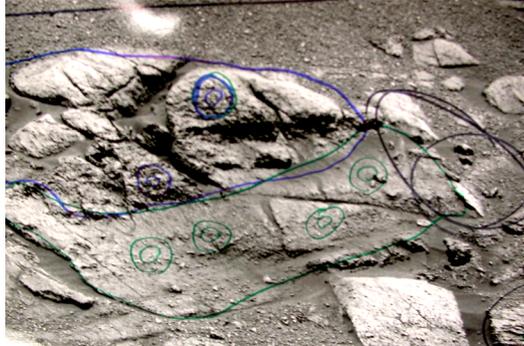
Consider how the scientists traveled together during these four years. It's like being a ship. You can't go off by yourself, you can only reach out from the rover so far. It's like we're all huddled together moving up those hills, slipping in the sand, going this way and that around Home Plate...

Just as on a ship, we all need to agree where we are going in the long term, when we should stay a little longer at one place, and what we should do tomorrow. We need to talk to each other about what we are learning -- chemists and geologists, relating atmosphere and climatology. The scientists and engineers are all moving together.... If I could draw it, I'd show all 150 people on a huge skateboard, all standing together, leaning off the sides, moving at a snail's pace through this terrain...

How strange that is compared to being a field scientist out working alone or in a small group, maybe covering that same territory in a day or two, with different people perhaps heading off in different directions sharing what they have learned. You can't do that on a ship, you voyage together and need each other if you're going to survive.



Surprise #1: Textbook Method



“... don't say let's RAT here to reveal this and let's RAT here to reveal that, let's talk it through in terms of the specific scientific hypotheses that we're trying to test.”

But there also some surprises on this mission--and that's our clue that this is a new approach to exploration that we need to look at carefully. Here is the outcrop in Eagle Crater where we first started to use the RAT on Opportunity....

It was mid February 2004 and I was in the Science Assessment room at JPL with Steve Squyres in the lead, and I couldn't believe my ears...<quote>

This is text book science! This is not how we use a hammer in the field!

But then you realize the constraints -- time is pressing, we just landed and have a 90 day warranty, the group called it “doing science with a sniper waiting for you,” The RAT won't last forever -- And the work highly public, expensive, the data we gather needs to serve many interests for years to come.

It's billed as being “field science” but it's a new way of doing field science, with very different constraints. It's more like writing a text book in real time.

Surprise #2: Rover as Hero

Jet Propulsion Laboratory
California Institute of Technology

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2004 News Releases

Spirit Lands on Mars and Sends Postcards
January 4, 2004

A traveling robotic geologist from NASA has landed on Mars and returned stunning images of the area around its landing site in Gusev Crater.

Mars Exploration Rover Spirit successfully sent a radio signal after the spacecraft had bounced and rolled for several minutes following its initial impact at 11:35 p.m. EST (8:35 p.m. Pacific Standard Time) on January 3.

"This is a big night for NASA," said NASA Administrator Sean O'Keefe. "We're back. I am very, very proud of this team, and we're on Mars."

Mosaic image taken by the navigation camera on the Mars Exploration Rover Spirit.

Related Links:
[+ Spirit's First Images from](#)

"The first ever *robot field geologist* on Mars..."

Here is another surprise -- the way the rover became the hero of the story --
<quote release>

All this started with the first press release about the mission. I cringed at the anthropomorphisms:

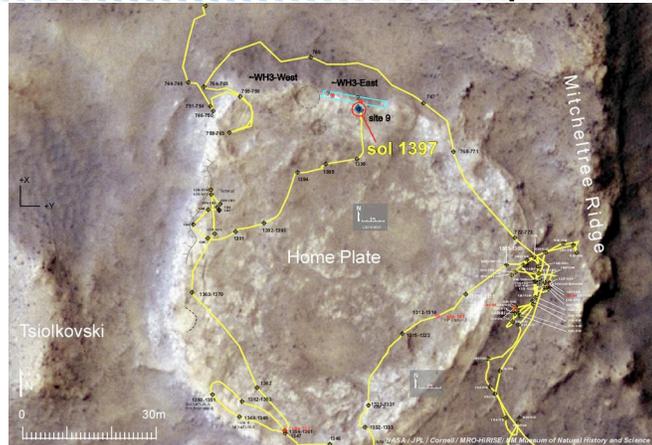
July 28, 2000 -- In 2003, NASA plans to launch a *relative* of the now-famous 1997 Mars Pathfinder rover. Using drop, bounce, and roll technology, this larger *cousin* is expected to reach the surface of the Red Planet in January, 2004.... This new *robotic explorer* will be able to trek up to 110 yards (100 meters) across the surface each Martian day.... "This mission will give us the first ever *robot field geologist* on Mars..." said Scott Hubbard, Mars Program Director at NASA Headquarters.

Throughout this metaphor continued, the MER scientists & engineers becoming like the Wizard of Oz behind the curtain, profiled perhaps on the web site now and then, but mostly only mentioned when something went wrong. In this communal science, the rover becomes the main character in the daily story.

But this is not just poetry or clever journalism, there's a logic here--for this perspective, making the rover the hero, unifies the team, and gives everybody something to cheer on and talk about, transcending the scientific interests of the different disciplines and affirming that it's not a platform of "payloads" like Galileo or Cassini, but rather "the rover is the instrument."



Surprise #3: Analyzing a Planet with a Microscope

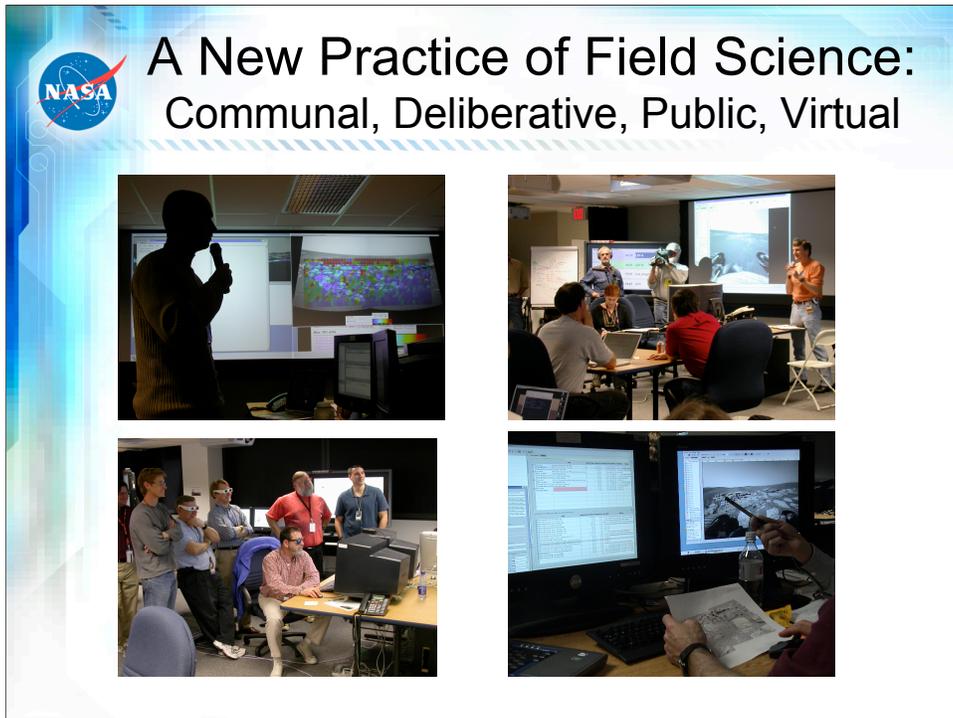


150 scientists & engineers have investigated 100m² for over 2 years, with 1 robot (Spirit)

Finally, the third surprise is what's happened at Home Plate. << subtitle >> this is like << title >>

Now, it's true that we stayed partly because of power reasons and partly because of the rover's decreased mobility. But we mainly stayed because we kept finding things of interest. The scientists are split on what might have happened if we had more power and mobility. Most say they have no idea, it's too circumstantial. One of the long-term planners thinks we might have zoomed right on by and missed the silica.

How will we explore an entire planet? MER is providing extensive data for examining that question and maybe for beginning to formulate an exploration strategy. One engineer suggested that Sojourner might have performed as well or better here in this small area. But also we can see the value of aerial and orbital surveys so we know where to send the rovers.



So, to sum up some of the paradoxes of working with a rover on Mars

You're In a dark room -- yet doing Field Science

You're anonymous, part of the team -- yet Famous in public, everybody knows about your work and is excited about it.

Your work is Extremely Remote -- yet you feel Present on the Ground, you are on Mars.

You are Seeing, scraping, & moving on Mars -- yet always Mediated by computer tools, numbers & images; virtual reality becomes your way of being there and touching the surface

And we could go on -- Studying Mars from the comfort of Pasadena, CA -- yet Living on MARS TIME with 24 hr 40 min sols for 3 months; Voyaging over hills and discovering possible fumaroles, sand dunes, shallow seas.... But at a GLACIAL PACE.

It's a new way of doing field science. It's a new exploration system -- and it works.



Types of Scientific Exploration

Type	Setting	Domains	Tools	Scale
Voyages of Discovery	Extreme	geography, bio, anthro	Hand	10s - 100s
Laboratory Science	In a building	bio, chem, physics	Lab	Few
Field Science	Isolated or Mundane	bio, geology, social	Hand	One - few
Modern Expedition	Base camp; City or Extreme	archaeology, geo, bio, robotics	Hand + Lab	Few - 10s
Big Science	Isolated site	physics, astro, ocean.	Huge machines	100s - 1000s
Planetary Missions	Extreme	astro, geo, bio, physics	Robotic spacecraft+	1000s

One way of putting MER into perspective, to see how it changes the practice of field science, is to categorize types of scientific exploration and see how MER fits. My conclusion is that MER combines all of these types of scientific exploration. Here are some main points:

MER is a Voyage of Discovery

It involves laboratory science through the instruments and analytic tools

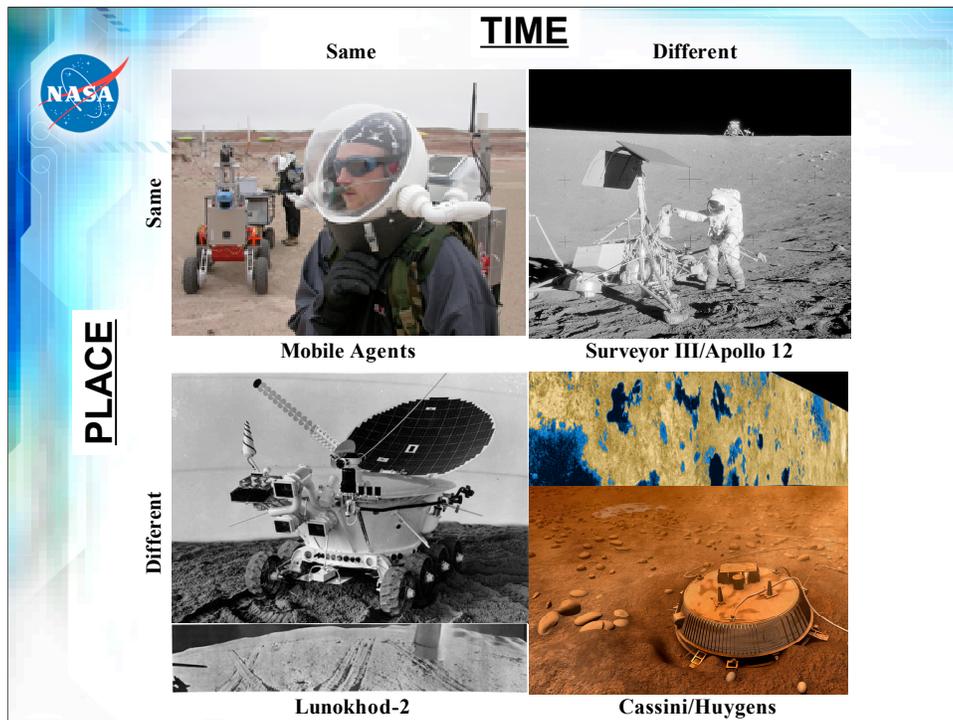
It's of course an exploration out in the field

But it's also a kind of expedition, in terms of how many people are sharing resources out in a remote environment

And it's of course big science, still involving hundreds of people and overall costing 100s of millions of dollars

Yet we can't forget it is a planetary mission with a robotic vehicle -- on the surface.

Rovers, much more than spacecraft provide a sense of being present and participating in the exploration, not the least because the route is opportunistic. And its being on a rover, using its tools and planning a path opportunistically, that makes MER so different.



In this second part of my talk, I want to examine the relation of people to the rover and its operations.

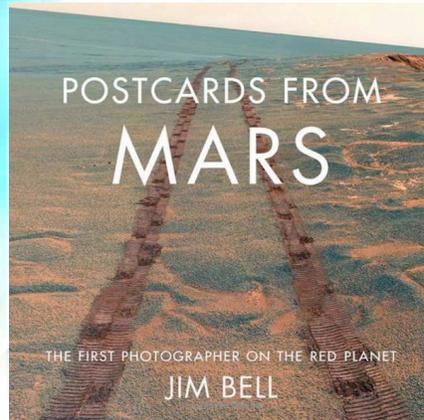
Here's a simple two by two comparison visualizing how people and rovers might interact in time and place.

- My own work on Mobile Agents simulates people interacting with rovers on Mars -- together at the same time.
- In Apollo, Surveyor III provided reconnaissance for Apollo 12, but wasn't operating when they arrived --- same place, different time
- Lunokhod was joysticked from earth -- different place, with a small delay, same time.
- And finally, we have what we used to call "batch operations" in computer programming, robotic systems carrying out procedures we uplink to them hours or even months in advance, and we only see and analyze their data later -- different place, different time. Yet, we get from that a sense of presence of being the rover!

Let's look quickly at how people conceive of their relation to a rover working at a different time and place.



Two Boots on the Ground...



“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. By and large, day in day out, it was always the perspective of being on the surface and trying to draw in your own field experience in places that might be similar—how you’d detect a landscape and interrogate it as much as you could.”

Jim Rice, MER Scientist, 2006

The overarching conception of the MER scientists is that “We’re on Mars.”
Jim Rice said --- << read >>

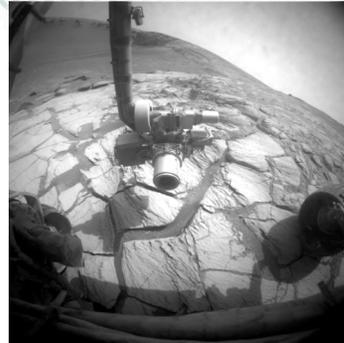
Jim Bell shows us his work as the first photographer on the Red Planet...

But this relation is complex -- what does that mean, “We’re on Mars”? And who is the “first photographer”: the MER or Jim Bell?



“We’re on Mars!”

First Person Perspective



Seeing & Direct Manipulation

“We realized *we had landed in a crater*, probably Eagle Crater, and that’s where we were. And then *we noticed, 800 meters away*—which is more than our 600 meters, but *maybe we can make it*—there’s Endurance Crater. We’re talking about that, “My god, wouldn’t it be great to actually get there!”

Steve Squyres, MER PI, 2007

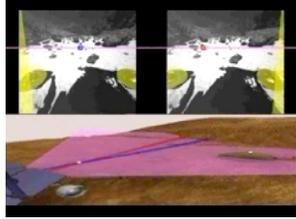
Here are three perspectives -- 1st, 2nd, and 3rd person -- and people slip between them very easily.

In the first person perspective, we think of ourselves as being embodied in the rover.... << quote >> Notice how different this is from the “rover as hero” reports.

Through Visualization tools, we can experience touching and manipulating Mars.... << point >> << now I take a close up and roll forward.... >> Such visualizations are essential for operating the rover.

“We’re on Mars!”
Second Person Perspective





“Partnership” – What You Do and What I Do

“I actually see the rover as an equal partner.... I have my limitations as a robot planner—resources, my time to build a sequence, then time to do the analysis. If I had all the resources in the world, I could ...build every little thing that I want the rover to do—intricate sequencing—so that the rover doesn’t have to think for itself. But because of that limitation, I’m forced to work in partnership with the robot.”

Ashitey Trebi-Ollennu, MER Rover Planner, 2007

Ashitey, a MER engineer and lead rover planner, describes his relation to the rovers in a different way -- for him it’s a kind of partnership ---<< read quote>>.

For Ashitey, the rover is a kind of surrogate, it’s a deputy that carries out tasks for him -- He says, “Find your own way....”

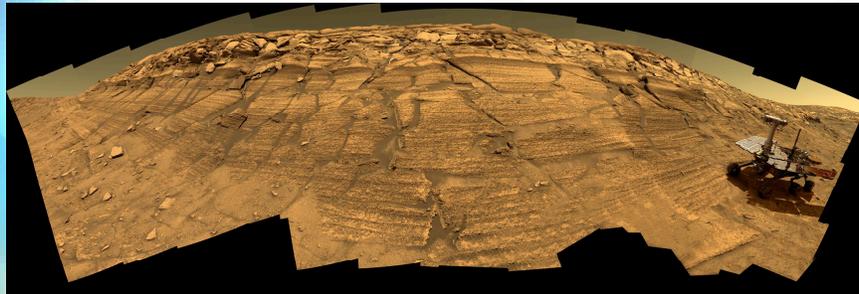
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11 May 2007 MER JPL web



“We’re on Mars!”

Third Person Perspective



It: The Robotic Geologist...alone in Victoria Crater...
and also

Us: standing before Burns Cliff, observing the robotic
laboratory...

And this brings us back to the “Robotic geologist” -- the rover is out there, doing it’s own thing. This is the metaphor in which individuals and the team itself steps back and the rover becomes the hero -- There’s intrepid Spirit on it’s road of trials, surviving, slipping along, and finally stumbling on its boon -- the silica soil. And lucky Opportunity, a hole in one, yet still tried in its journey by the sand pit and now dedicated to spend its days happily examining Victoria Crater...

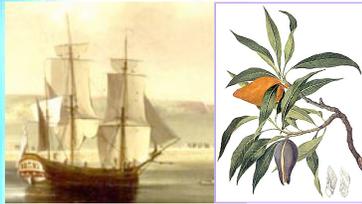
As one MER manager said in December 2005 -- "The great adventure continues, and both rovers look forward to starting a second martian year of discovery." Nov 29, 2007: **Spirit’s Race Against Winter While struggling to reach a winter outpost necessary for survival on Mars, Spirit has been slowed by sand in the bottom of a shallow, bowl-like depression. Spirit’s goal is to reach a slope on the north edge of “Home Plate” that will keep its solar panels trained on the Sun.**

This synthetic image (of Opportunity) represents this conception -- and it’s of course useful for scale. But it realizes another relationship -- -- who took this photo? We are on Mars after all!

The way we slide between perspectives is partly why the MER exploration system is so successful -- I am the rover, we are on Mars together, the rover works for me, and from orbit and on the computer screen, we can see it... Using our tools, we slide between these perspectives of operation effortlessly and without thought... I think that helps make the remoteness and anonymity more tolerable.



Voyages of Discovery



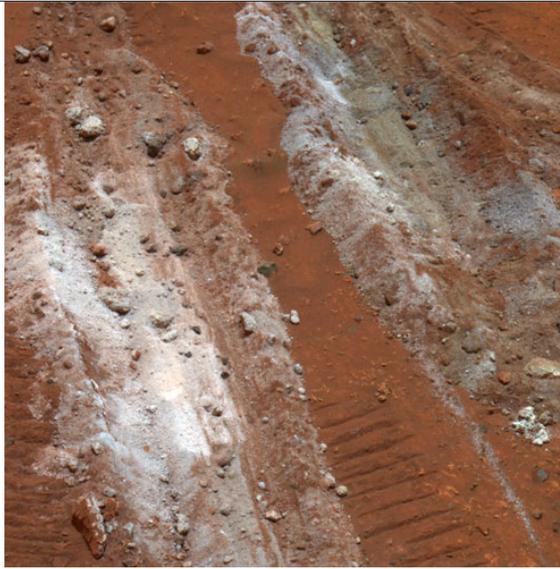
- “A Heroic Journey”
- Move together
- Collaboratively investigate
- Engineers operate vessel
- Survey and study lands known to exist
- “Gathering data for the ages”
- Opportunistic
- Don’t know what we’re missing

As one way of summarizing, let’s go back to the voyages of discovery...

Here you see in the Science Officers Working Group (SOWG) meeting towards evening of the sol during nominal operations in 2004. The chair at center right runs the meeting, like a captain on a ship at the helm. Displayed ahead is the surface of Mars with tomorrow’s plans with target visualizations in a form of virtual reality. Behind sit the engineers, like the operators below deck, managing the resources and responsible for operating the vessel.

<< read main points >>

And finally, like Cook, who “discovered” that Antarctica did not exist, we of course do not know what we are missing. That uncertainty is part of all real exploration and adds to the sense of awe and mystery of Mars for years to come.



Our marks on another planet —
The embodiment of human curiosity & probing...
our physical & intellectual reach...

I'd like to conclude with an image I find a bit haunting.

It's easy to be impressed by this photo -- it's clarity, what it reveals, the sense of gives you of being right there...

But there's a larger point, what the photo reveals about us as human beings... Pull back about 50 million miles and consider -- right now, these tracks and scuff marks are out there, on Mars... We have been there. These are our marks, our boots on the ground of another planet...

Just think about what that means about the extent of our needing to know and now our reach in space...