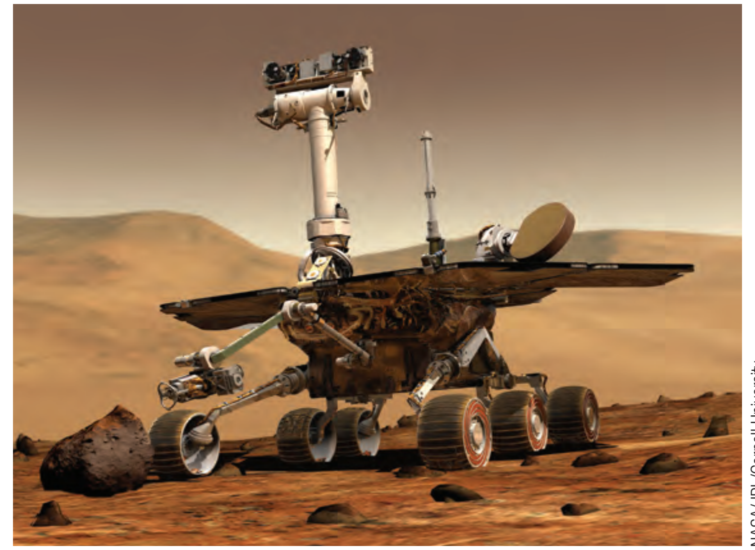
Opportunity

Mars Exploration Rovers

National Aeronautics and Space Administration

Opportunity has a look around

The full-circle scene on the front of this poster combines 817 images taken by the panoramic camera (Pancam) on NASA's Mars Exploration Rover Opportunity. It shows the terrain that surrounded the rover while it was stationary for four months of work during the Martian winter. The view is presented in false color to make some differences between materials easier to see.



NASA/JPL/Cornell University

Opportunity's Pancam took the component images between the 2,811th Martian day, or sol, of the rover's Mars surface mission (December 21, 2011) and Sol 2,947 (May 8, 2012). Opportunity spent those months on a northward-sloped outcrop, "Greeley Haven," in a position that angled the rover's solar panels toward the Sun low in the northern sky during southern hemisphere winter. The site is near the northern tip of the "Cape York" segment of the western rim of Endeavour Crater.

Bright wind-blown deposits on the left are banked up against the Greeley Haven outcrop. Opportunity's tracks can be seen extending from the south, with a turn-in-place and other maneuvers evident. The tracks in some locations have exposed darker underlying soils by disturbing a thin, bright dust cover.

On the front: Tracks of a Martian

Leaving tracks over carefully navigated and thoroughly studied ground, Opportunity sits out the Martian winter on a sloping outcrop of Endeavour Crater. The image is a full-circle panorama made of 817 images taken over 136 sols, or Martian days.

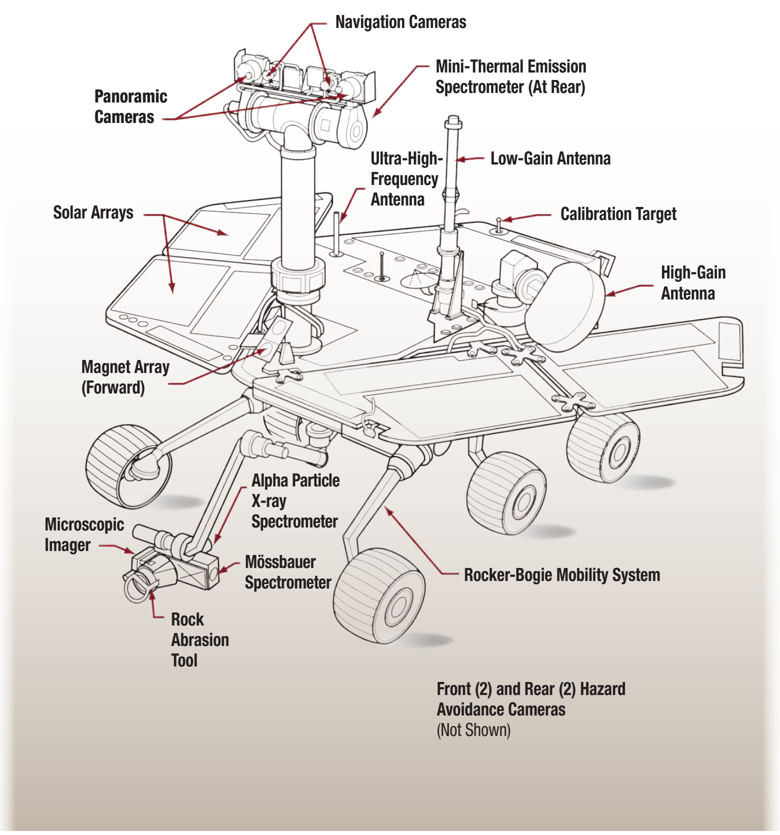
Opportunity's Sols 2,811–2,947 (12/21/2011–05/08/2012)
NASA/JPL-Caltech/Cornell Univ./Arizona State Univ.

During the four months that Opportunity remained at Greeley Haven, it accomplished several important tasks. The rover performed radio science observations to better understand Martian spin-axis dynamics and thus interior structure of the planet. It investigated the composition and textures of an outcrop exposing an impact-jumbled rock formation on the crater rim. It monitored the atmosphere and surface for changes. It also acquired this full-color mosaic of the surroundings.

The Mars Exploration Rovers

NASA's Mars Exploration Rover Opportunity and its twin rover Spirit landed on opposite sides of Mars in January 2004. The rovers were originally planned to operate for 90 Martian days (sols). Spirit ceased operation March 22, 2010, on Sol 2,210. As of December 1, 2012, Opportunity continues to explore and communicate with Earth, having traveled over 22 miles (35 kilometers) and operated for more than 3,100 sols.

The objective of the mission is to assess the geology and past habitability of two sites on Mars where evidence of past and persistent water has been preserved. The still-functioning Opportunity rover has high-resolution stereoscopic imagers and an arm with instruments attached that can be used to investigate surface materials.



Driving on Mars

From stereo images captured by Opportunity's autonavigation system, the rover's software generates 3-D terrain maps. The software then analyzes the height and density of rocks or steps and excessive tilts and roughness of the terrain to determine traversability and safety for the rover. The program considers dozens of possible paths before choosing the shortest, safest path toward the programmed geographical goal. The rover then drives from 0.5 to 2 meters (1.6 to 6.6 feet) closer to its goal, depending on how many obstacles are nearby. The whole process repeats until the rover reaches its goal, encounters an obstacle, or runs out of time.

The Mars Exploration Rover autonomous driving software is more advanced than that of the Mars Pathfinder mission's Sojourner, the first rover to traverse the surface of another planet. Sojourner's onboard safety system also looked for obstacles, but could only measure 20 points at each step; Spirit and Opportunity typically measure more than 16,000 points from each pair of images. The average Mars Exploration Rover obstacle-avoidance driving speed of nearly 34 meters (about 112 feet) per hour is 10 times faster than Sojourner's. During its entire three-month mission, Sojourner drove just a little more than 100 meters (328 feet). Spirit and Opportunity each broke that record in a single day; Spirit drove 124 meters (407 feet) during Sol 125, and Opportunity 220 meters (about 722 feet) on Sol 410.

Keeping track of the meters

Another improvement over Sojourner is the Mars Exploration Rover visual odometry software system. As Opportunity drives over sandy and rocky terrain, it can slip by unpredictable amounts—even backwards when driving up very steep slopes. The visual odometry system helps by giving the rover a much better notion of how far it has actually traveled.

It works by comparing pictures taken before and after a short drive, automatically finding dozens of features in the terrain (for example, corners of rocks, high-contrast corners in rover tracks, and sharp soil texture changes), and tracking their motion between images. Combining the measured 3-D motion of all such terrain features lets the rover figure out how much it really moved and turned much more precisely than simply counting how much its wheels have turned.

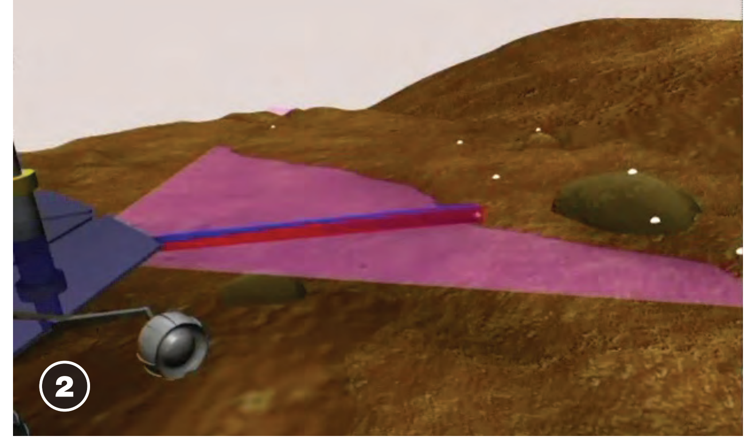
Autonomous navigation

To give Spirit and Opportunity more ability to explore, the rovers' autonavigation driving software was improved over that of the first Mars rover, Sojourner.

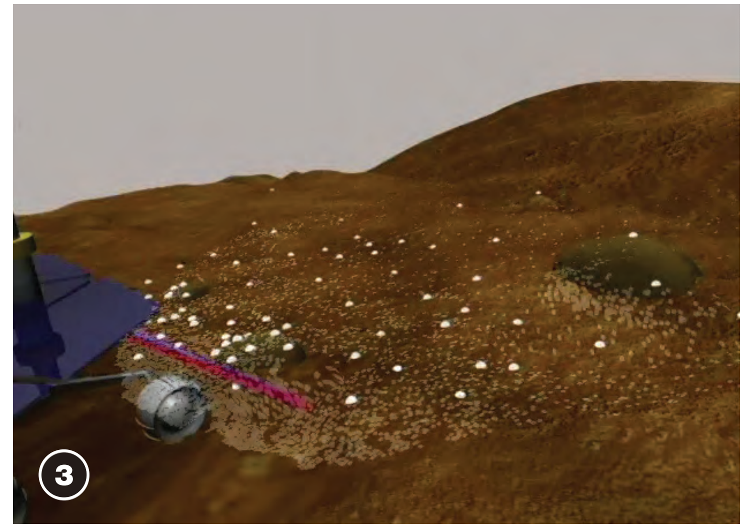
When the rovers are navigating themselves, they get a command telling them where to end up. Then, using their stereo imagers and special software, they figure out for themselves the best and safest way to get there. They must avoid any obstacles they identify. This capability has enabled longer daily drives than would have been possible by simply depending on step-by-step navigation commands sent from Earth.

Here is an overview of the Mars Exploration Rovers' navigation algorithm, GESTALT, including explanations of stereo vision, traversability analysis, path selection, and driving. GESTALT is an acronym for Grid-based Estimation of Surface Traversability Applied to Local Terrain.

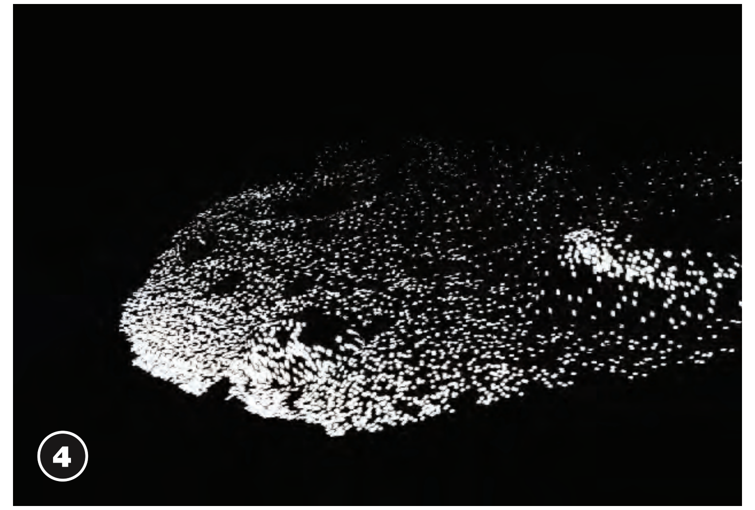
The autonavigation system takes left and right pictures of the nearby terrain using the Mars Exploration Rover body-mounted stereo hazard-avoidance cameras or mast-mounted stereo navigation cameras.



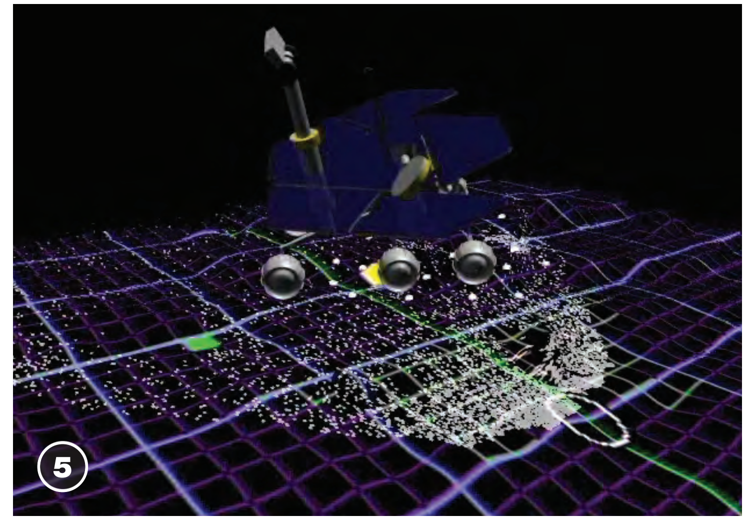
The software looks for all pairs of pixels that show the same spot on the terrain. Distances from the cameras to all such corresponding points are calculated using a simple technique of geometry called triangulation.



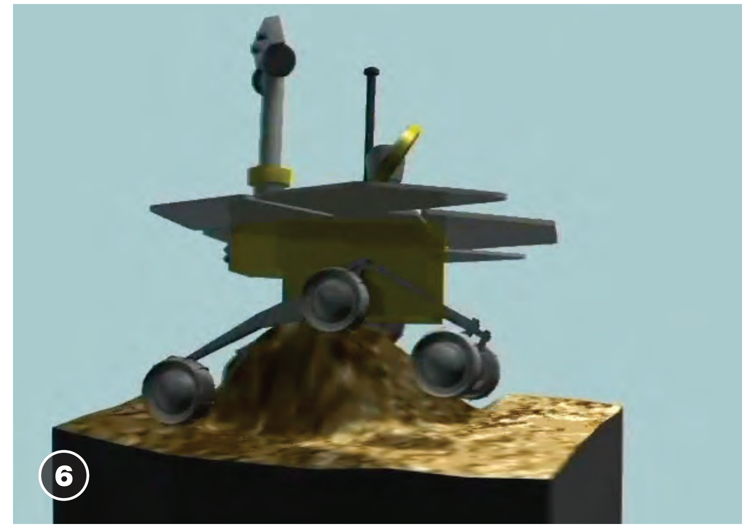
The resulting points are accumulated into a 3-D geometric model or grid of the terrain.



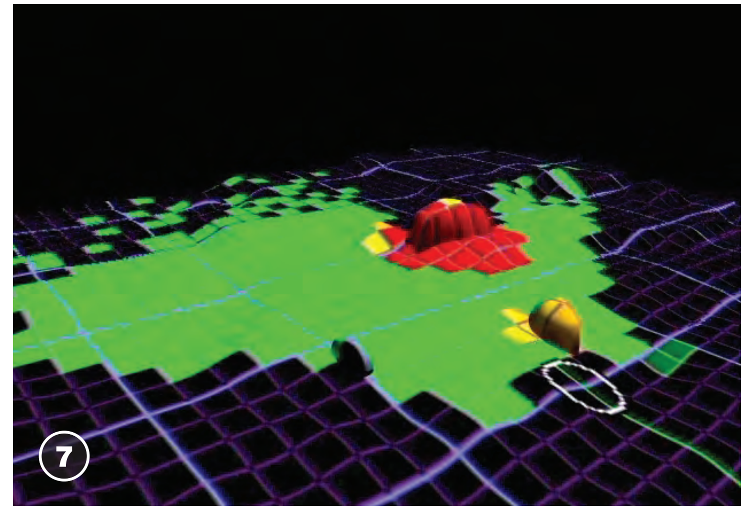
Spirit and Opportunity typically measure more than 16,000 points from each pair of images.



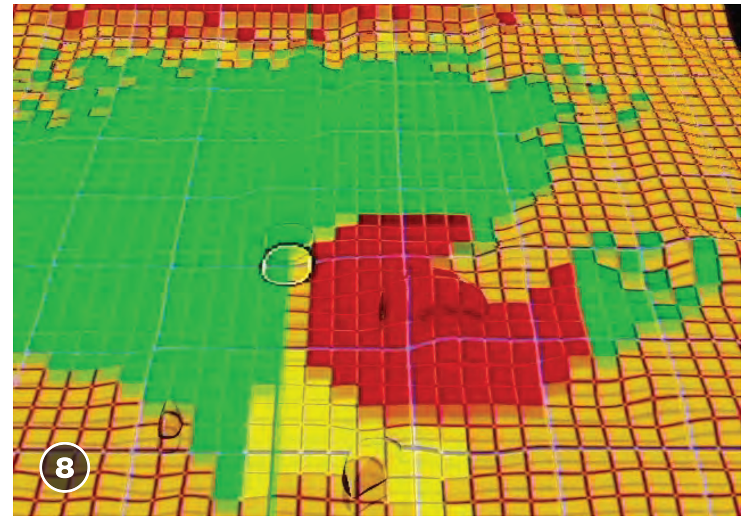
This 3-D model is evaluated for safety across the grid at rover-wheelprint resolution. For each rover-sized grid patch, the points are fitted onto a plane and evaluated for rover traversability.



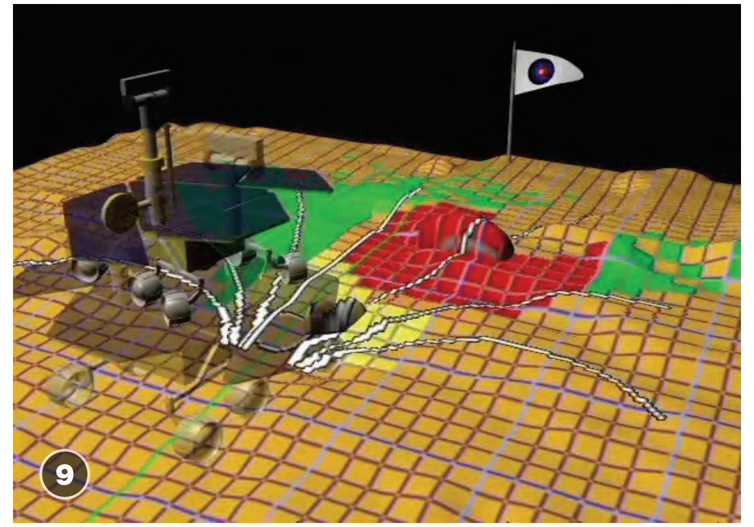
Each patch is evaluated for steps, excessive tilt, and roughness.



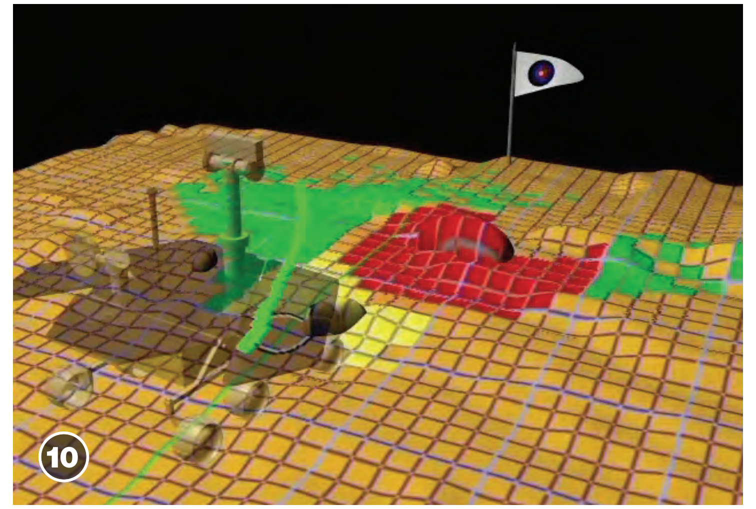
Objects are expanded by the radius of the rover so that the rover center will stay far enough away from the obstacle to keep the rover out of danger.



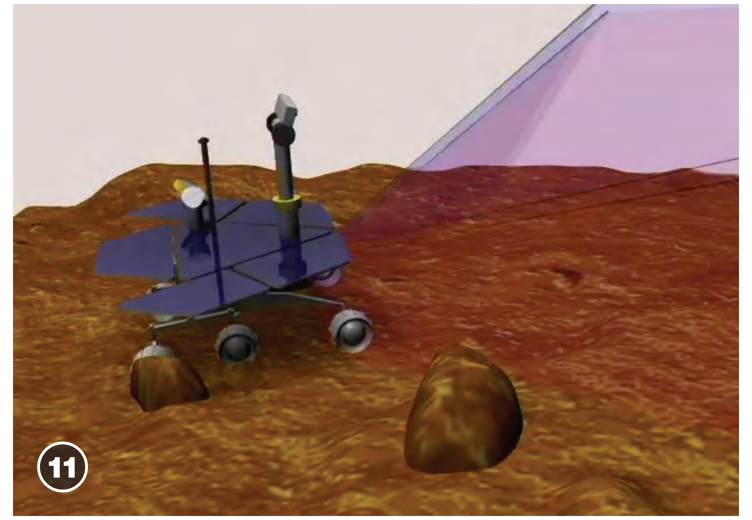
All the patches are accumulated into a gridded traversability map that drapes across the terrain near the rover, including areas not currently visible from the cameras.



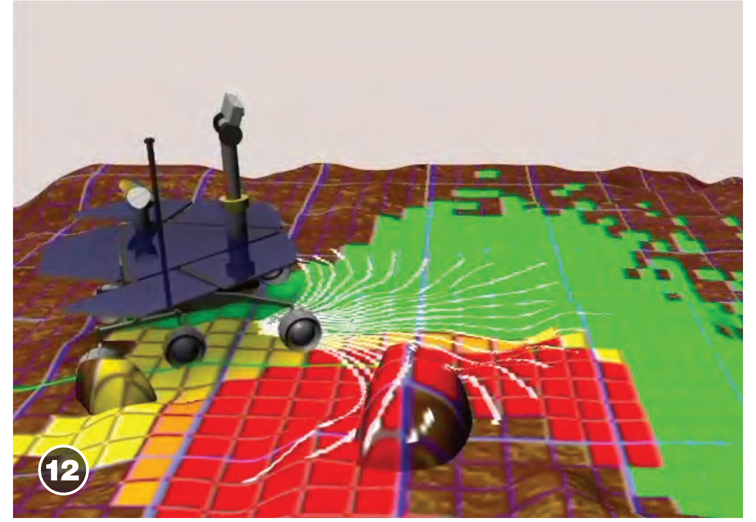
A small number of paths are draped across the map and evaluated for safety and how close each will bring the rover to the goal.



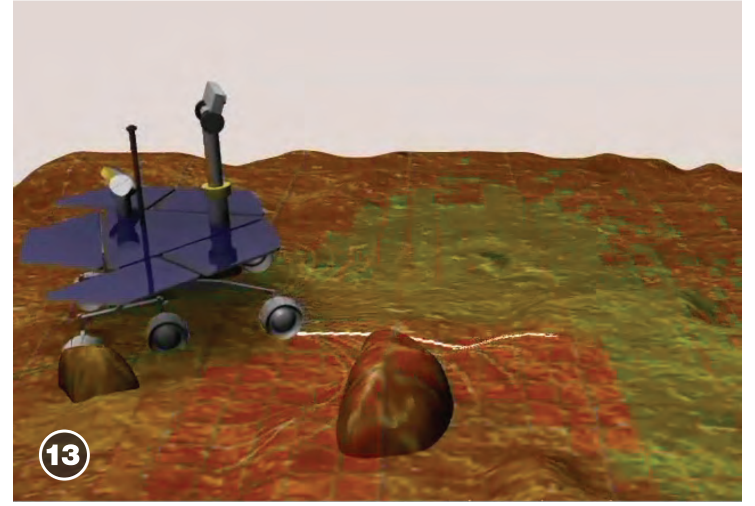
The rover chooses the safest path that will get it closer to its goal and drives a short distance along that path.



After each step, the navigation process repeats, taking stereo images, generating the 3-D terrain model and analyzing.



Again, the software evaluates each path for safety and route efficiency.



The rover drives a few meters closer to the goal and repeats the whole process until the it reaches the goal, encounters an obstacle, or runs out of time.

More information

For more about the Mars Exploration Rovers, NASA's other Mars missions, and more Mars images and discoveries, visit the following websites:

http://mars.jpl.nasa.gov

http://marsrovers.jpl.nasa.gov

http://photojournal.jpl.nasa.gov/targetFamily/Mars

http://mars.jpl.nasa.gov/science

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