ROVING FOR ROCKS ON THE RED PLANET:
THE MARS PATHFINDER MISSION

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Mars is the most 1%d~-like plaint in our solar system. It is the first planet humans will visit and the only planet that can support life in the future, with abundant water and the potential for terraforming it to make it more clement. Mars is the only planet in which scientific evidence has been presented to suggest that life formed somewhere other than the Earth. In addition, the geologic record on Mars is suggestive of an early climate that was warmer and wetter in which liquid water (a requirement for life) may have been stable. Mars is also a unique terrestrial planet with evidence for major climatic changes and a geologic record of rocks on the surface. that spans the entire history of the solar system. As a result, an exploration program to the Red Planet will allow the investigation of a wide variety of important geological, climatological and exobiological topics, but can also address in a scientific manner the almost theological question of: "Are we alone in the. universe?".

Despite the great inlet-cst in Mars, Pathfinder will be the first spacecraft to land cm the Red Planet since the Viking landers more than 20 years ago. The landing of Mars Pathfinder on July 4, 1997 will initiate an exciting era of Mars exploration and will be followed closely by the arrival of the Mars Global Surveyor orbiter and the Russian Mars '96 spacecraft in mid-September 1997. The Mars Global Surveyor and the Mars '96 orbiters will systematically characterize the atmosphere, surface and interim to provide a remote sensing characterization of the entire surface of the planet. The two Russian landers and two penetrators will also provide first-order characterization of the atmosphere and surface at the few point locations where they land. Mars Pathfinder, however, will be the first mission to explore a landing area cm Mars with a mobile platform capable of measuring the chemical composition of surface materials. Because of this mobility, it will be able to explore a landing area that is of order hundreds of square meters (as opposed to a few square meters accessible by lander-mounted mechanical arms). Pathfinder's instruments and rover will provide a characterization of martian rocks and surface materials over a substantial area, thereby providing "ground truth" for humankind's view of Mars that is currently based mostly on global remote sensing data.

The Mars Pathfinder Project received a new start in October 1993 as one of the first Discovery-class missions, which are low cost ($171 M development cost cap in real year dollars), short development (about 3 years) missions that have a set of significant, but focused engineering, science, and technology objectives. In addition to the development cost, the launch vehicle cost is about $55M, the rover development and/operations cost is $25M, and the mission operations and data analysis cost is $14M, all in real year dollars. The spacecraft is a novel design that combines the cruise, entry, descent and landing functions into a single "free-flyer". The primary objectives of Pathfinder are to demonstrate a low-cost cruise, entry, descent, and landing system that can safely place a payload on the martian surface, and to deploy and operate a microrover and science instruments. Pathfinder demonstrates a cost effective approach for future Mars missions, with the Mars Surveyor '98 lander and orbiter that are under development extensively using Pathfinder components and systems, including the aeroshell, backshell, parachute, flight computer and software, aspects of the command and data handling systems, and the solid-state power amplifier. The Jet Propulsion Laboratory (JPL) of the California Institute of Technology, which is NASA's lead center for the robotic exploration of the solar system, built and manages the Pathfinder spacecraft and rover, with most subsystem components contracted out to industry. Existing flight qualified hardware has been used wherever possible to reduce cost, at the expense of increasing the mass of the spacecraft (launch mass is 890 kg).

After launch on an expendable Delta rocket in December 1996 and 7 month cruise to Mars, the cruise stage orients the spacecraft for direct entry into the martian atmosphere behind the aeroshell. A parachute unfurls, slowing the vehicle, and the aeroshell is jettisoned. During descent, the lander is lowered on a bridle from the backshell and near the surface an altimeter triggers the firing of three small solid tractor rockets to further slow the lander. Giant six-lobed airbags inflate around each face of the tetrahedral shaped lander, the bridle is cut and the airbag-enshrouded lander bounces a number of times on the surface of Mars. Landing takes about 5 minutes and occurs at about 3am local time. After coming to rest the airbags are retracted and the triangular panels open up to right the lander. The lander is solar powered, with rechargeable batteries for nighttime operations. It is operated by a 32 bit high-performance central computer that is programmable in C, with about a gigabit of memory and communicates directly to the Earth via a steerable high-gain antenna capable of transmitting many kilobits of data per second. The lander carries a multispectral stereoscopic imager (IMP, Imager for Mars Pathfinder) on an extendable mast and an atmospheric structure instrument/meteorology package (ASI/MET), as well as a free- ranging rover, with forward stereo and rear color cameras, an alpha proton X-ray spectrometer (APXS) and sensors for a number of technology experiments. Surface operations are planned for up to one Earth year.

The rover on Mars Pathfinder is a mail, six-wheel drive "rocker bogie" design vehicle, which is 65 cm long by 48 cm wide by 30 cm high. The rocker bogie chassis provides a very stable platform for mounting instruments and has demonstrated remarkable mobility, including both the ability to climb obstacles that are a full wheel diameter in height and the capability of turning in place. It is a solar powered vehicle with a primary battery back-up, that allows APXS measurements at night. The vehicle communicates with the lander via a UHF antenna link and will operate almost entirely within view of the lander cameras, or within a few tens of meters of the lander. Extended mission traverses up to hundreds of meters from the lander (limited by the UHF link) are possible. The APXS is mounted on a deployment device at the rear of the vehicle that will allow placement of the APXS sensor head up against both rocks and soil at wide range of orientations (from horizontal on the ground to vertical rock faces at lower height). The rear facing camera will image the APXS measurement sites at slightly better than 1 mm per pixel resolution. The rover control system includes a variety of autonomous hazard detection systems (such as forward laser light stripers for detecting obstacles or crevasses and potentiometers for detecting bogie tilts) for safing the vehicle. in potentially hazardous situations. The rover also performs a number of technology experiments designed to provide information that will improve the design and operation of future planetary rovers (e.g., rover and sensor navigation and performance, soil mechanics, and material adherence and abrasion).

The surface imaging system will be used to understand the geologic processes and surface-atmosphere interactions at a scale currently known only at the two Viking landing sites. It will observe the general physiography, surface slopes and rock distribution in order to understand the geological processes that created and modified the surface. Together, the alpha proton X-ray spectrometer will measure the elemental composition of surface materials, and the spectral filters on the imaging system and rover close up imaging will be used to infer the petrology and the mineralogy of rocks and surface mate.rials, which can be used to address questions concerning the origin of crustal materials and the development of weathering products on Mars. An understanding of near-surface stratigraphy and soil mechanics and properties will be obtained by rover and lander imaging of rover wheel tracks, holes dug by rover wheels, and any disruptions caused by airbag retraction. imaging of airborne deposited dust over time on a series of small magnets on the lander is designed to distinguish the magnetic component of the martian dust. The atmospheric structure instrument will determine a pressure, temperature and density profile of the atmosphere (with respect to altitude) during entry and descent. Diurnal variations of the atmospheric boundary layer will be characterized by regular pressure and temperature measurements. Wind speed and direction versus height in the boundary layer will be determined by a wind sensor on top of a meter high mast, along with 3 wind socks on the mast; these data will also allow calculation of aerodynamic roughness of the. surface, which is important for understanding the forces acting on small particles and their entrainment in the wind. in addition, the imager will determine the. characteristics and distribution of aerosols and atmospheric water vapor abundance from sky and solar spectral observations. Tracking of the lander over time will determine the location of the lander, the orientation of the pole of rotation, the precession rate and the moment of inertia of Mars, which will help constrain the size and density of any central metallic core.

Mars Pathfinder will land within a 70 km by 200 km ellipse (resulting from navigational and ephemeris uncertainties during cruise and atmospheric entry) in Ares Vallis, Chryse Planitia (19.5°N, 32.8°W). This site lies just downstream from the mouth of the Ares and Tiu Valles catastrophic outflow channels, which drained from the highlands to the south. Selection of this site was made after consideration of engineering constraints derived from the spacecraft and rover designs (both of which are particularly robust) and the entry, descent and landing scenario; site safety inferred from a suite of remote sensing observations (including high-resolution imaging, radar reflectivity and roughness, thermal inertia, rock abundance, albedo and red to violet ratio); science potential; and study of the Ephrata Fan and Channeled Scabland in eastern Washington, which formed from the catastrophic release of glacial Lake Missoula and is an Earth-analog for the landing site and Ares Vallis region (e.g., EOS, v. 77, p. 9-10, Jan. 9, 1996). landing at this site (a so called "grab bag" site) offers the prospect of sampling a diversity of rock types that makeup the ancient heavily cratered terrain on Mars, the ridged plains and a variety of reworked channel materials. Examination of these materials allows the prospect for addressing first-order scientific questions such as the primary differentiation and early evolution of the crust, the development of weathering products and the early environments and conditions on Mars. Even though the exact provenance of the samples will not be known, data from subsequent orbital remote sensing missions will then be used to infer the provenance for the samples studied by Pathfinder.

The selection of the landing site took place over a three year period, prior to the announcement of the evidence for life in the meteorite Alan Hills 84001. In retrospect, the Ares Vallis landing site is well chosen to provide new information about Mars regarding this debate. The outflow channels drain a large area dominated by ancient heavily cratered terrain that is likely older than 3.5 Ga, which is the age of AH 84001 and the putative evidence for life. Landing at Ares Vallis and examining a variety of ancient rocks with the rover and its instruments, could yield information directly relevant to the nature of the ancient environment on Mars and whether liquid water was stable at that time. By roving for these rocks, Pathfinder could radically change our view of Mars and its evolution through time. More information is available about the Pathfinder mission on the World Wide Web (http: //mpfwww.jpl.nasa.gov/)"- [illegible]

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Mars Global Surveyor Home Page (http://[illegible].nasa.gov)

Color lugWc/1'late 1. Artists rendition of the Mars Pathfinder lander and rover exploring the surface of Mars (courtesy of Mike Carroll). The lander base is attached at each of its three sides to triangular panels (solar cells are shown in blue). Actuators (shown) at the attachment points allow the tetrahedral shaped lander to open up and right itself, regardless of which face the Lander comes to rest on. Airbags used to cushion the landing are shown beneath the panels in yellow. Gold covered enclosure on base panel houses central computer and batteries, Mounted on the top of the enclosure are the lollipop shaped high-gain antenna, cylindrical imager deployed on its open lattice mast, and three vertical rods, which are, in order of decreasing height, the low gain antenna, the UHF antenna for rover communications, and a radiometric calibration target for the. imager. The other mast is 1 m high for meteorology, with temperature sensors and wind sods (shown) at three heights and an electronic wind sensor at the top. Yellow and light blue ramps unfurl to allow rover to drive off the panel (note small square blue magnetic targets at the center of the end of the ramps, which allows the APXS to measure the elements making up the magnetic dust on Mars). Six-(spiked) wheel-drive rocker bogie rover shown in foreground, with flat top solar panel, UHF antenna sticking up and warm electronics box beneath. Bar on front of rover houses two monochrome cameras (providing stereo views in front of the rover) and **51** aser light stripers for autonomous hazard avoidance. Protruding from the back of the vehicle is the APX S instrument in its deployed configuration for roving, which can be placed up against rocks and soil in a wide variety of orientations for measuring the.ir elemental composition.