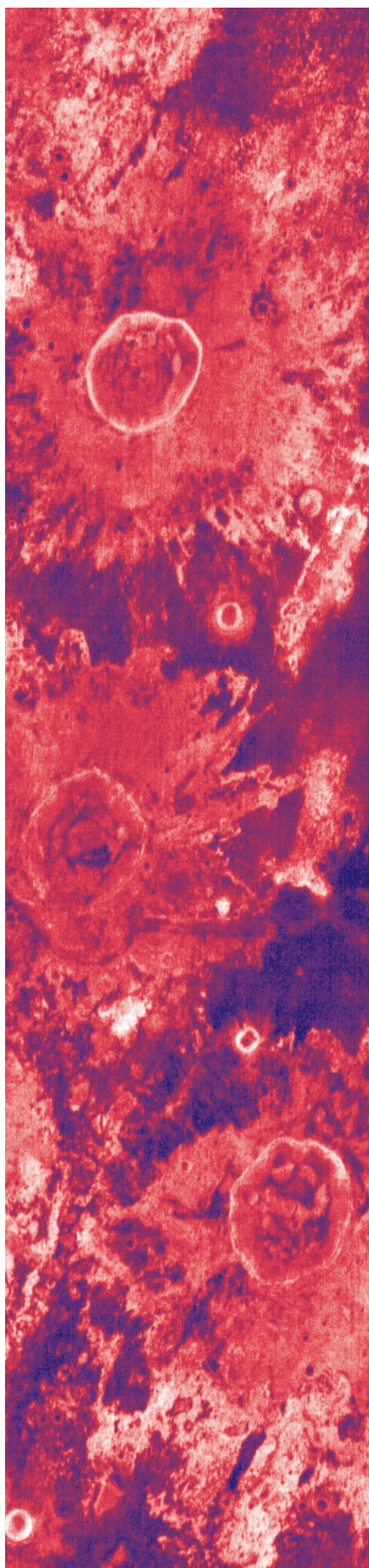
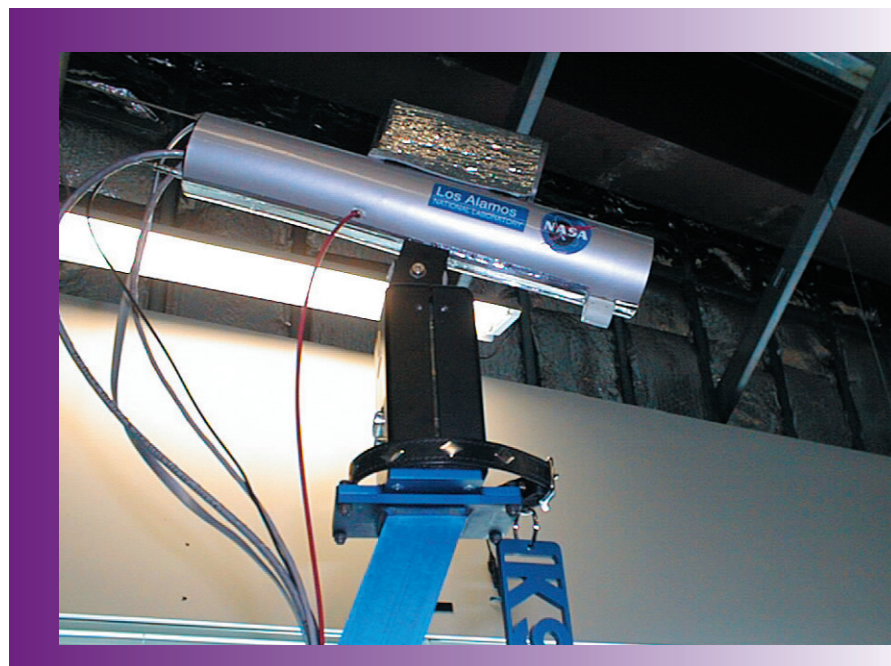


Uncovering the Secret of the Rocks with LIBS

After nearly three decades and three spacecraft landings on the surface of Mars, we still do not know what the rocks are made of . . .



NASA/JPL/ARIZONA STATE UNIVERSITY



LOS ALAMOS NATIONAL LABORATORY

The sensor head of the remote LIBS prototype instrument is shown mounted on NASA Ames Research Laboratory's "K9" rover testbed. The LIBS instrument was designed and built at Los Alamos National Laboratories under NASA contract.

Barry E. DiGregorio

Martian rocks have been analyzed using in situ x-ray fluorescence spectroscopy and alpha proton x-ray spectroscopy (APXS) on two previous space missions. However, analysis by these methods required many assumptions and inferences about their mineralogy, because it was later discovered that dust and possibly other thin weathering coatings were masking the rock data. A terrestrial example of this type of coating is rock varnish, a manganese and iron oxide coating that can be as much as half a millimeter thick and that can completely obscure the underlying rock, both visually and to remote sensing instruments. This has become one of the most annoying problems in planetary science today. It is frustrating to think that after 26 years of study, planetary scientists are still unsure whether the Martian rocks are sedimentary, igneous, or metamorphic in origin. The thickness of likely Martian rock weathering coatings is unknown, but it is assumed they are on a scale of 10–100 μm or more.

To solve the puzzle of the Martian rocks' composition, David A. Cremers and Roger C. Wiens of Los Alamos National Laboratory (Los Alamos, New Mexico) have been working with a number of colleagues to

adapt laser-induced breakdown spectroscopy (LIBS) for use on a future Mars mission. LIBS is an extremely versatile and portable method for determining the elemental composition of gases, liquids, and solids, and can be combined with other optical techniques such as Raman spec-

LIBS, demonstrated in laboratories since the 1990s, has not been used on another planet – until now.

troscopy and light detection and ranging (LIDAR) to provide a full analysis of elemental, mineralogical, atmospheric, and biological samples. No sample preparation such as scraping or abrasion is required and integration time is recorded in minutes instead of hours. Although the use of LIBS has been demonstrated in laboratories on Earth since the 1990s, its application has not been used on another planet — until now.

Cremers and Wiens began testing a prototype LIBS instrument in a Los Alamos laboratory using a simulated carbon-dioxide Martian atmosphere of 5–10 torr. They employed the use of a compact, 35-mJ Nd:YAG laser and demonstrated the ability of LIBS to “burn through” rock

varnish coatings as thick as 100 μm , and obtained high-quality spectral information from the rock substrate underneath. Outdoor field tests in the Black Rock Summit area of Nevada with a prototype LIBS instrument mounted on a Mars rover demonstrated that spectra from rocks as far as several meters away could be obtained quickly.

LIBS can use single or multiple laser pulses that are focused on a target rock and produce a plasma or spark. The excited plasma atoms then emit characteristic wavelengths in the near-ultraviolet and visible regions of the spectrum, which are then spectrally analyzed. Dust layers on rocks as thick as 1–3 mm can be completely removed by using 4–28 laser pulses.

A typical analysis of rocks on a planetary surface such as Mars's might include first examining the spectra produced from the rock coatings themselves, revealing elemental information about dust or perhaps rock varnish, and then, by firing additional laser pulses, burning through and removing the rock or dust coating to expose the bare rock surface. LIBS laser pulses would then be fired to analyze the spectra coming off the “cleaned” vaporized rock sample. An average of 10–20 laser pulses was used in the Los Alamos lab tests to clean coatings from rocks and obtain quality elemental spectra. Detection limits for all spectra were found to be in the 2–700-ppm range.

The field instrument used for the LIBS testing program (see photograph) has two

sections. The sensor head (shown mounted on the rover mast) weighs ~ 800 g and consists of a rangefinder and optical transmission/acquisition systems. The transmission system has a compact, flash-pumped Nd:YAG laser that produces pulses of 10 ns and ~ 85 mJ of energy at 1064 nm. It also has a filter and $7\times$ beam expander. A beam splitter is then used to carry a fraction of the sampled plasma light to a fiber-optic cable, which carries it to the spectrograph and detector located inside the rover vehicle body. The spectrograph has two 2400-line/mm gratings with blaze wavelengths of 250 and 500 nm coupled to an intensified CCD detector.

The advantages of using LIBS for planetary exploration are many. It can be used

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on either a rover vehicle mission to cover large areas, or on a stationary lander. On a stationary lander it would acquire the elemental analysis of near-field rocks as far away as ~20 m. For relatively small cosmic bodies such as asteroids, this range is

ideal because a rover could not explore them. LIBS has another advantage in Mars exploration scenarios — greater plasma intensities are achieved at Mars's atmospheric pressure, providing a greater signal-to-noise ratio. Combine this with the abil-

ity to analyze LIBS data in almost real-time, compared to the APXS on the *Mars Pathfinder*, which takes a number of hours (and still may not provide the correct information), and it is understandable why in situ planetary spectroscopy is moving

in the direction of efficient systems like LIBS. ■