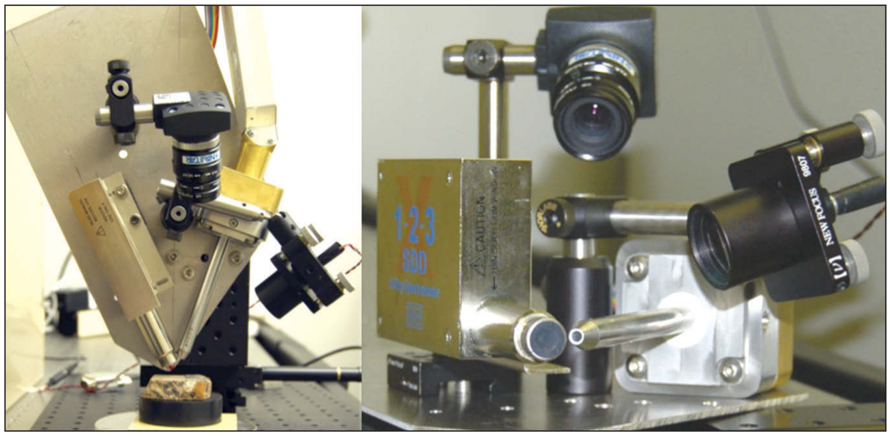
Physical Sciences

Micro-XRF for *In Situ* Geological Exploration of Other Planets

X-ray fluorescence instruments are used for non-destructive testing, sorting of recycled materials, and hazardous waste detection.

NASA's Jet Propulsion Laboratory, Pasadena, California

In situ analysis of rock chemistry is a fundamental tool for exploration of planets. To meet this need, a high-spatial-resolution micro x-ray fluorescence (Micro-XRF) instrument was developed that is capable of determining the elemental composition of rocks (elements Na–U) with 100 μm spatial resolution, thus providing insight to the composition of features as small as sand grains and individual laminae. The resulting excitation beam is of sufficient intensity that high signal-to-noise punctual spectra are acquired in seconds to a few minutes using an Amptek Silicon Drift Detector (SDD).



Two views of the breadboard **Micro-XRF Instrument**, which includes a Peltier-cooled detector with electronics, Moxtek HVPS, and x-ray tube integrated with an XOS polycapillary optic, a camera, and a focused laser.

The instrument features a tightly focused x-ray tube and HVPS developed by Moxtek that provides up to 200 μA at 10 to 50 keV, with a custom polycapillary optic developed by XOS Inc. and integrated into a breadboard Micro-XRF (see figure). The total mass of the complete breadboard instrument is 2.76 kg, including mounting hardware, mounting plate, camera, laser, etc. A flight version of this instrument would require less than 5W nominal power and 1.5 kg mass.

The instrument includes an Amptek SDD that draws 2.5 W and has a resolution of 135 to 155 eV FWHM at 5.9 keV. It weighs 180 g, including the preamplifier, digital pulse processor, multichannel analyzer, detector and preamp power supplies, and packaging. Rock samples are positioned relative to the instrument by a three-axis arm whose position is controlled by closed-loop translators (mimicking the robotic arm of a rover). The distance from the source to the detector is calculated from the position of a focused laser beam on the sample as imaged by the camera. The instrument enables quick scans of major elements in only 1 second, and rapid acquisition (30 s) of data with excellent signal-to-noise and energy resolution for trace element analysis.

This work was done by Lawrence A. Wade, Robert P. Hodyss, and Abigail C. Allwood of Caltech; Ning Gao of XOS; and Kris Kozaczek of Moxtek for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48599

Hydrogen-Enhanced Lunar Oxygen Extraction and Storage Using Only Solar Power

Oxygen-generating concept can be developed in an efficient system with low specific mass.

Marshall Space Flight Center, Alabama

The innovation consists of a thermodynamic system for extracting *in situ* oxygen vapor from lunar regolith using a solar photovoltaic power source in a reactor, a method for thermally insulating the reactor, a method for protecting the reactor internal components from oxidation by the extracted oxygen, a method for removing unwanted chemical species produced in the reactor from the oxygen vapor, a method for passively storing the oxygen, and a method for releasing high-purity oxygen from storage for lunar use.

Lunar oxygen exists in various types of minerals, mostly silicates. The energy required to extract the oxygen from the minerals is 30 to 60 MJ/kg O. Using simple heating, the extraction rate depends on temperature. The minimum temperature is approximately 2,500 K, which is at the upper end of available oven temperatures. The oxygen is released from storage in a purified state, as needed, especially if for human consumption.

This method extracts oxygen from regolith by treating the problem as a closed batch cycle system. The innovation works equally well in Earth or Lunar gravity fields, at low partial pressure of oxygen, and makes use of *in situ* regolith for system insulation.

The innovation extracts oxygen from lunar regolith using a method similar to vacuum pyrolysis, but with hydrogen cover gas added stoichiometrically to react with the oxygen as it is produced by radiatively heating regolith to 2,500 K. The hydrogen flows over and through the heating element (HE), protecting it from released oxygen. The H_2–O_2 heat of reaction is regeneratively recovered to assist the heating process. Lunar regolith is loaded into a large-diameter, low-height "pancake" reactor powered by photovoltaic cells. The reactor lid contains a 2,500 K HE that radiates downward onto the regolith to heat it and extract oxygen, and is shielded above by a multi-layer tungsten radiation shield. Hydrogen cover gas percolates through the perforated tungsten shielding and HE, preventing oxidation of the shielding and HE, and reacting with the oxygen to form water vapor. The water vapor is filtered through solid regolith to remove unwanted extraction byproducts, and then condensed to a liquid state and stored at 300 to 325 K. Conversion to usable oxygen is achieved by pumping liquid water into a high-pressure electrolyzer, storing the gaseous oxygen at high pressure for use, and diverting the hydrogen back to the reactor or to storage.

The results from this design effort show that this oxygen-generating concept can be developed in an efficient system with low specific mass. Advantages include use of regolith as an oxygen source, filter, and thermal insulator. The system can be tested in Earth gravity and can be expected to operate similarly in lunar gravity. The system is scalable, either by increasing the power level and output of a standard module, or by employing multiple modules.

This work was done by Rodney Burton and Darren King of CU Aerospace LLC for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32933-1.

Uplift of Ionospheric Oxygen Ions During Extreme Magnetic Storms

NASA's Jet Propulsion Laboratory, Pasadena, California

Research reported earlier in literature was conducted relating to estimation of the ionospheric electrical field, which may have occurred during the September 1859 Carrington geomagnetic storm event, with regard to modern-day consequences.

In this research, the NRL SAMI2 ionospheric code has been modified and applied the estimated electric field to the dayside ionosphere. The modeling was done at 15-minute time increments to track the general ionospheric changes. Although it has been known that magnetospheric electric fields get down into the ionosphere, it has been only in the last ten years that scientists have discovered that intense magnetic storm electric fields do also. On the dayside, these dawn-to-dusk directed electric fields lift the plasma (electrons and ions) up to higher altitudes and latitudes. As plasma is removed from lower altitudes, solar UV creates new plasma, so the total plasma in the ionosphere is increased several-fold. Thus, this complex process creates super-dense plasmas at high altitudes (from 700 to 1,000 km and higher).

This work was done by Bruce T. Tsurutani, Anthony J. Mannucci, and Olga P. Verkhoglyadova of Caltech; Joseph Huba of Naval Research Laboratory; and Gurbax S. Lakhina of the Indian Institute of Geomagnetism for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-48762

Miniaturized, High-Speed, Modulated X-Ray Source

An extremely robust photon-driven electron source is used that can tolerate weeks or more of exposure to air.

Goddard Space Flight Center, Greenbelt, Maryland

A low-cost, miniature x-ray source has been developed that can be modulated in intensity from completely off to full intensity on nanosecond timescales. This modulated x-ray source (MXS) has no filaments and is extremely rugged. The energy level of the MXS is adjustable from 0 to more than 100 keV. It can be used as the core of many new devices, providing the first practical, arbitrarily time-variable source of x-rays. The high-speed switching capability and miniature size make possible many new technologies including x-ray-based communication, compact time-resolved x-ray diffraction, novel x-ray fluorescence instruments, and low- and precise-dose medical x-rays.

To make x-rays, the usual method is to accelerate electrons into a target material held at a high potential. When the electrons stop in the target, x-rays are produced with a spectrum that is a function of the target material and the energy to which the electrons are accelerated. Most commonly, the electrons come from a hot filament. In the MXS, the electrons start off as optically driven photoelectrons. The modulation of the x-rays is then tied to the modulation of the light that drives the photoelectron source. Much of the recent development has consisted of creating a photoelectrically-driven electron source that is robust, low in cost, and offers high intensity.

For robustness, metal photocathodes were adopted, including aluminum and magnesium. Ultraviolet light from 255- to 350-nm LEDs (light emitting diodes) stimulated the photoemissions from these photocathodes with an efficiency that is maximized at the low-wavelength end (255 nm) to a value of roughly 10^{-4}. The MXS units now have much higher brightness, are much smaller,