TECHNOLOGY

Determining the composition of Earth's surface minerals from space, mining and caching Martian rock, detecting single photons from the depths of the cosmos, and expanding the Lab's world-leading store of space navigational knowledge: newly developed JPL technology vaulted from promising to proven in 2023.

***Left:** JPL sample handling lead observes the mechanisms designed to core, cache, and store future Mars rock samples*

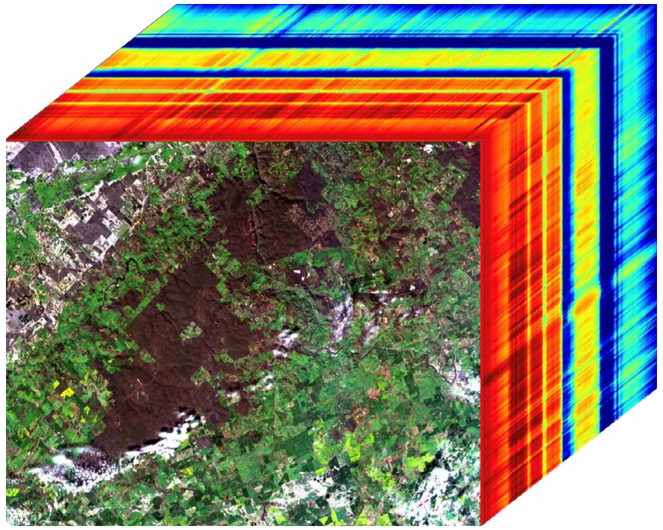
Minerals Detective Lifts Prints from Space

High above Earth, a sharp-eyed instrument takes the fingerprints of molecules in Earth's system with exquisite precision.

EMIT, the Earth Surface Mineral Dust Source mission, uses spectroscopy to determine the composition and location of minerals on the surface that can be blown as dust particles into Earth's atmosphere. The sources of mineral dust in arid land regions are poorly understood, but the effects of transported dust in the atmosphere are well-documented, influencing radiation, clouds, terrestrial/aquatic ecosystems, snow, and human health.

EMIT is enabled by new optical technologies from JPL's Microdevices Laboratory. The core of EMIT's unmatched capability is the shaped-groove diffraction grating, written with electron beam lithography, that creates the spectrum (rainbow) in the heart of the spectrometer. These grooves are precisely shaped to produce tailored diffraction efficiency that keeps the instrument's performance optimal over a broad spectral range, despite solar irradiance, Earth reflectance, and detector quantum variations. EMIT's grating is MDL's largest to date at 92 mm (nearly four inches) and achieves the highest performance, with a straylight control of 1 part in 10,000.

Below: EMIT's first measurements as it passed over Western Australia

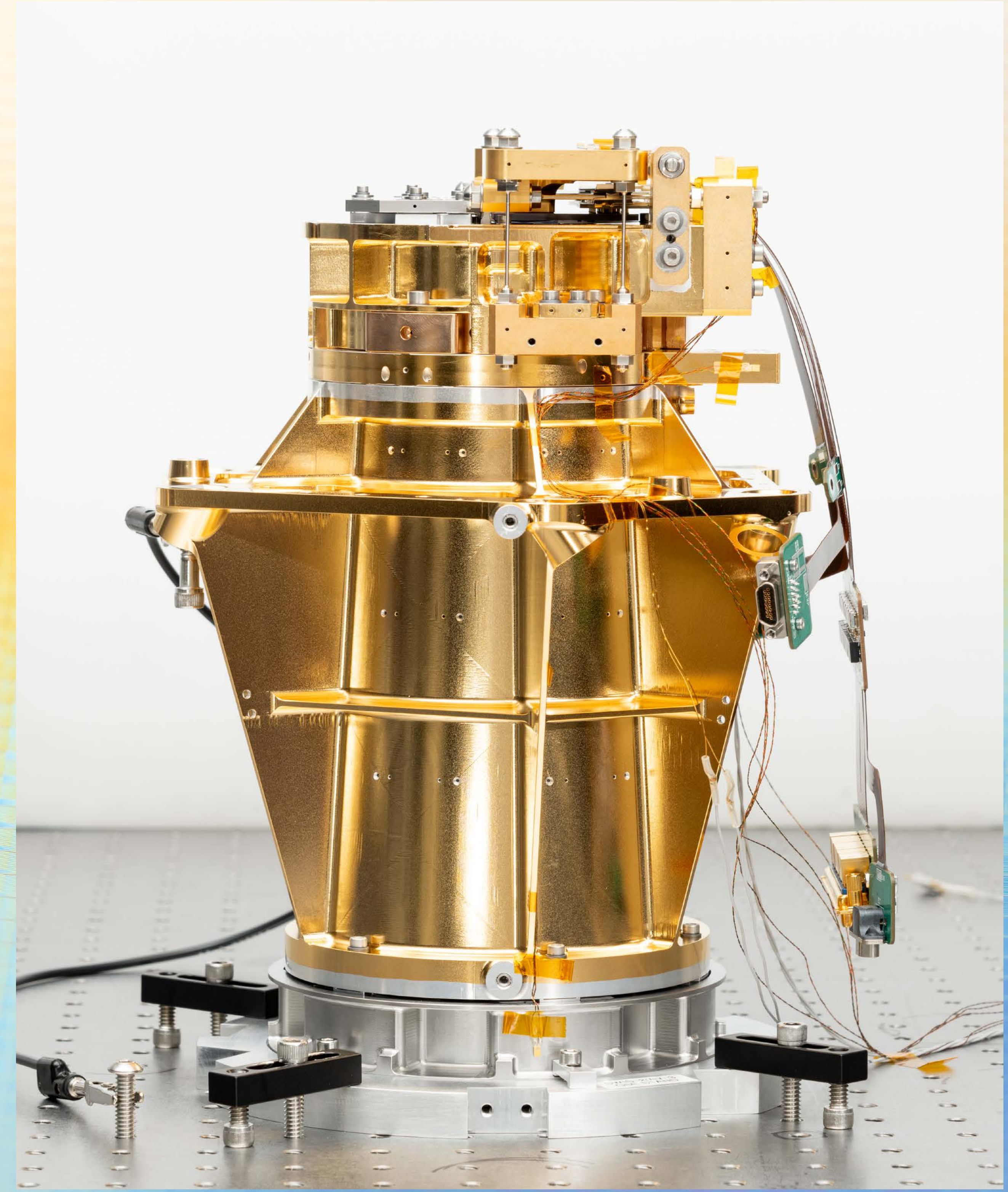


MDL also developed two supporting technologies: a micromachined black silicon slit and a zero-order light trap.

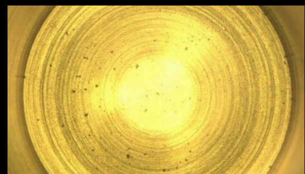
The ideal slit lets light pass in a specified wavelength range without unwanted reflection and misdirection of photons around the slit's edges. The MDL team used a custom process based on electron beam patterning and plasma etching to transform the reflective surface around the slit into a forest of silicon needles that absorbs nearly all light. With this technology, only the photons intended to reach the detector make it to their target.

The same process was used to fabricate a zero-order light trap to absorb un-diffracted light from the grating and prevent it from bouncing around inside the spectrometer.

For over three decades, JPL has been perfecting electron-beam lithography techniques for fabricating optical components used in instruments across the solar system. The result, as shown in the Earth Science section of this annual report, is the most advanced and precise imaging spectrometer in Earth's orbit.



Above: EMIT's imaging spectrometer contains the grating, slit, and light trap enabled by JPL-invented technology.



Roubion
Aug. 6, 2021

Montdenier
Sept. 6, 2021

Montagnac
Sept. 8, 2021

Salette
Nov. 15, 2021

Coulettes
Nov. 24, 2021

Robine
Dec. 22, 2021

Malay
Jan. 31, 2022

Ha'ahóni
March 7, 2022

Atsá
March 13, 2022

Swift Run
July 7, 2022

Skyland
July 12, 2022

Hazeltop
July 27, 2022

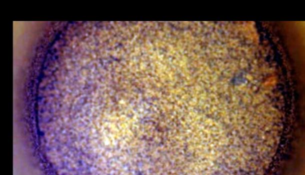
Bearwallow
Aug. 3, 2022

Shuyak
Oct. 2, 2022

Mageik
Nov. 16, 2022

Kukaklek
Nov. 29, 2022

Atmo Mountain
Dec. 2, 2022



Crosswind Lake
Dec. 7, 2022

Melyn
March 30, 2023

Otis Peak
June 23, 2023

Pilot Mountain
Sept. 15, 2023

Pelican Point
Sept. 25, 2023

Lefroy Bay
Oct. 21, 2023

Samples collected by the Perseverance rover through the end of 2023. These samples record the history of the Jezero Crater landing site and may preserve signs of ancient life.

The Intricate Sequence before Sample Return

Above: *A tray holding 39 of the 43 sample tubes was installed into the Perseverance rover before its journey to Mars in May 2020.*

Any samples from Mars returned to Earth in the coming years will owe their existence to JPL developments for drilling, retrieving, and storing Martian rock free of direct human assistance.

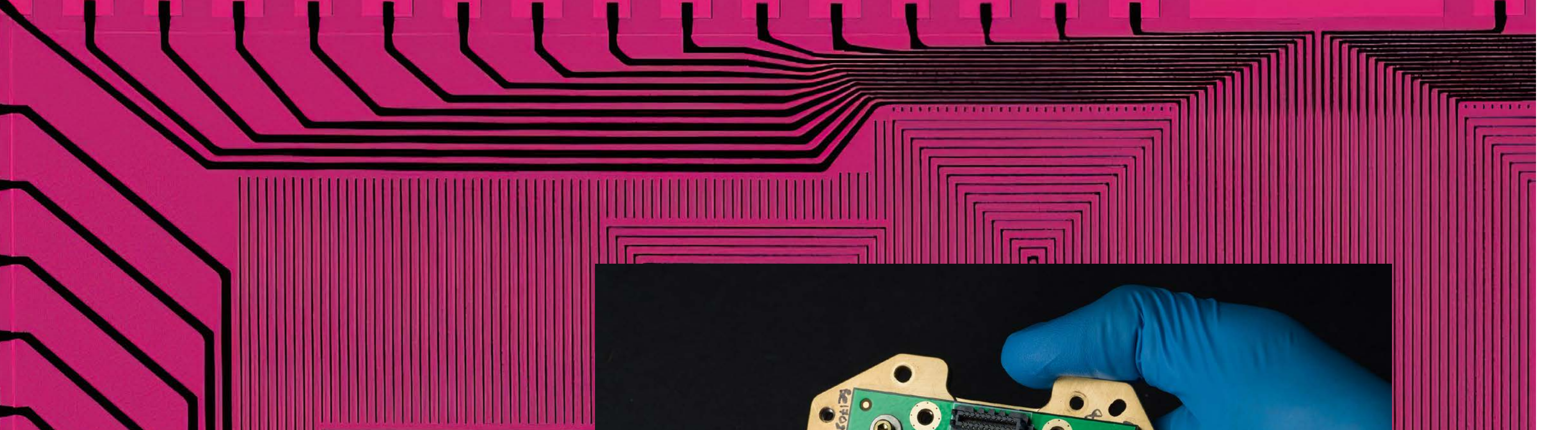
The Mars 2020 Sample Caching System allows the Perseverance rover to acquire grainy regolith and solid rock cores for eventual scientific analysis on Earth. A percussive drill is mounted on the end of the rover's long robotic arm, and at the tip of the drill, the teeth of the bit encircle the opening to a sample tube. As the drill sinks into the rock, the core and loosened material collect in the tube.

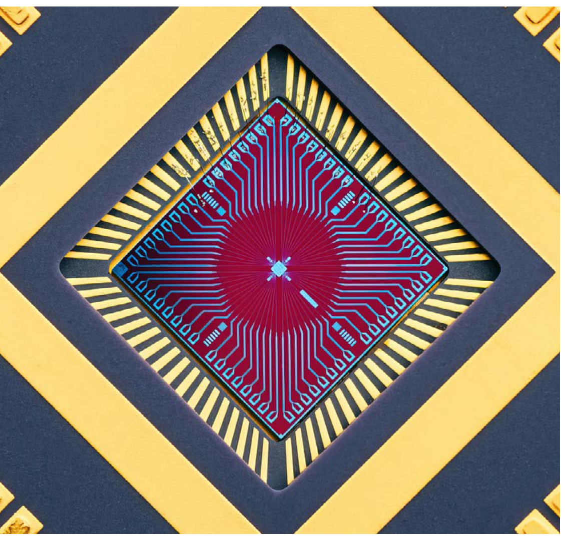
The arm then retracts, docks with the rover, and transfers the tube and surrounding drill bit to an Adaptive Caching Assembly for processing. A small arm within the ACA removes the filled tube from the drill bit and moves the tube through a series of steps to image the sample, measure its length, hermetically seal the tube, and cache the sealed tube either onboard the rover or on the surface of Mars.

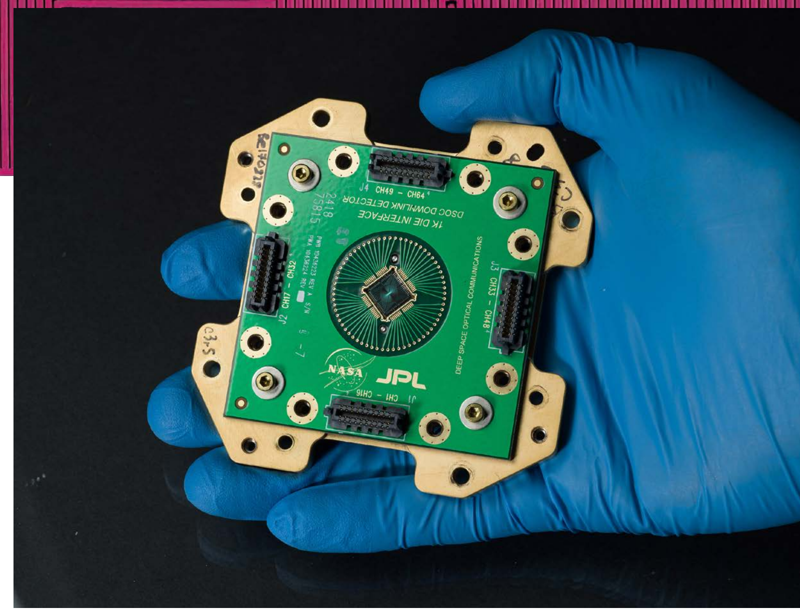
The system comes with six core drill bits, a regolith bit, and two abrading bits for removing weathered outer layers of rock and enabling on-site experiments by the rover's other instruments.

New technologies developed for the system include sample acquisition directly into a tube, tube/bit drop-off, tube sealing and on-board tube storage, along with control algorithms.

Few industrial systems on Earth could carry out this kind of complex sequence with no manual intervention and no maintenance. By the end of 2023, the sampling system did so 23 times, depositing scientific treasures on the surface of Mars and aboard Perseverance.







When Discovery Turns on a Point of Light

Top: *Scanning electron microscope image of Superconducting Nanowire Single Photon Detectors array wires*

Left*: A 64-pixel array of SNSPDs can count over 1 billion photons per second. The array is mounted in a chip carrier and can be efficiently coupled to a 5-meter telescope.*

Right: *DSOC's SNSPD is coupled to Caltech's 200-inch Hale Telescope. It is designed to receive near-infrared laser signals from the DSOC flight transceiver traveling with NASA's Psyche mission.*

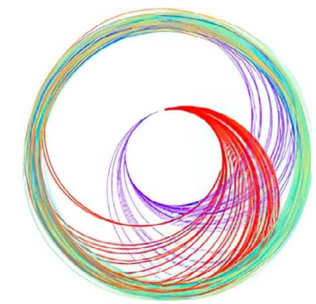
In a *Nature* paper published in 2023, JPL and the National Institute of Standards and Technology announced the development of a single-photon detector 20 times larger than its predecessors and potentially capable of detecting light from planets outside our solar system.

The thermally-coupled imager is an example of a superconducting nanowire single-photon detector. SNSPDs are the highest-performing light sensors available, with efficiency as high as 98 percent in the near-infrared, stray pixel activation (dark count) probabilities under 1 in 100,000, and sensitivity across the spectrum from the ultraviolet to the mid-infrared. The detectors are currently deployed at the Palomar Observatory to receive laser signals from NASA's Deep Space Optical Communication technology demonstration on the Psyche spacecraft.

Further development of the technology is focused on demonstrating SNSPD arrays with broadband efficiency from the far-UV to the near-infrared, as well as raising the technology readiness level of detectors through radiation, vibration, and lifetime testing.

The detectors could figure in planned future missions, such as the Habitable Worlds Observatory, and also serve a critical role in quantum communication and computing, as well as in biomedical imaging.

JPL Cuts to the Chase in Navigation Contest



Above: *The graphic trajectory plots of the winning solution to the GTOC 2023 "nearly impossible" problem of interplanetary trajectory*

It's not enough to forge a new path. In the forbidding void of space, it has to be the best possible path.

A JPL team in 2023 won the latest edition of the Global Trajectory Optimization Competition. Created by the European Space Agency's Advanced Concepts Team, GTOC is so demanding that only 28 of 100 registered teams submitted solutions in the latest round. Of the 12 competitions held to date, JPL has won five of seven entered and hosted four others.

The 2023 challenge was to maximize the mass of asteroid material brought to Earth over a 15-year time span by a fleet of cooperating spacecraft. Teams had 60,000 asteroid candidates from which to choose. Using electric propulsion, spacecraft had to rendezvous with each chosen asteroid twice: first to drop off a mining craft, then to retrieve the collected mass. Final solutions were due within one month after the problem statement's release. The JPL solution, involving 35 spacecraft, collected nearly 60,000 pounds of asteroid material, well ahead of the nearest competitor.

Participating in GTOC over the years has prompted innovation in the development and use of JPL trajectory design tools and algorithms. In 2023, the JPL team developed a mixed integer linear programming tool to optimize the asteroid groupings and encounter sequences. This capability, along with well-honed search and preliminary trajectory design capabilities and some experienced insight, allowed JPL to pull ahead of the competition.

More importantly, these capabilities are used to explore complex trade spaces for new mission concepts, enabling JPL to maximize science while minimizing cost and risk.