

The extension of the method to videogrammetry is straightforward: The laser and cameras can be operated in a sequence of pulses to acquire a sequence of projected-dot images. The im-

ages, or the sets of location and shape data extracted from the images, can be used to synthesize a motion picture showing how the target surface moves and/or deflects over time.

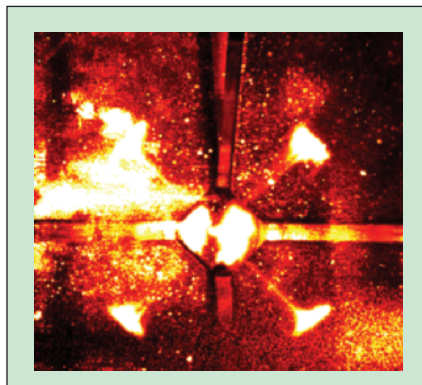
*This work was done by Paul Danehy, Tom Jones, John Connell, Keith Belvin, and Kent Watson of Langley Research Center. Further information is contained in a TSP (see page 1). LAR-16426*

## Laboratory Apparatus Generates Dual-Species Cold Atomic Beam

**A pyramidal magneto-optical trap extracts atoms from one chamber into another.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A laser cooling apparatus that generates a cold beam of rubidium and cesium atoms at low pressure has been constructed as one of several intermediate products of a continuing program of research on laser cooling and atomic physics. Laser-cooled atomic beams, which can have temperatures as low as a microkelvin, have been used in diverse applications that include measurements of fundamental constants, atomic clocks that realize the international standard unit of time, atom-wave interferometers, and experiments on Bose-Einstein condensation. The present apparatus is a prototype of one being evaluated for use in a proposed microgravitational experiment called the Quantum Interferometric Test of Equivalence (QuITE). In this experiment, interferometric measurements of cesium and rubidium atoms in free fall would be part of a test of Einstein's equivalence principle. The present apparatus and its anticipated successors may also be useful in other experiments, in both microgravity and normal Earth gravity, in which there are requirements



This is a False-Color Image of fluorescence from cesium atoms in the pyramidal magneto-optical trap. The cold atomic beam in the extraction column is visible in the side views afforded by the 45° mirrors.

for dual-species atomic beams, low temperatures, and low pressures.

The apparatus includes a pyramidal magneto-optical trap in which the illumination is provided by multiple lasers tuned to frequencies characteristic of the two atomic species. The inlet to the apparatus is located in a vacuum chamber that con-

tains rubidium and cesium atoms at a low pressure; the beam leaving through the outlet of the apparatus is used to transfer the atoms to a higher-vacuum (lower-pressure) chamber in which measurements are performed.

The pyramidal magneto-optical trap is designed so that the laser cooling forces in one direction are unbalanced, resulting in a continuous cold beam of atoms that leak out of the trap (see figure). The radiant intensity (number of atoms per unit time per unit solid angle) of the apparatus is the greatest of any other source of the same type reported to date. In addition, this is the first such apparatus capable of producing a slow, collimated beam that contains two atomic species at the same time.

*This work was done by Robert Thompson, William Klipstein, James Kohel, Lute Maleki, Nathan Lundblad, Jaime Ramirez-Serrano, Dave Aveline, Nan Yu, and Daphna Enzer of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-30396*

## Laser Ablation of Materials for Propulsion of Spacecraft

*Marshall Space Flight Center, Alabama*

A report describes experiments performed as part of a continuing investigation of the feasibility of laser ablation of materials as a means of propulsion for small spacecraft. In each experiment, a specimen of ablative material was mounted on a torsion pendulum and irradiated with a laser pulse having an energy of 5 J. The amplitude of the resulting rotation of the torsion pendulum was taken to be an indication of the momentum transferred from the laser beam. Of the ablative materials tested, aluminum foils yielded the smallest rotation amplitudes — of the order of 10°. Black coating materials yielded rotation

amplitudes of the order of 90°. Samples of silver coated with a fluorinated ethylene propylene (FEP) copolymer yielded the largest rotation amplitudes — 6 to 8 full revolutions. The report presents a theory involving heating of a confined plasma followed by escape of the plasma to explain the superior momentum-transfer performance of the FEP specimens. It briefly discusses some concepts for optimizing designs of spacecraft engines to maximize the thrust obtainable by exploiting the physical mechanisms of the theory. Also discussed is the use of laser-ablation engines with other types of spacecraft engines.

*This work was done by David L. Edwards, Ralph Carruth, and Jonathan Campbell of Marshall Space Flight Center and Perry Gray of Native American Services.*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to*

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