tion with thermal cycling, can contribute to damage that degrades insulating performance. Materials are changed internally when subjected to large sub-ambient temperature gradients.

The CMA (see figure) includes a cold mass in the form of an insulated vessel filled with liquid nitrogen or other suitable liquid at a desired below-ambient temperature. The 200-mm diameter specimen is placed over an opening on the top of an environmental chamber, wherein a temperature of 293 K and relative humidity of 90 percent are maintained in still air at ambient atmospheric pressure. The cold mass is placed atop the specimen, and a 152-mm-diameter cold surface at the bottom of the cold mass makes contact with the top surface of the specimen. The bottom surface of the specimen is exposed to the atmosphere inside the environmental chamber. Temperatures at the top and bottom surfaces of the specimen are measured by thermocouples and are monitored and recorded. The cold mass includes features that guard the outer edge surface of the specimen against substantial heat leakage and against intrusion of moisture so that the uptake of water or ice occurs only or primarily in the vertical, through-the-thickness direction. A typical test run lasts 8 hours from the beginning of cooldown, but test time can be changed as needed to achieve steady-state uptake of moisture.

This work was done by James Fesmire, Trent Smith, Robert Breakfield, and Kevin Boughner of Kennedy Space Center and Kenneth Heckle and Barry Meneghelli of Sierra Lobo, Inc. Further information is contained in a TSP (see page 1). *KSC-13049*

A Transportable Gravity Gradiometer Based on Atom Interferometry

Gravity field mapping technology enables more detailed study of dynamic Earth processes like climate change.

NASA's Jet Propulsion Laboratory, Pasadena, California

A transportable atom interferometer-based gravity gradiometer has been developed at JPL to carry out measurements of Earth's gravity field at ever finer spatial resolutions, and to facilitate high-resolution monitoring of temporal variations in the gravity field from ground- and flight-based platforms. Existing satellite-based gravity missions such as CHAMP and GRACE measure the gravity field via precise monitoring of the motion of the satellites; i.e. the satellites themselves function as test masses. JPL's quantum gravity gradiometer employs a quantum phase measurement technique, similar to that employed in atomic clocks, made possible by recent advances in laser cooling and manipulation of atoms. This measurement technique is based on atom-wave interferometry, and individual laser-cooled atoms are used as drag-free test masses.

The quantum gravity gradiometer employs two identical atom interferometers as precision accelerometers to measure the difference in gravitational acceleration between two points (Figure 1). By using the same lasers for the manipulation of atoms in both interferometers, the accelerometers have a common reference frame and non-inertial accelerations are effectively rejected as common-mode noise in the differential measurement of the gravity gradient. As a result, the dual atom interferometer-based gravity gradiometer allows gravity measurements on a moving platform,

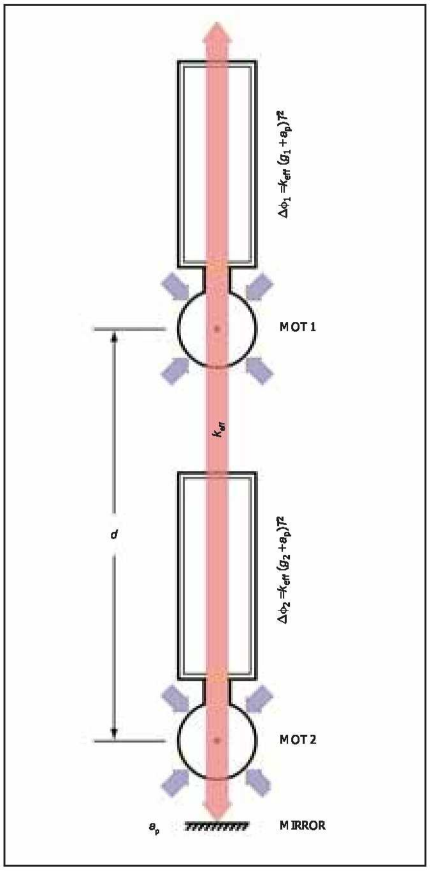


Figure 1. As shown in the schematic of the **Atom Interferometer-Based Gravity Gradiometer**, the dual atom interferometers measure the gravity gradient over the measurement baseline d. The platform accelerations a_p are effectively cancelled in the differential measurement. (T is the time between pulses, k_{eff} is the effective Raman laser wave number, and g is gravitational acceleration.)

Figure 2. The photograph shows the **Quantum Gravity Gradiometer** in the laboratory. The magnetic shields around the lower atom interferometer have been removed for clarity.

while achieving the same long-term stability of the best atomic clocks.

In the laboratory-based prototype (Figure 2), the cesium atoms used in each atom interferometer are initially collected and cooled in two separate magneto-optic traps (MOTs). Each MOT, consisting of three orthogonal pairs of counter-propagating laser beams centered on a quadrupole magnetic field, collects up to 10^9 atoms. These atoms are then launched vertically as in an "atom fountain" by switching off the magnetic field and introducing a slight frequency shift between pairs of lasers to create a moving rest frame for the trapped atoms. While still in this moving-frame molasses, the laser frequencies are further detuned from the atomic resonance (while maintaining this relative frequency shift) to cool the atom cloud's temperature to 2 μK or below, corresponding to an rms velocity of less than 2 cm/s. After launch, the cold atoms undergo further state and velocity selection to prepare for atom interferometry. The atom interferometers are then realized using laser-induced stimulated Raman transitions to perform the necessary manipulations of each atom, and the resulting interferometer phase is measured using laser-induced fluorescence for state-normalized detection. More than 20 laser beams with independent controls of frequency, phase, and intensity are required for this measurement sequence.

This instrument can facilitate the study of Earth's gravitational field from surface and air vehicles, as well as from space by allowing gravity mapping from a low-cost, single spacecraft mission. In addition, the operation of atom interferometer-based instruments in space offers greater sensitivity than is possible in terrestrial instruments due to the much longer interrogation times available in the microgravity environment. A space-based quantum gravity gradiometer has the potential to achieve sensitivities similar to the GRACE mission at long spatial wavelengths, and will also have resolution similar to GOCE for measurement at shorter length scales.

This work was done by Nan Yu, Robert J. Thompson, James R. Kellogg, David C. Aveline, Lute Maleki, and James M. Kohel of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-46280

Three Methods of Detection of Hydrazines

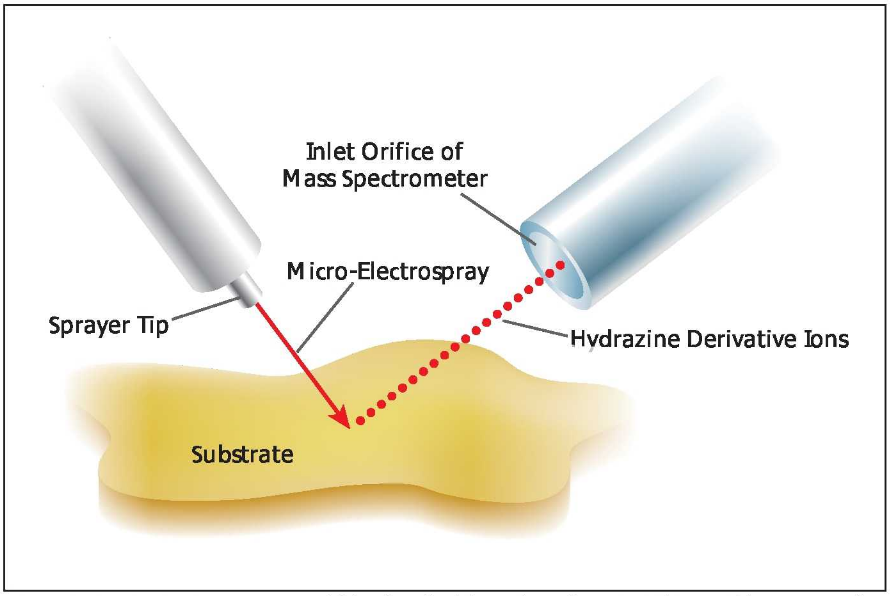
Concentrations could be measured more accurately than in prior methods.

John F. Kennedy Space Center, Florida

Three proposed methods for measuring trace quantities of hydrazines involve ionization and detection of hydrazine derivatives. These methods are intended to overcome the limitations of prior hydrazine-detection methods.

Hydrazine (Hz), monomethylhydrazine (MMH), and unsymmetrical dimethylhydrazine (UDMH) are hypergolic fuels and are highly reactive, toxic, and corrosive. A capability to measure concentrations of hydrazines is desirable for detecting leaks and ensuring safety in aerospace settings and in some industrial settings in which these compounds are used. One of the properties (high reactivity) that make it desirable to detect trace amounts of hydrazines also makes it difficult to detect hydrazines and measure their concentrations accurately using prior methods: significant amounts are lost to thermal and catalytic decomposition prior to detection. Further complications arise from the "sticky" nature of hydrazines: Sample hydrazine molecules tend to become irreversibly adsorbed onto solid surfaces with which they come into contact during transport to detectors, giving rise to drift in detector responses.

In each proposed method, the reactive, sticky nature of hydrazines would be turned to advantage by providing a suitably doped substrate surface with which the hydrazines would react. The resulting hydrazine derivatives would be sufficiently less sticky and sufficiently more stable so that fewer molecules would be lost to decomposition or adsorption during transport. Consequently, it would be possible to measure concentration with more sensitivity and less error than in prior techniques.



Hydrazine Derivative Molecules would be desorbed from the substrate and ionized by a micro-electrospray. The resulting hydrazine derivative ions would be detected by a mass spectrometer.

The first proposed method calls for the use of a recently developed technique known as desorption electrospray ionization (DESI), in which a pneumatically assisted micro-electrospray at ambient pressure is directed at a surface of interest. In this case, the surface of interest would be that of a substrate described above. The impingement of the electrically charged micro-droplets in the spray upon the substrate would dislodge and ionize the hydrazine derivative molecules, giving rise to stable ejected hydrazine derivative