

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  $\mu$ K 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

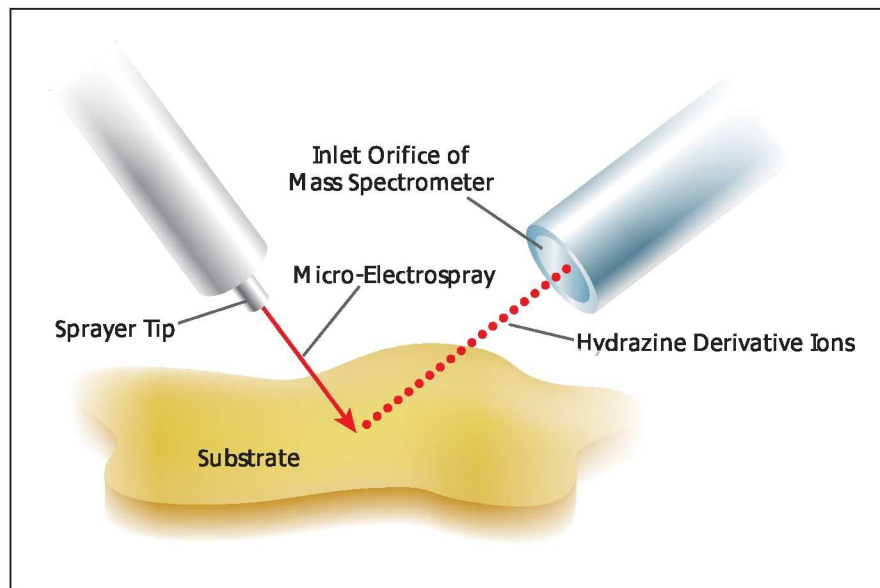
Concentrations could be measured more accurately than in prior methods.

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



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.

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.

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

ions, which would then be detected and quantitated by use of a mass spectrometer, ion-mobility spectrometer, or other suitable instrument (see figure).

The second proposed method calls for the use of another recently developed technique known as desorption atmospheric-pressure chemical ionization (DAPCI), in which an atmospheric-pressure corona discharge in the vapor of toluene or another suitable compound is used to generate projectile ions. In this case, the ions would be made to impinge on the substrate, with consequent ejection and

ionization of stable hydrazine derivative ions as described above. Again, as described above, the hydrazine derivative ions would be detected and quantitated by use of a mass spectrometer, ion-mobility spectrometer, or other suitable instrument.

In the third proposed method, one would use yet another recently developed desorption-and-ionization technique known as direct analysis in real time (DART). In this technique, a plasma containing excited-state atoms and ions is formed in a gas (e.g., helium or nitrogen) that has a high ionization

potential. The excited-state atoms and ions impinge on the surface of a solid sample, causing desorption of low-molecular weight molecules from the sample. In the proposed method, the sample would be the substrate, from which the hydrazine derivative molecules would be desorbed. The desorbed hydrazine derivative molecules would then be ionized and detected as described above.

*This work was done by Timothy Griffin of Kennedy Space Center and Cristina Berger of ASRC Aerospace Corp. Further information is contained in a TSP (see page 1), KSC-13121/2/3*

## Crossed, Small-Deflection Energy Analyzer for Wind/ Temperature Spectrometer

**This analyzer has application in improving the predictability of GPS operations.**

*Goddard Space Flight Center, Greenbelt, Maryland*

Determination of neutral winds and ion drifts in low-Earth-orbit missions requires measurements of the angular and energy distributions of the flux of neutrals and ions entering the satellite from the ram direction. The magnitude and direction of the neutral-wind (or ion-drift) determine the location of the maximum in the angular distribution of the flux. Knowledge of the angle of maximum flux with respect to satellite coordinates (pointing) is essential to determine the wind (or ion-drift) vector.

The crossed Small-Deflection Energy Analyzer (SDEA) spectrometer (see Figure 1) occupies minimal volume and consumes minimal power. Designed for upper atmosphere/ionosphere investigations at Earth altitudes above 100 km, the spectrometer operates by detecting the angular and energy distributions of neutral atoms/molecules and ions in two mutually perpendicular planes. In this configuration, the two detection planes actually cross at the spectrometer center. It is possible to merge two SDEAs so they share a common optical axis and alternate measurements between two perpendicular planes, and reduce the number of ion sources from two to one. This minimizes the volume and footprint significantly and reduces the ion source power by a factor of two. The area of the entrance aperture affects the number of ions detected/second and also determines the energy resolution.

Thermionic emitters require heater power of about 100 mW to produce 1

mA of electron beam current. Typically, electron energy is about 100 eV and requires a 100-V supply for electron acceleration to supply an additional 100 mW of power. Thus, ion source power is at most 200 mW. If two ion sources were to be used, the ion source power would be, at most, 400 mW. Detector power, deflection voltage power, and microcontroller and other functions require less than 150 mW. A WTS (wind/temperature spectrometer) with two separate optical axes would consume about 650 mW, while the crossed SDEA described here consumes about 350 mW.

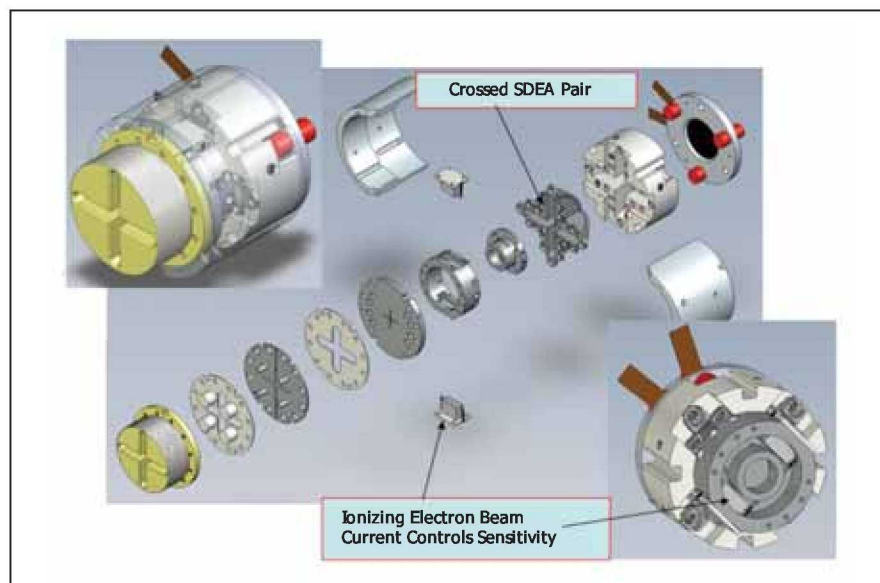


Figure 1. Drawing of the Crossed SDEA WTS assembled and in separate parts.

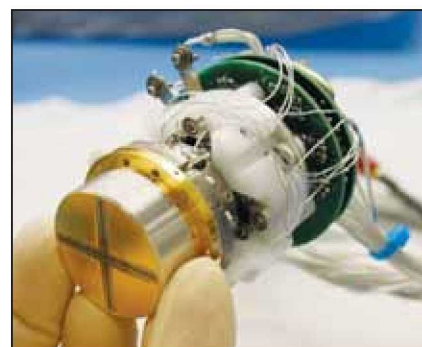


Figure 2. Photo of the Actual Crossed SDEA WTS when it was delivered for integration in NRL's ANDE Satellite.