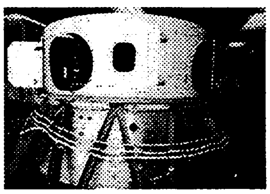
SURFSAT-1

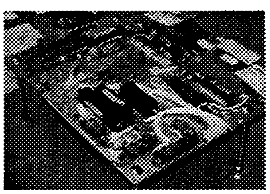
Steve Johnson

SURFSAT-1 is a small, low-Earth-orbiting satellite being developed by the DSN Technology Program. The primary goal of SURFSAT-1 is to provide a better understanding of the performance of Ka-band signals relative to X-band signals. The experiment will provide an end-to-end test of Ka-band signals under all weather conditions and ground antenna elevation angles. The experiment will be performed by examining low-power Ka-band and X-band signals transmitted by SURFSAT-1 as it passes over DSS 13 at Goldstone. The data gathered by this experiment will be combined with data from similar experiments (e.g., KaAP and KaBLE) to gain a better understanding of the performance advantages of Ka-band for future missions.



Two SURFSAT boxes mounted to a mock-up Delta II second stage.

SURFSAT-1 will also provide support to NASA's Orbiting Very Long Baseline Interferometry (OVLBI) project. SURFSAT-1 will be used to test a new set of 11-m DSN ground stations being built to provide X- and Ku-band support to two international OVLBI spacecraft — Russia's RADIOASTRON and Japan's VSOP. A key aspect of that support is to validate the transfer of a stable frequency reference from the ground stations to the OVLBI spacecraft.



SURFSAT X-/Ka-band transponder

Originally conceived in 1986, SURFSAT-1 is a very simple, inexpensive experiment package carried as a secondary payload aboard a Delta II rocket. SURFSAT-1 consists of a pair of boxes that are permanently bolted to the second stage of the Delta II launch vehicle, which remains in orbit after launch. After the primary payload, the Canadian RADARSAT satellite, has safely separated from the Delta II, SURFSAT-1 will be placed into a 990- by 1410-km Sun-synchronous orbit. Launch is currently scheduled for September 20, 1995.

Co-op student assembling structure

Within the two boxes are a pair of transponders used to generate the desired milliwatt level Ka-band, X-band, and Ku-band signals (X- and Ka-band for the X/Ka link experiment, X- and Ku-band for the OVLBI ground station experiment). The boxes also carry electronics that receive commands from the ground to switch operational states and electronics that provide regulated power. Power for the satellite is provided by solar panels mounted on the outside of each box. Crossed slot omnidirectional antennas located on the front corners of each box provide overlapping hemispherical coverage for all three frequencies.

In addition to the scientific goals of the mission, SURFSAT-1 has another major programmatic goal — to provide hands-on experience in spacecraft design and fabrication to college undergraduate students. Students from Caltech's Summer Undergraduate Research Fellowship (SURF), a 10-week summer program, initially began work on the satellite design in the summer of 1987. Since then, more than 45 students have worked on SURFSAT-1 under a variety of student programs (SURF, JPL Co-op, USRA Fellowship, Caltech senior projects, and others). While most of these students came from Caltech, participants have also included students from Stanford, Berkeley, Arizona State, Occidental, UCLA, UC-San Diego, Cal Poly-Pomona, Oklahoma State University, University of Texas, New Mexico State University, and Cornell.

SURFSAT-1 is currently undergoing integration and test. Following systems-level functional testing, the satellite will undergo environmental testing at the Phillips Laboratory at Edwards AFB. This testing will then be followed by an end-to-end test with DSS 13 at Goldstone, after which the satellites will be stored until they are shipped to Vandenberg AFB for launch.

Mission operations planning is currently underway, led by Greg Kazz of Mission and Systems Architecture, Section 311. The two main areas currently under investigation are initial acquisition and commanding of the satellite and long-term tracking and orbit determination. After preliminary planning is complete, opportunities for undergraduate students will be identified, and students will be involved in many phases of mission operations.

Atomic Clocks and Variations of the Fine Structure Constant

John Prestage

The electromagnetic force that holds atoms together is characterized by the dimensionless fine structure constant $\alpha = e^2/hc$. Biology, chemistry, solid state physics, etc., are influenced in a very basic way by the fine structure constant.

The size of α, roughly 1/137, describes the strength of the electromagnetic force relative to the nuclear strong force that binds neutrons and protons together in atomic nuclei. It involves the elementary unit of electric charge, e, the speed of light, c, and Planck's constant, h, and thus blends electromagnetism, relativity, and quantum mechanics. It is *the* primary expansion parameter used in quantum electrodynamics (QED) to accurately model certain measurable properties of the electron to the parts-per-billion level.

The value for α, however, is not predicted in QED but should be the outcome of a successful unified theory of all four interactions. Such grand unified theories are being developed and, surprisingly, many have cosmological solutions where α and other "constants" actually change over time.

Variation of nongravitational constants is forbidden for the theory of general relativity and other metric theories of gravity, where gravitational fields are described as a geometrical property of space-time. The equivalence principle forms the basis for all metric theories of gravity, and requires local position invariance: in local freely falling frames, the outcome of any local nongravitational test experiment is independent of where and when in the universe it is performed.

A changing fine structure constant, α, as predicted in some cosmological string theories, would violate the equivalence principle, signaling the breakdown of gravitation as a geometrical phenomena and, as we have recently discovered, would lead to a drift in the relative frequencies of H-masers, Rb, Cs, Hg^+, etc. clocks. To date, no violations of the equivalence principle have been found, but NASA is involved in a sensitive space-based test of the equivalence principle with the Space Technology Experiments Program (STEP) mission.

These findings show that clock comparisons between the next generation of ultrastable laser cooled clocks now under development may reach the sensitivity to reveal equivalence principle violations in Earth-based measurements. Thus, low-budget, table-top, clock-comparison experiments may go far beyond accelerator-based experiments in exploring grand unified theories and the overlap of gravitational and quantum physics.

The experimental search for a temporal variation of α is divided into what might be called cosmological and modern measurements. Cosmological tests are indirect measurements of $\dot{\alpha} / \alpha$ based on isotope ratios observed in current materials. For example, a stringent limit on α variation follows from an analysis of isotope ratios $^{149}Sm/^{147}Sm$ in the natural uranium fission reaction that took place some 2×10^9 years ago at the present-day site of the Oklo mine in Gabon, West Africa. This ratio is 0.02 rather than 0.9 as in natural samarium from the neutron flux onto ^{149}Sm during the uranium fission.

Thus, it appears that the neutron capture cross section in ^{149}Sm has not changed significantly in 2×10^9 years from its present day value. Modeling of this process yields a limit $\dot{\alpha} / \alpha \leq 10^{-15}$/yr for the integrated change in α over the cosmological time period of 2×10^9 yrs.

Modern searches for $\dot{\alpha} / \alpha$ involve much more direct laboratory tests based on

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comparisons of the rates between clocks of different physical composition. The classic test compares a cavity oscillator with an atomic clock transition. All continuously operated atomic frequency standards (H, Rb, Cs, and Hg^+) are based on transitions between hyperfine levels determined by the interaction of a nuclear magnetic moment with the magnetic moment of the valence electron. The energy splitting between these hyperfine levels, and hence the atomic clock rate, scales as α^4.

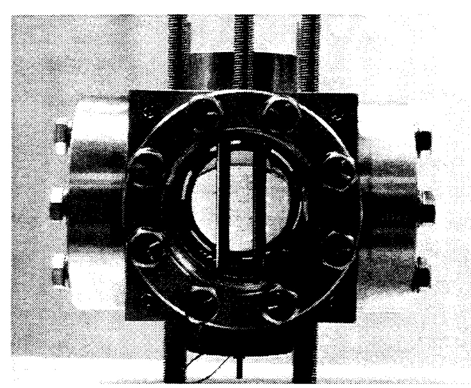
A cavity oscillator, on the other hand, has a resonant frequency that is determined by the cavity size, which scales as α. Comparison of a cavity oscillator with an atomic standard thus provides a sensitive test of stability of α, as the relative clock rates will scale as α^3. This comparison, using a Cs clock, represented the best modern-day test for variations of α, providing a limit of $\dot{\alpha} / \alpha \leq 4 \times 10^{-12}$. This measurement is limited by the natural instability of the cavity oscillator.

Because all atomic clocks are based on hyperfine transitions, it was thought that they would share the same scaling with α and thus not exhibit any relative clock rate variations if α varied. Recently, however, we realized that previously ignored relativistic corrections to the hyperfine splitting, which become substantial for high-Z clock atoms, could significantly alter the α-dependence for different types of atomic clocks.

As a result, we calculated that different atomic clocks would indeed drift relative to each other if α varied. For example, if $\dot{\alpha} / \alpha = 10^{-14}$/yr, a frequency drift of 2.2×10^{-14}/yr between an H-maser and an Hg^+ clock would result. Because both of these clocks are inherently much more stable than a cavity oscillator, this comparison would provide a much more sensitive test of the variability of α.

The ultrastable frequency standard based on Hg^+ ions confined to a linear ion trap, which was developed at JPL, has recently been used to conduct a 140-day clock-rate comparison with a cavity tuned H-maser. In that comparison, a limit of $2.1(\pm 0.8) \times 10^{-16}$/day was established for the frequency drift between these two long term stable clocks. This comparison establishes an upper bound $\dot{\alpha} / \alpha \leq 4 \times 10^{-14}$/yr, representing a 100-fold improvement over the best laboratory limits established in comparisons of the superconducting cavity with Cs frequency. This improvement follows from the very good long-term stability of the atomic Hg^+ and H-maser clocks, with relative drift $\sim 10^{-16}$/day, as compared to the superconducting cavity oscillator, where instrumental drifts can lead to frequency drifts of a few parts in 10^{-14}/day.

In summary, we have developed a new method for detecting variations of the fine structure constant, α, by comparing the relative drift rates of atomic clocks that are continuously monitored in time scales in several labs worldwide. We have searched for such drifts in a clock comparison between Hg^+ and H-maser clocks and improved modern-day limits on an a variation by two orders of magnitude. Further improvements will follow as laser-cooled Be^+, Rb, Yb^+, Cs, and Hg^+ microwave standards are developed. Comparisons of their clock rates should establish the most sensitive search for any temporal variation of α and should reach a sensitivity approaching the equivalence principle violating string theory predictions. (See *Physical Review Letters*, **74**, 3511 (May 1, 1995) for more details of this work.)



HEART OF THE JPL LINEAR ION TRAP STANDARD, THE WORLD'S MOST STABLE CLOCK ON TIME SCALES OF A FEW HOURS AND BEYOND.