HIGH STABILITY FREQUENCY STANDARDS BASED ON $^{199}Hg^{+}$ IONS IN A LINEAR ION TRAP*

R. L. Tjoelker, J.D. Prestage, and L. Maleki
California Institute of Technology, Jet Propulsion Laboratory
4800 Oak Grove Drive, Bldg 298
Pasadena, California 91109

Microwave-Optical double resonance spectroscopy measurements of the ground state $^2S_{1/2}(F=0, m_F=0)$ to $^2S_{1/2}(F=1, m_F=0)$ hyperfine transition of ^{199}Hg ions [1] are used to control a local oscillator providing the most stable atomic frequency standard for averaging times longer than 20,000 seconds. Mercury ions are confined in a Linear Ion Trap (LIT) [2] and collisions with a helium buffer gas cool the ions to near room temperature [3]. Atomic state selection is accomplished by optical pumping using 194 nm light from a ^{202}Hg lamp and the 40.507347997x GHz atomic transition is interrogated using Ramsey successive oscillatory fields[4]. With interrogation times of 16 seconds a stability of 7x10-14/T $^{1/2}$ is achieved (Fig.1)[5].

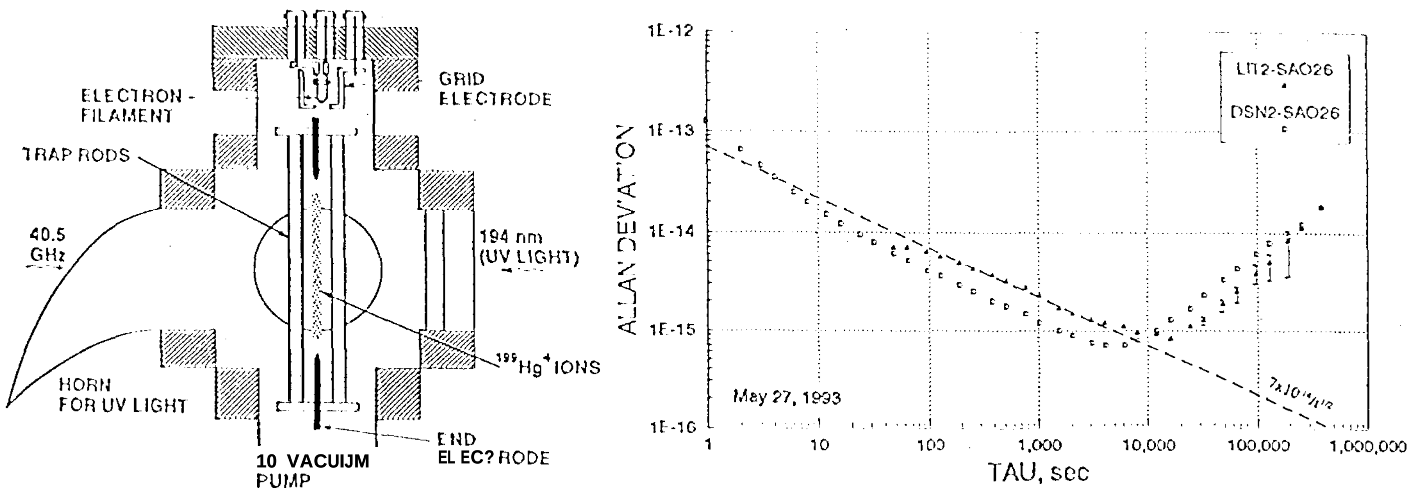

Figure 1: (a) Linear Ion Trap. (b) Ten day stability comparison of LITS-2 and the H-maser SAO-26. The dashed line represents a performance of $7 \times 10^{-14}/\tau^{1/2}$. Also shown for reference is the stability comparison of two H-masers, SAO-26 and DSN-2 over the same time interval.

Because of the large atomic mass and ground state hyperfine splitting, mercury ions are less susceptible to magnetic and thermal effects than hydrogen or cesium. For good S/N, approximately 107 ions are confined in the trap. Remaining sensitivity to second order Doppler shifts due to thermal and driven motion from the rf trapping field is the tradeoff for the inherent simplicity in a lamp based, high S/N (i.e. large ion cloud), room temperature system. With the addition of a 194 nm laser, laser cooling and interrogation on only a few ions would reduce sensitivity to second order Doppler shifts [6].

Stability comparisons are currently underway between two JPL lamp based $^{199}Hg^{+}$ trapped ion research standards LITS-1 and LITS-2. In the present configuration, each standard steers a separate VLG-11 hydrogen maser receiver [7] phase locked to a common hydrogen maser oscillator. In a preliminary 10 day measurement, the short term performance of both standards is $\sigma_y(\tau) = 1 \times 10^{-13}/T^{1/2}$. Figure 2 shows the fractional frequency of the JPL standard LITS-2 compared against our first research standard LITS-1.

The deviation from the 1x $10^{-13}/\tau^{1/2}$ slope between 30,000 and 60,000 is due to limited stability of the control electronics in 1 ITS-1. The long term differential drift between the two Hg+ standards is measured to be less than 5x10"]6/ clay. Also shown is a 30 day stability comparison of 1 ,ITS-2 against the]]-maser SAO-26 [7]. Beyond 20,000 seconds the measurement is limited by the $4x10^{-15}$/day drift of the hydrogen maser.

The],] '] 'S-?,/] ,ITS-] Comparison is expected to reach 10'16 in 5x10s seconds when electronic upgrading is completed. In the present ion trap standards, the stability floor is most sensitive to ion number and temperature fluctuations through the second order Doppler shift [5]. A new extended linear ion trap Configurate ion (LITE) which separates the ion loading and State select ion region from the microwave at omic interrogation region is currently under development [8]. This configuration should eliminate most of the remaining sensitivity to ion number fluctuations

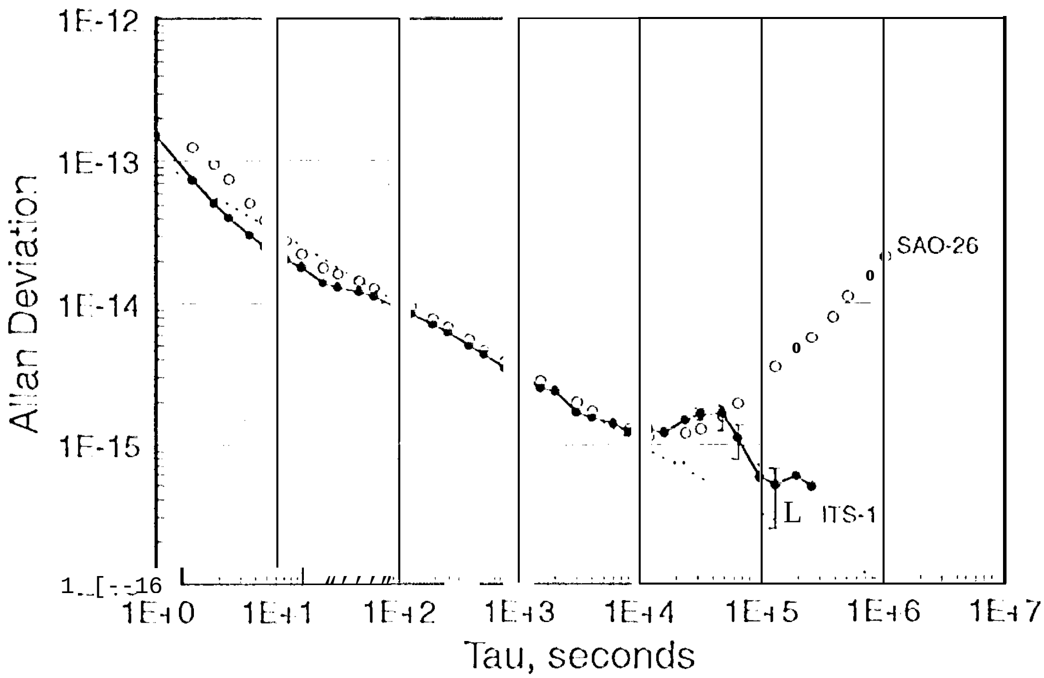

Figure 2: The fiat.tiona] frequency stability of the Hg+ ion trap standard I ,1'1'S-2 compared against 1.1'1"S- 1, and hydrogen maw SAO-26 [6].

*This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to the National Aeronautics and Space Administration.

[1] F.G. Major and G. Werth, Appl. Phys. 1 S, 201 -20S(198 1).

[2] J.D. Prestage, G.J. Dick, and L. Maleki, J. Appl. Phys., 66, 1013, (1 989).

[3] 1.. S. Cutler, R. P. Giffard, and M. D. McGuire, Appl. Phys. **B 36**, 137, (1985).

[4] N.F. Ramsey, Molecular Beams (Oxford University Press, Oxford, 1956).

[5] R.L. Tjoelker, J.D. Prestage, G.J. Dick, 1,. Maleki, in *Proc. 47th Ann. Symp. Freq. Cont.* (1 993), p 132.

[6] M.E. Poitzsch, J.C. Bergquist, W.M. Itano, and 1). J. Wineland, in *Proc. 48th Ann. Symp. Freq. Cont.* (1 994).

[7] Smithsonian Astrophysical observatory; Cambridge, h4A 02138.

[8] J.D. Prestage, R.L. Tjoelker, G.J. Dick, 1,. Maleki, *in Proc. 47th Ann. Symp. Freq. Cont.*, (1 993) p. 144.