

**Ground-based investigations with the
cryogenic hydrogen maser**

NASA Grant NAG8-1434

Technical Progress Report

For the period 1 January 2001 through 31 December 2001

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December, 2001

Prepared for NASA

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**The Smithsonian Astrophysical Observatory
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Background and motivation

The room temperature hydrogen maser is an active atomic oscillator used as a high-frequency-stability local oscillator for radio astronomy, metrology, and spacecraft navigation, and in tests of fundamental physics. The cryogenic hydrogen maser (CHM) operates at 0.5 kelvin, employing superfluid helium-coated walls to store the masing hydrogen atoms. We are investigating whether the CHM may provide better frequency stability than the room temperature hydrogen maser: one to three orders of magnitude improvement may be possible because of greatly reduced thermal noise and larger signal power. Exceptional frequency stability will be required for spacecraft tracking in future deep-space missions, for space-based tests of relativity and gravitation, and for local (i.e., flywheel) oscillators used with absolute frequency standards such as laser-cooled atomic fountains and linear ion traps. These new devices are passive high-resolution frequency discriminators. Alone, they cannot function as superior atomic clocks; their effective operation depends on being integrated with an active local oscillator with excellent short term stability — such as that possible with the CHM.

In addition, we intend to use the CHM to study important effects in low temperature atomic physics: hyperfine-induced hydrogen-hydrogen spin-exchange collisions. Low temperature hydrogen spin-exchange collisions depend sensitively upon: (i) details of the hydrogen-hydrogen interaction potential at long range that are otherwise experimentally inaccessible; (ii) non-adiabatic (i.e., non-Born-Oppenheimer) effects particular to cold atomic collisions; and (iii) inclusion of the intra-atomic hyperfine interaction (strength ~ 0.07 K) in addition to the electron exchange interaction (strength $\sim 50,000$ K), which fundamentally alters the rotational symmetry of the hydrogen-hydrogen collisional process. Furthermore, the calculated values for cold hydrogen-hydrogen collision cross-sections are sensitive to the theoretical techniques used in the calculations, making experimental comparisons particularly significant.

Accomplishments during current grant year

During the report period (1/1/01 to 12/31/01), we successfully achieved active maser oscillation of the CHM at 0.5 K with the new quartz hydrogen atom storage bulb installed. Preliminary measurements of the CHM oscillation frequency as a function of temperature indicated no adverse effect of the new atom storage bulb.

We have not yet been able to flow sufficient helium into the CHM to create a saturated superfluid helium film wall coating, while simultaneously maintaining operation ~ 0.5 K, in order to achieve the desired null point for the CHM frequency as a function of temperature. This limitation may be due to limited cooling power from the ^3He refrigerator and/or unwanted heat leaks (still to be determined). Measurements of the CHM frequency as a function of temperature and input helium flow rate are shown in Figures 1 and 2. Importantly, these data indicate that even for the undersaturated helium films employed to date, the variation of the CHM frequency with temperature has approximately the same slope as that measured previously by other groups in hyperfine resonance experiments. Thus we expect that once we correct the system's thermal limitations, and thus are able to achieve a saturated superfluid helium film, we will achieve the desired null point for the CHM frequency as a function of temperature — the optimal operating point for greatest CHM frequency stability.

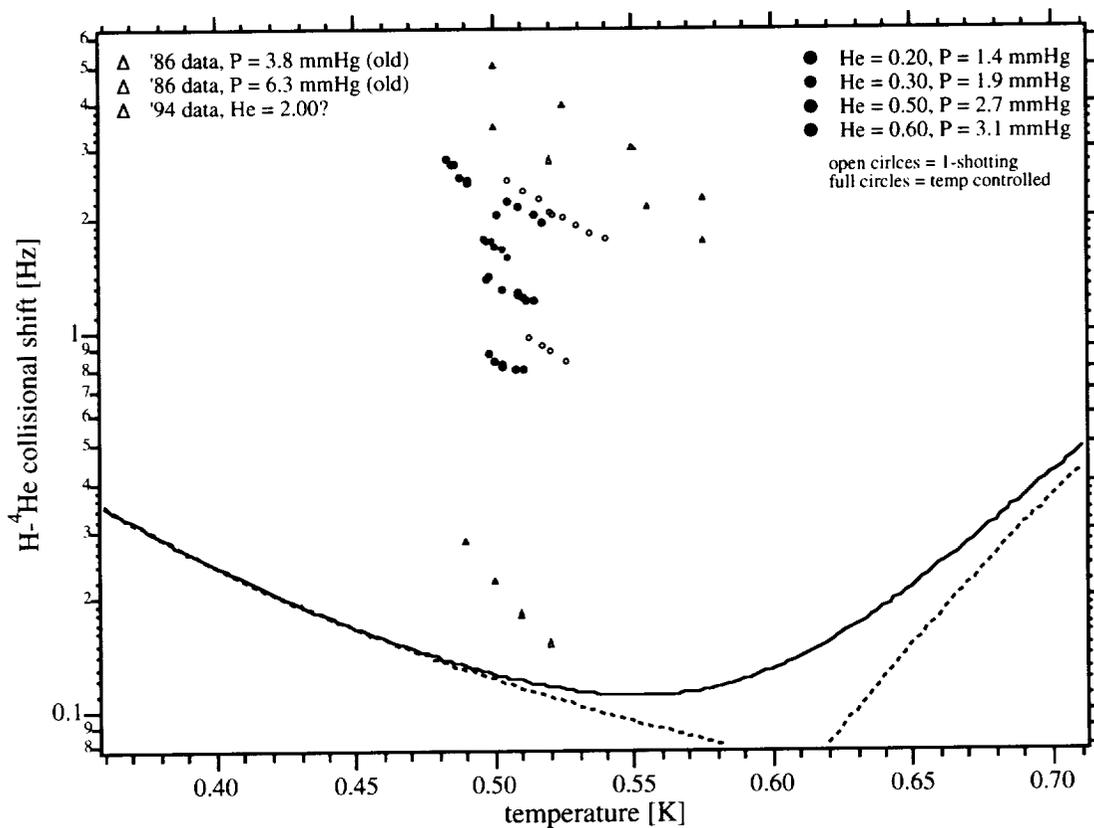


Figure 1. Measured change in CHM frequency as a function of temperature and input helium flow rate. Past CHM measurements are shown before the quartz storage bulb was installed. Solid line shows expected behavior.

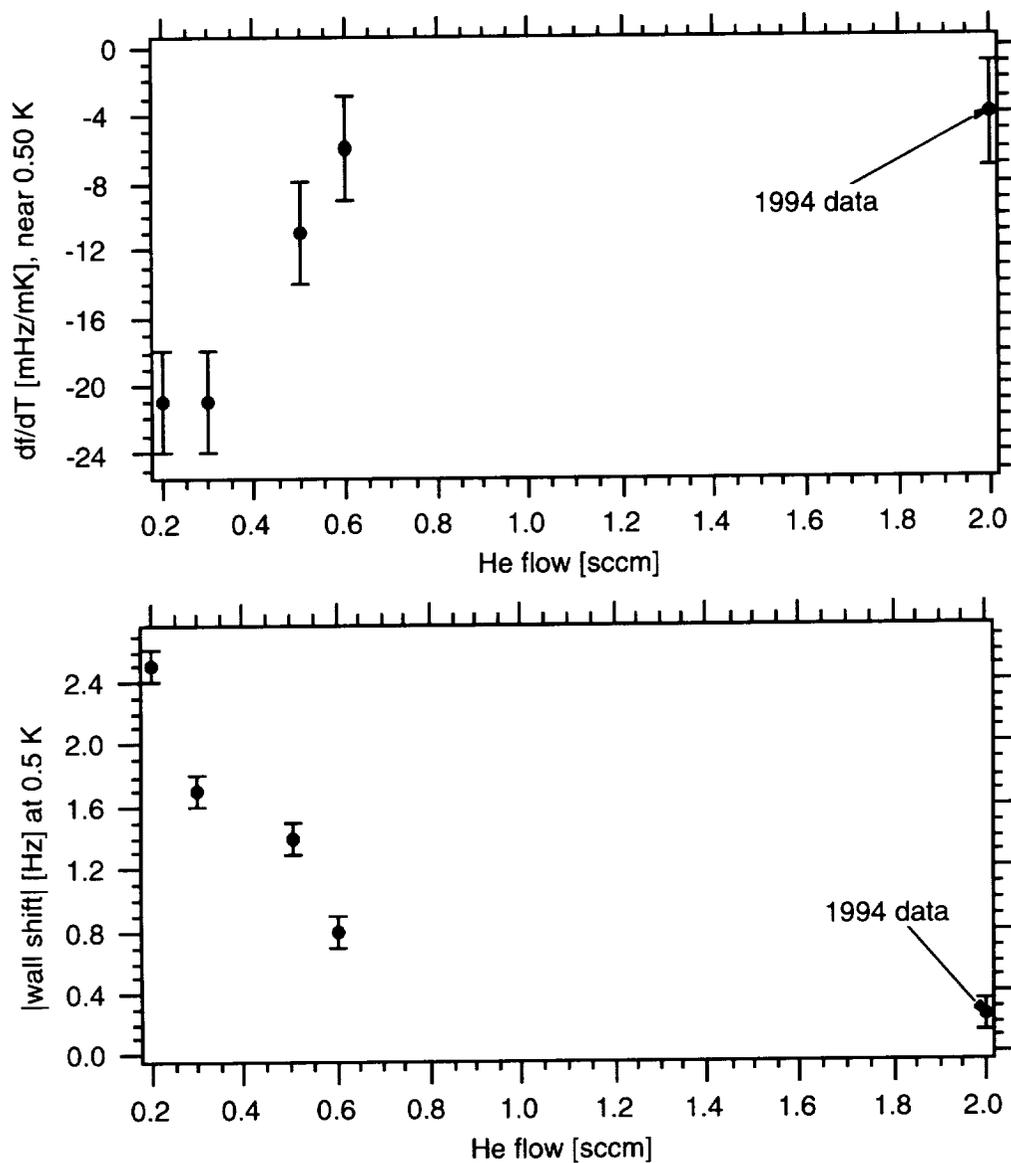


Figure 2. Measured CHM frequency and variation of frequency with temperature as a function of input helium flow rate. For comparison, past measurements (from 1994) are shown before installation of quartz storage bulb.

Relevant journal papers during grant period

Testing Lorentz and CPT symmetry with hydrogen masers..

M.A. Humphrey, D.F. Phillips, E.M. Mattison, R.E. Stoner, R.F.C. Vessot, and R.L. Walsworth, submitted to Physical Review A (2001), physics/0103068.

Limit on Lorentz and CPT violation of the proton using a hydrogen maser.

D.F. Phillips, M.A. Humphrey, E.M. Mattison, R.E. Stoner, R.F.C. Vessot, and R.L. Walsworth, Physical Review D **63**, 111101 (2001).

Relevant conference abstracts during grant period

Tests of CPT and Lorentz symmetry using hydrogen and noble-gas masers.

R.L. Walsworth, Second Meeting on CPT and Lorentz Symmetry, Bloomington, IN, August, 2001.

New clock comparison searches for Lorentz and CPT violation..

R.L. Walsworth, Pan Pacific Basin Workshop on Microgravity Sciences, Pasadena, CA, 2001.

Studies in low temperature atomic physics using a cryogenic hydrogen maser.

M.A. Humphrey, E.M. Mattison, D.F. Phillips, R.F.C. Vessot, and R.L. Walsworth, presented at the DAMOP Meeting of the American Physical Society, London, Ontario, 2001.

Research plans

We will solve the heat load/cooling power problem to enable active maser oscillation with saturated superfluid helium films. We will then measure and optimize the CHM's frequency stability, and begin investigations of cold atomic hydrogen collisions. By measuring a number of spin-exchange parameters, a direct test of theory can be made which will lead to an improved understanding of cold hydrogen and cold alkali atom collisions, an understanding which will be applicable to many laser-cooled atomic physics experiments.

