Characterization of a Cold Cesium Source for PARCS: Primary Atomic Reference Clock in Space

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Abstract

The PARCS (Primary Atomic Reference Clock in Space) project is a joint NIST JPL venture aimed at placing a Cesium (Cs) atomic clock aboard the International Space Station. This orbiting clock will achieve high accuracies in part due to the long Ramsey times afforded by the microgravity environment. The clock will allow a wide range of precision tests of fundamental physics including relativity theory. Our group at NIST is performing experimental studies of a "prototype" cold Cs source based on launching atoms from an optical molasses. The results of our work will be applied to the design and construction of a robust, space qualified device. Additionally, this work is important for the development of future Cs fountains. Here we describe our apparatus, the present state of our experimental work, and planned improvements.

Summary

An overview of the PARCS space clock project has been presented elsewhere[1]. Similarly, the French PHARAO space clock addresses many of the same issues and problems [2]. The PARCS design goals are to achieve a stability of $\sigma_y(\tau) \approx 3 \times 10^{-14}\ \tau^{-1/2}$ with a Ramsey time on the order of 10 s and an accuracy of 1×10^{-16}. This requires 2×10^{7} Cs atoms in the m=0 state with a temperature of 2 μK to be launched into the PARCS microwave cavity. The design of the PARCS Cs source will have to confront problems that are not present in current Cs fountain clocks. For example, consider the long Ramsey times ($\approx$10 s) afforded by the microgravity environment. In this regime, atom loss due to background collisions and thermal expansion of the launched ball of atoms becomes significant. Although the PARCS will employ shutters between the source and the microwave interrogation region, atoms with a small launch velocity will still encounter elevated background pressures before leaving the source. This paper describes laboratory studies of a "prototype" cold Cs atomic source and studies of parameters that are required to achieve these goals. Additionally, we are concerned with developing design guidelines for producing a robust and reliable space qualified device.

Our laboratory based cold atom source experiment is shown in Figure 1. The system consists of a vacuum chamber and accompanying lasers and optics. The

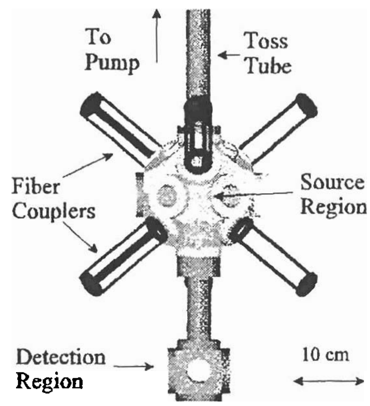

Figure 1. The cold Cs atom source experimental apparatus

vacuum chamber consists of source region, a long toss tube (~1.5 m), and a detection region. The source region contains twelve 3.8 cm windows. Six windows are located on the faces of a cube oriented in the (1,1,1) beam geometry [3] and are used for introducing the cooling beams into the vacuum. The remaining six windows are used for viewing and future experimental studies. There are several smaller ports containing among other things, a Cs oven and a small window suitable for introducing a Zeeman slower beam. The source region is surrounded by three pairs of Helmholtz coils for nulling out the background magnetic field.

A MOPA (Master Oscillator Power Amplifier) pumped by a DBR (Distributed Bragg Reflector) diode laser supplies the cooling light at the 852 nm D_2 sightly detuned from the $F = 4 \rightarrow F' = 5$ transition. The beams are delivered to the vacuum chamber via polarization maintaining fiber optic cables and then expanded to a size of $\approx$1.5 cm. The fiber coupler assemblies allow for the addition of various optical elements. For example, this allows us to work with either Lin $\perp$ Lin or σ^+ - σ^- polarization geometries and to monitor laser power levels in real time. An Extended Cavity Diode Laser (ECDL) locked on the F=3 →F′=4 transition serves as a repump and is added into one of the fibers.

Cs atoms cooled in the optical molasses are launched upwards into the drift tube by detuning the upward and downward beams to create a moving molasses. The atoms travel up, turn around, and fall back through the source region and down below into the detection region. The detection region consists of a sheet of light in a standing wave tuned to the F =4 → F′ = 5 transition, a spherical collection mirror, and a photodetector.

The temperature and density of the Cs cloud is measured by tossing the atoms to various heights and recording the fluorescence of the atoms as they pass through the detection beam. Presently we have achieved launch velocities in excess of 4 m/s and we are pursuing several avenues to increase the number of atoms returning to the detection region in order to improve our temperature and density measurements. Preliminary launch data are shown in Figure 2. Here, Cs from the molasses has been launched to several heights and the returned signal measured. These results indicate an initial atom ball of radius ≈0.5 cm and a temperature of less than 10 μK . The signal from the atoms dropped out of the molasses indicates that there are $\geq 10^7$ atoms in the molasses.

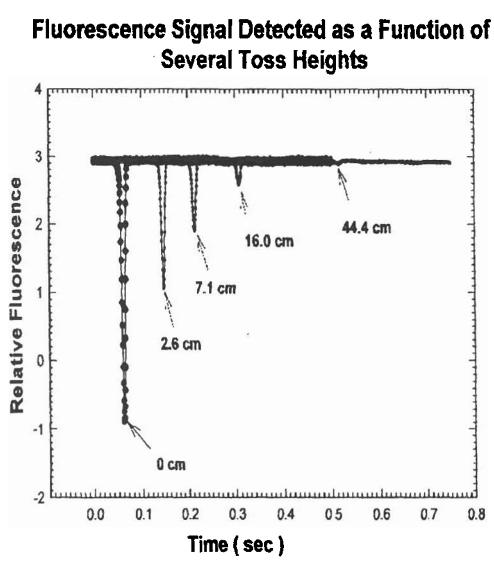

Figure 2. Plot of the Fluorescence signal of Cs launched from a molasses to several heights.

The (1,1,1) beam geometry of this source seems to be experimentally more difficult to launch from compared to a conventional (0,0,1) molasses beam geometry because of the lack of retro reflected beams which automatically maintain beam to beam power balance. Our system is sensitive to beam to beam power imbalance and it is likewise difficult to accurately adjust in our current configuration. Thus, we are presently developing an active laser beam intensity servo. We anticipate that this improvement will allow us to achieve higher launches with much larger numbers of atoms returning to the detection region.

We have begun to investigate various parameters and their effect on the temperature and density of our cold atom source and will present these results. These parameters include, cooling beam power, alignment of the beams in the (1,1,1) geometry, polarization requirements on the (1,1,1) beams, power imbalance tolerance, molasses load times, launch and post cool parameters, Cs oven performance and magnetic field uniformity required in the source region.

Once the cold atom source parameters have been satisfactorily characterized, this apparatus will be useful for investigating other PARCS related issues. For example, we plan to attach the PARCS prototype microwave cavity above the source in order to evaluate the performance of the cavity.

References

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