Identifying and Resolving Key Problems for Next-Generation Space Clocks

Daniele Monahan, James Camparo, Michael Huang, Hunter Kettering, Charles Klimcak, Arielle Little, and Nate Ristoff

Physical Science Laboratory, The Aerospace Corporation, El Segundo, California, USA

Email: daniele.m.monahan@aero.org

On the path to development of next-generation microwave atomic clocks for space, there are a number of key atomic physics problems that fall into a "valley of neglect," a valley that divides the research conducted in academic laboratories from the problems facing commercial manufacturers. The Aerospace Corporation is a non-profit Federally Funded Research & Development Center in the United States with an Atomic Clocks Laboratory that is targeting the important problems falling into this valley. Here we discuss several of our research projects aimed at hastening the development of near-term, next-generation space clocks: studies on the consumption of Hg in the rf-discharge lamps employed in Hg+ clocks, studies aimed at a better understanding and mitigation of PM-to-AM noise conversion in laser-pumped vapor-cell clocks, and the development of a "bridge technology" for laser-pumped vapor-cell clocks (i.e., Aerospace's LaLI-POP clock), investigations into space-clock ensembling algorithms. In all of these efforts, the goal is to facilitate technology transfer from the academic community to the clock manufacturing industry.

One of the more important near-term, next-generation space clocks is the Hg+ atomic clock[1]. In this device, a Hg rf-discharge lamp optically pumps the ions and monitors their absorption of microwave radiation. The problem is that little is known about the lifetime and reliability of such lamps, especially when systems engineers plan for decade-long mission lifetimes. In our laboratory, we have measured Hg consumption in rf-discharge lamps, using Differential Scanning Calorimetry (DSC) as illustrated in Fig. 1, and spectroscopic studies of discharge lamp conditions that can optimize the 194 nm light from the lamp that is required for Hg+ optical pumping.

In addition to Hg rf-discharge lamps, we have developed an ensemble-algorithm testbed. Ensembling algorithms developed to date routinely deal with clocks of similar quality, or clocks whose Allan deviations have separate (averaging time) regimes where they show best performance. However, as we begin to develop space systems that (potentially) stretch from Earth to Mars, we will need ensembling algorithms that are much more versatile. Specifically, algorithms that can deal with much broader classes of clock with very diverse levels of frequency stability.

The above are just two examples of how our laboratory's research is attempting to facilitate the transition of academic next-generation clock efforts to wide application. It is our contention that through investigations like those conducted in our laboratory, the important problems that fall into the valley of neglect can be attacked, and consequently will not hinder next-generation atomic clock use in future space systems.

[1] E. A. Burt, J. D. Prestage, R. L. Tjoelker, D. G. Enzer, D. Kuang, D. W. Murphy, D. E. Robinson, J. M. Seubert, R. T. Wang, and T. A. Ely, "Demonstration of a trapped-ion atomic clock in space," Nature, vol. 595, 43, 2021.