

Characterization of Laser Cooling in Microgravity via Long-term Operations in TianGong-2 Space Lab

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ABSTRACT

The invention of laser cooling has fundamentally influenced the research frontier of atomic physics and quantum physics, and recently an intense focus has been on the studies of cold atom physics in microgravity environments. Herein, we report the results of our laser cooling experiments in TianGong-2 Space Lab, which was conducted for 34 consecutive months in orbit. Over such an extended operation time, the quality of laser cooling did not experience any significant decline, while the properties of laser cooling in orbital microgravity were systematically studied. In particular, we demonstrate magneto-optical trapping and polarization-gradient cooling in orbit and carefully examine their performances. A comparison of the in-orbit and on-ground results indicates that a higher cooling efficiency exists in microgravity, including a smaller loss rate during the trapping and cooling process and lower ultimate temperature of laser-cooled atoms. Our progress has laid the technical foundations for future applications of cold atoms in space missions with operation times in the order of years.

Keywords: laser cooling, polarization-gradient cooling, orbital microgravity, space lab

INTRODUCTION

Since the invention of laser cooling and trapping of atoms [1–6], cold atom physics and its applications have rapidly developed. Typically the temperature of laser-cooled atoms can reach as low as a few μK , corresponding to several photon recoils. With sub-recoil cooling techniques such as evaporative or sideband cooling, the cold atom ensemble can arrive at the exotic states of Bose-Einstein condensation (BEC) [7,8] or degenerate Fermi gas [9–11], which become the standard tools of quantum simulation with neutral atoms [12–14]. Cold atoms have become an essential platform in metrology, quantum sensing, quantum information, and precision measurement of fundamental physical constants, such as in microwave atomic clocks [15], optical atomic clocks [16–18], cold atom interferometers [19–24], atomic qubit platform [25–27], and measurement of the electron's electric dipole moment [28,29]. These experiments are generally operated on ground where the influence of gravity is inevitable and persistent.

However, the study of cold atom physics in microgravity has recently attracted significant interest. BECs were realized in drop tower and sounding rocket experiments with microgravity times of several seconds and several minutes respectively [30,31], which can serve as ultracold atom sources for future space missions [32]. A cold atom interferometer operating in microgravity was also demonstrated in a parabolic flight [33]. In particular, the observation of BEC in the International Space Station has been reported [34], and intense on-going efforts have been devoted to sub-nK physics in the space lab [35]. Moreover, the cold atom platform in space is believed to have great potential for applications for quantum sensing and fundamental physics, and several promising proposals have been suggested, including the detection of gravitational waves and search for dark matter [36,37]. These proposals typically require long-term in-orbit experiments running continuously for years. Therefore, a systematic study of laser cooling in orbital microgravity with an ex-

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