

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-

¹CAS Key Laboratory of Quantum Optics and Center of Cold Atom Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China; ²Aerospace Laser Engineering Department, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China

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Chapter 2 Laser Cooled Atomic Physics In Microgravity

York E. Young



Chapter 2 Laser Cooled Atomic Physics In Microgravity:

RLE Progress Report Massachusetts Institute of Technology. Research Laboratory of Electronics,1993 **Scientific and Technical Aerospace Reports** ,1994 *Handbook of Optics* Optical Society of America,2000-10-27 A new volume in the field s bestselling optics reference an entirely new opus focusing exclusively on fiber optics Contains an ultra handy comprehensive index to all four Handbook of Optics volumes **Laser Cooling and Trapping** Harold J. Metcalf,Peter van der Straten,2012-12-06 Laser cooling is a relatively new technique that has led to insights into the behavior of atoms as well as confirming with striking detail some of the fundamental notions of quantum mechanics such as the condensation predicted by S N Bose This elegant technique whereby atoms molecules and even microscopic beads of glass are trapped in small regions of free space by beams of light and subsequently moved at will using other beams provides a useful research tool for the study of individual atoms and clusters of atoms for investigating the details of chemical reactions and even for determining the physical properties of individual macromolecules such as synthetic polymers and DNA Intended for advanced undergraduates and beginning graduate students who have some basic knowledge of optics and quantum mechanics this text begins with a review of the relevant results of quantum mechanics it then turns to the electromagnetic interactions involved in slowing and trapping atoms and ions in both magnetic and optical traps The concluding chapters discuss a broad range of applications from atomic clocks and studies of collision processes to diffraction and interference of atomic beams at optical lattices and Bose Einstein condensation **Metals Abstracts** ,1984 **Government Reports Announcements & Index** ,1993-07 Coherent Atomic Manipulation and Cooling Alexander J. Dunning,2015-08-18 This work unites the concepts of laser cooling and matter wave interferometry to develop an interferometric laser cooling technique in an experimental system of cold rubidium atoms Serving as an introduction to graduate level coherent optical atomic manipulation the thesis describes the theory of stimulated Raman transitions and atom interferometry along with the experimental methods for preparing and manipulating cold atoms before building on these foundations to explore tailored optical pulse sequences and novel atomic cooling techniques Interferometric cooling originally proposed by Weitz and H nsch in 2000 is based upon the coherent broadband laser pulses of Ramsey interferometry and in principle allows laser cooling of atomic and molecular species outside the scope of traditional Doppler laser cooling On the path toward cooling composite pulses quantum error correction methods developed by chemists to mitigate the effects of in homogeneities in NMR spectroscopy are investigated with a view to improving the performance of atom interferometers *Cws'99* ,2000 Cold Collisions of Laser Cooled Na and Rb Atoms York E. Young,2001 **Laser Cooled Atomic Clocks in Space** W. M. Klipstein,2000 **Third International Workshop on Low Temperature Physics in Microgravity Environment (CWS-2002)** International Workshop on Low Temperature Physics in Microgravity Environment. 3, 2002, Černogolovka,Rossiiskai[a] akademii[a] nauk. Institute of Solid State Physics,L. P. Mezhov-Deglin,Rossiiskai[a]

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