Fundamental physics research aboard the international space station

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Abstract

NASA's research plans aboard the International Space Station (ISS) are discussed. Experiments in low temperature physics and atomic physics are planned to commence in late 2005. Experiments in gravitational physics are planned to begin in 2007. A low temperature microgravity physics facility is under development for the low temperature and gravitation experiments. The facility provides a 2 K environment for two instruments and an experimental lifetime of 4.5 months. Each instrument will be capable of accomplishing a primary investigation and one or more guest investigations. Experiments on the first flight will study non-equilibrium phenomena near the superfluid 4He transition and measure scaling parameters near the 3He critical point. Experiments on the second flight will investigate boundary effects near the superfluid 4He transition and perform a red-shift test of Einstein's theory of general relativity. Follow-on flights of the facility will occur at 16 to 22-month intervals. The first couple of atomic physics experiments will take advantage of the free-fall environment to operate laser cooled atomic fountain clocks with 10 to 100 times better performance than any Earth based clock. These clocks will be used for experimental studies in General and Special Relativity. Flight definition experiment studies are underway by investigators studying Bose Einstein Condensates and use of atom interferometers as potential future flight candidates.

Key words: Space station experiments; Low Temperature Physics; Laser Cooling ;Atomic Clock

1. Introduction

NASAs plans for performing research in fundamental physics on the International Space Station have evolved over the last decade based on results from past experiments, inputs by the scientific community to NASA Research Announcements, advise from key researchers representing the broad physics community, and from programmatic considerations. The plans now include the development of a Low Temperature Microgravity Physics Facility (LTMPF) and development of apparatus for performing experiments utilizing Laser Cooled Atom Physics (LCAP). Both LTMPF and LCAP will operate as attached payloads to the exposed facility of the Japanese experiment module. The LTMPF will enable research that requires temperatures in the 2-Kelvin range in a free fall environment for up to 4.5 months duration. Flights of the LTMPF will occur at 16 to 22 month intervals. Each flight will accommodate two instruments that operate concurrently. Each instrument is built to accommodate a primary investigation and one or more guest investigations. Research areas supported by the LTMPF include: low temperature physics, condensed matter physics, quantum phenomena, and gravitational and relativistic physics. The LCAP experiment hardware will be configured in a modular way to allow adaptation for a variety of experimental needs in this research area. Initially, the LCAP hardware will support operation of highly stable atomic clocks for gravitational physics tests on the ISS for durations beyond one year. Subsequent launches of the LCAP hardware will be approximately every 2 years and will

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be for studies in atomic physics, macroscopic quantum phenomena, and relativity physics. In what follows, the planned ISS experiments for LTMPF and LCAP are described in more detail.

2. Planned LTMPF experiments

The first launch of the LTMPF is currently planned in late 2005. The first four experiments listed below will be accommodated on the first flight. The last two experiments will be part of the second flight of the LTMPF. Critical Dynamics in Microgravity (DYNAMX) will determine the thermal conductivity very close to the 4He superfluid-to- normal fluid interface where it exhibits complex non- linear behavior. Free-fall conditions are required to reduce static pressure variations across the sample. Microgravity Scaling Theory Experiment (MISTE) will perform thermodynamic measurements near the liquid-gas critical point of 3He and determine critical exponents and critical amplitudes in the asymptotic region very near the critical point. Heat capacity at constant Q (CQ) is a guest investigation that will use the DYNAMX instrument to measure the heat capacity at constant heat current in the superfluid phase immediately below the lambda transition of 4He. Coexistence Curve Experiment (COEX) is a guest investigation that will use the MISTE instrument to measure the shape of the liquid-gas coexistence curve in terms of density and temperature near the 3He critical point. Boundary Effects near the Superfluid Transition (BEST) will study quantitatively the effects of solid-boundary and dimensionality on fluid properties. Specifically, BEST will provide the first test of the validity of dynamic finite size scaling theory, and will examine critical thermal transport in regions of dimensionality crossover. Superconducting Microwave Oscillator (SUMO) will use perpendicularly oriented highly stable superconducting microwave oscillators to test three basic theories of physics: Special Relativity, General Relativity, and the Standard Model of matter. It may also be used as a flywheel oscillator for atomic clock experiments. Investigations beyond the second flight of the LTMPF will be selected from future NASA research announcements. Research announcements will also be used to select guest investigations for already designed and/or built instruments.

3. Planned LCAP experiments

The first LCAP experiment is the Primary Atomic Reference Clock in Space (PARCS) and it is currently scheduled to launch in late 2005. PARCS will improve on the realization of the second as the base unit of time by one to two orders of magnitude. The improved clock will be used to test Einsteins prediction local-position invariance by comparing the frequency of clocks of different composition under various orbital conditions. Rubidium Atomic Clock Experiment (RACE) is planned to be launch ready in late 2007. RACE will improve clock performance by another factor of ten beyond PARCS. The clock will be used for additional tests of general relativity and to search for new physics beyond the Standard Model of fields and particles. RACE will also distribute a superiorly stable time and frequency signal from the ISS to benefit researchers in Earth based laboratories. Condensate Laboratory Aboard the Space Station (CLASS) will cool to temperatures as low as 1 pico-Kelvin and achieve Bose-Einstein condensation (BEC) of a dilute atomic gas in a free fall environment. CLASS will also study the properties of an atom laser in space. Quantum Interferometer Test of Equivalence (QuITE) will perform a precision test of Einsteinss equivalence principle using collections of laser- cooled Rubidium and Cesium atoms as test masses. NASA will select investigations beyond those mentioned here from future research announcements. NASA will explore the guest investigator concept used for LTMPF instruments also for use by the LCAP hardware.

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