A Low Temperature Facility for Experiments On the International Space Station

Melora Larson, Talso Chui, Arvid Croonquist, Warren Holmes, Don Langford, Feng-Chuan Liu and John Pensinger
Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109
818-354-8751
Melora.Larson@jpl.nasa.gov

Abstract— The Jet Propulsion Laboratory (JPL) is currently developing the Low Temperature Microgravity Physics Experiments Facility (LTMPEF), a multiple user and multiple flight facility that will provide a long duration low temperature environment on board the International Space Station. The LTMPEF will be attached to the Japanese Experiment Module (KIBO) Exposed Facility of the International Space Station with an initial flight starting in late 2005. The LTMPEF is a self contained, reusable, cryogenic facility containing a 180-liter superfluid helium tank, two experiment packages, and electronics to provide experiment control and telemetry. Two distinct primary experiments will be accommodated during each mission, and secondary experiments requiring no additional hardware beyond that built for the primary experiments will also be accommodated during each mission. Detailed technical capabilities of the Facility will be presented, along with a brief description of the six science investigations currently selected to fly on the first two missions.

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1. INTRODUCTION

Achieving temperatures near absolute zero in space has many scientific applications from astronomy, general relativity research, to condensed matter fundamental physics research. Low temperatures enable the use of several types of sensitive detectors because of unique material properties that manifest close to absolute zero. As one example, at temperatures below 100K superconductive technology can be used. Superconductivity not only can be used for the dissipation free transportation of electrical currents, but it also makes possible the use of ultra sensitive detectors called Superconducting Quantum Interference Devices (SQUIDs). SQUIDs can be used to detect extremely small magnetic fields, current, or voltages. Low temperatures in space can be achieved by a variety of methods including: active coolers, or passive dewars using solid cryogen (nitrogen, hydrogen, or neon), or liquid helium.

In the 1980’s, JPL developed the Low Temperature Platform Facility (LTPF)[1] to provide a reusable platform for short duration (less than 2 weeks), Space Shuttle based experiments that needed temperatures near 2K in a microgravity environment. The LTPF has been used for three very successful Space Shuttle experiments from 1985 through 1997. Between each of the missions, the capabilities of the LTPF were increased substantially, both by improving the performance of the cryogenic system, and by taking advantages of the improvements available in electronics.

During the LTPF’s initial flight in 1985, the technical aspects of the performance of a superfluid helium dewar in microgravity were tested in the Superfluid Helium Experiment (SFHE). The LTPF next flew as part of the first United States Microgravity Payload (USMP) in 1992. During this second flight the LTPF contained the Lambda Point Experiment (LPE)[2]. LPE performed both benchmark science and trailblazing technology demonstration as it probed the superfluid transition of liquid helium to within a billionth of a degree of the transition, much more closely than is possible on the ground. The last flight of the LTPF occurred in 1997 as part of USMP-4 with the Confined Helium Experiment (CHeX)[3] installed. CHeX probed the effect of introducing two-dimensional confinement on a sample of liquid helium at the superfluid transition point, and CHeX demonstrated an order of magnitude improvement in sensitivity over LPE by measuring temperatures to 1/10th of a billionth of a degree. Unfortunately, by 1997 the construction of the International Space Station (ISS) caused an end to regularly scheduled Space Shuttle flights dedicated to microgravity science payloads, and currently there are no plans for flying the LTPF again.
While the construction of the ISS has eliminated the possibility for Shuttle opportunities to perform science experiments except in GAS Can payloads for the foreseeable future, a new opportunity for long duration microgravity research has been created. The series of Space Shuttle based experiments in the LTPF proved that very high-resolution experimentation can be implemented in the hostile environment of space. To continue progress made by these experiments in low temperature microgravity research, and to take advantage of the opportunity provided by the ISS, JPL is currently developing a new low temperature platform called the Low Temperature Microgravity Physics Experiments Facility (LTMPEF). This new facility will provide a platform for breakthrough scientific investigations requiring both low temperatures and microgravity conditions.

2. Description

The LTMPEF will be a self contained, reusable cryogenic facility that will accommodate a series of experiment pairs to be conducted attached at the Japanese Experiment Module Exposed Facility (JEM-EF) of the ISS. The LTMPEF is being developed with the objective to expand upon the capabilities provided for the previous Shuttle based low temperature experiments. The LTMPEF should provide more frequent access to space than the 5+ year separation achieved by the Space Shuttle experiments. The LTMPEF will also provide a significantly longer duration of low temperatures for the experiment beyond the approximately two weeks limitation imposed by the Shuttle. This longer duration will enable experiments that need months in a microgravity environment to achieve their scientific goals. Also, unlike the LTPF, the LTMPEF will fly two independent sets of instrument hardware (cold instrument and dedicated electronics) performing two or more experiments per instrument during each mission.

The LTMPEF will be transported to and from the ISS on the Space Shuttle. The facility will be launched full of cryogen, operated for approximately 5 months and retrieved some time after the cryogen is depleted.

Figure 1: LTMPEF overview.

Figure 2: Cartoon of the LTMPEF dewar and instruments.

The LTMPEF consists of a cryogenic superfluid helium dewar containing the experiment specific instruments, facility and experiment specific electronics, a mechanical enclosure structure, and the government furnished equipment (GFE) necessary for interfacing with the launch vehicle, the remote manipulating systems, and the JEM-EF (see Figure 1). The facility will fit within the envelope of a standard JEM-EF payload, 1.85m X 1.0m X 0.8m. Also, the total facility weight will be less than 600kg to meet the constraints imposed by the remote manipulating arms of the Space Shuttle and the ISS.

Dewar and Instruments

The central feature of the Facility is the approximately 180 liter superfluid helium dewar. As can be seen in Figure 1, the cross section of the dewar is oblong, not cylindrical, in shape to maximize the use of the volume available within the envelope of a JEM-EF payload. This large helium volume not only increases the lifetime of the facility, but the mass of helium also keeps the dewar below the superfluid transition temperature without active evacuation prior to launch. During the last fill prior to launch, the helium and everything else in the dewar will be cooled to as low a temperature as possible. Because of the small heat leak into the dewar and the large thermal mass of the liquid helium, the helium will then warm slowly until the vent valve is opened after launch. Launching with the dewar below the superfluid transition temperature is necessary to be able to meet the required four and a half month of on orbit science time. The dewar is designed to operate on orbit at a helium bath temperature of 1.6K.

The LTMPEF dewar has two openings into the liquid helium volume, one on each end, to mount two separate
The science instruments (see Figure 2). The science instruments are packaged for installation in the dewar inside individual vacuum cans each 20 cm in diameter and 45 cm long. Each scientific instrument consists of the experiment specific sensor package developed by the science investigators and a cryo insert provided by JPL as a standard interface to the dewar. The JPL provided cryo insert also will provide mechanical support, thermal isolation and magnetic shielding for the sensor packages.

Electronics

To drive the scientific instruments located inside the dewar, the facility includes several electronic boxes outside the dewar. The electronic boxes include 3 large multi-card VME boxes each with a single board computer dedicated to each experiment and the facility, and many smaller boxes. The smaller boxes will house the most sensitive, experiment amplifiers and controllers located as close to the dewar as possible and away from the potential noise source of the digital electronics in the main electronics assemblies.

The electronics being developed include SQUID readouts and controls for making precision temperature and pressure measurements, high resolution capacitance bridges, and high precision heater power supplies. The LTMPEF is also designing a generic resistance readout and heater control for general temperature readout and control for use by both instruments and the facility.

Radiators will be included on the earth facing and aft facing sides of the LTMPEF to provide passive, vibration free cooling of the electronics. The maximum power available to the electronics during the mission will be limited by the ability of these radiators to reject heat. The current radiator design will limit the available power of the electronics to about 235 W.

Most of the current and projected experiments are sensitive to random vibrations, charged particles, and stray magnetic fields. The vibration and charged particle radiation environments will be monitored and real-time data on both will be included in the data telemetry. Several layers of magnetic shielding are incorporated around the cryogenic portion of the instrument as briefly mentioned above to insulate the experiments from the on orbit variations in the magnetic field environment.

Enclosure

The main mechanical structure of the LTMPEF will be provided by the dewar. A set of lightweight panels will be hung from the dewar to provide attachment sites for the large electronics boxes, the radiators, the Payload Interface Unit (PIU, see below), and for thermal blankets. These panels form the mechanical enclosure for the facility.

GFE
Principle Investigator (PI) Prof. Robert Duncan of the
mission are Critical Dynamics in Microgravity (DYNAMX,
Mission 1 E
been chosen.
Announcement (NRA) process. The NRA process chooses
primary slots available on each mission. These initial
multiple candidate experiments to compete for the two
LTMPEF. Two primary experiments have been selected for
there are currently six experiments selected to fly on the
primary experiments and any secondary guest investigations
will be turned on, and initial on orbit calibrations and
verifications will begin. After these initial checks, the
investigations will take data until the helium supply in the
dewar is exhausted, after approximately four and a half
months.
The experiments and the facility will run semi-
automonomously while attached to the ISS because real-time
downlink will be limited to approximately 50 percent of the
time. Except during communication outages from the ISS, data will be
downlinked in real-time through an Ethernet interface on the ISS. All data collected during the
communication outages will be sent down in the telemetry stream later along with the real-time data. Commands can be
up-linked to both the facility and the experiments when necessary through a low data rate 1553B interface. JPL will
coordinate the telescience capabilities necessary to allow the experiments to be run from the investigators’ home
institutions.
After the facility has been attached to the JEM-EF, the two
primary experiments and any secondary guest investigations
will receive their Authority to Proceed (ATP) to Flight in 1999 after
their successful Requirements Definition Reviews (RDR). The guest investigations CQ and COEX will hold a
combined Science Concept Review and RDR in March of
2002. After passing this combined review, the guest investigations will receive their ATP to Flight, and they will
join the flight development process with the primary experiments.

DYNAMX and CQ
The DYNAMX experiment will study the behavior of helium under a very small heat flow very near the superfluid transition temperature. In particular, the experiment will
probe the dynamic behavior at a phase transition. Starting with a cell completely in the superfluid state, a constant
amount of heat is added to one end of the cell to raise the temperature of the helium. Eventually, a small portion of the
helium will pass through the superfluid transition and become a normal fluid. By monitoring the temperature as a
function of time at three locations in the cell, the experiment will be able to determine the thermal conductivity of liquid helium very close to the lambda point.

The guest investigation utilizing the DYNAMX hardware, CQ, will measure the heat capacity near the superfluid transition in the presence of an steady applied heat flux to investigate the onset of normal-fluid behavior. CQ will use
these measurements of the heat capacity as a function of temperature and heat flux to understand the transition
temperature and to confirm ground observations of an enhancement of the heat capacity due to the applied heat
flux[8].

MISTE and COEX
The liquid-vapor phase transition of helium-3 will be studied in MISTE to obtain precision measurements of the
specific heat, $C_V$, and the isothermal compressibility, $k_T$, both as a function of temperature at a constant density and
as a function of density at a constant temperature. The experiment will be performed on an isolated cell of helium-3, and the volume of the sample will be varied using an cold
volume control system. These data will be used to determine

5. SCIENCE EXPERIMENTS
There are currently six experiments selected to fly on the
LTMPF. Two primary experiments have been selected for
each mission, and two guest investigations were recently
selected to fly as part of the first mission. The investigations
were selected initially through the NASA Research
Announcement (NRA) process. The NRA process chooses
multiple candidate experiments to compete for the two
primary slots available on each mission. These initial
experiments were reduced to the two mission experiments
through the standard flight experiment review process. The
guest investigations for the first mission were selected from
an NRA occurring after the two primary experiments had
been chosen.

Mission 1 Experiments
The two primary experiments that will fly on the first
mission are Critical Dynamics in Microgravity (DYNAMX,
Principle Investigator (PI) Prof. Robert Duncan of the
University of New Mexico)[4] and the Microgravity Scaling
Theory Experiment (MISTE, PI Dr. Martin Barmatz of
JPL)[5]. As mentioned above, guest investigations were
recently chosen to add to the scientific return of the first
mission. One guest investigation has been selected to fly
with each of the primary experiments. The experiment the
Heat Capacity at Constant Heat Flux (CQ, PI Prof. David
Goodstein of the California Institute of Technology)[8] will
use the hardware being developed by DYNAMX, and the
Coexistence Experiment (COEX, PI Dr. Inseob Hahn, JPL)
will make use of the hardware of the MISTE experiment.

The primary experiments, DYNAMX and MISTE, received
their Authority to Proceed (ATP) to Flight in 1999 after
their successful Requirements Definition Reviews (RDR). The guest investigations CQ and COEX will hold a
combined Science Concept Review and RDR in March of
2002. After passing this combined review, the guest investigations will receive their ATP to Flight, and they will
join the flight development process with the primary experiments.
critical exponents and amplitude ratios to test the scaling laws relating these exponents. Equations of state for the helium-3 system will also be tested through comparison using MISTE’s simultaneous measurements of the pressure, temperature, and density.

Using the MISTE hardware, the COEX experiment will vary temperature and density to scan the coexistence curve of the helium-3 system. COEX’s measurements of the coexistence curve can be used to further test the scaling laws fundamental to the current understanding of critical phenomena.

Mission 2 Experiments

The two experiments selected for the second mission are Boundary Effects on the Superfluid Transition (BEST, PI Prof. Guenter Ahlers of the University of California, Santa Barbara)[6] and Superconducting Microwave Oscillator (SUMO, PI Prof. John Lipa of Stanford University)[7]. These primary experiments have successfully passed their SCR’s, and are currently preparing for their RDRs. After passing their RDRs, they will receive their ATP for flight. Guest investigations for this second mission can be selected from any of the upcoming NRAs.

BEST

The BEST Experiment will study the effects of applying heat to confined liquid helium using three parallel thermal conductivity cells, one with bulk liquid helium and the other two confining the helium to one or two small dimensions. In one cell the helium is confined in cylindrical holes (one dimensional confinement); in the other non-bulk cell, the helium is contained in rectangular cross section holes. The thermal conductivity in the three cells will be measured simultaneously to provide information on cross-over behavior as the number of dimensions changes from three to two or three to one.

SUMO

All of experiments flying in the LTMPEF except for SUMO are condensed matter experiments performed on samples of liquid helium (\(^3\)He or \(^4\)He). SUMO belongs to a class of experiments exploring gravitational and relativistic physics using the technological advantages provided by a low temperature microgravity environment. SUMO will perform gravitational and relativity experiments utilizing a ultra-stable superconducting microwave cavity oscillator. SUMO can be used for both relativity and clock experiments either by itself or in conjunction with other types of clocks on the ISS or on the ground. SUMO can also be used as a local oscillator for experiments with cold-atom clocks on the ISS like the NASA experiments RACE or the ESA experiment ACES.

6. Status and Conclusions

The LTMPEF is currently moving into the critical design phase, with a Critical Design Review (CDR) scheduled for late 2002. While the overall system is at the design phase, several components of the design have started their flight build including the helium dewar and the cryogenic insert. Also, prototypes of several critical pieces of hardware, including prototype instrument sensor packages for both the primary experiments on the first mission, have been developed and successfully performance tested. After passing the system CDR, the flight build for all subsystems of the LTMPEF will begin. All the components of the Facility will be delivered to JPL for integration in late 2003 or early 2004.

The LTMPEF will provide the unique environment of low temperature and microgravity for experiment desiring a long duration for data collection. When the facility is launched in late 2005, it will provide exciting new science investigation opportunities onboard the International Space Station. JPL will provide the necessary infrastructure and service to enable a user-friendly interface to the scientific community, making easy and low cost access to space a reality for scientists.

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References


**Biography**

**Dr. Melora Larson** is a Senior Member of the Technical Staff at the Jet Propulsion Laboratory (JPL). She has worked on space related projects since she was an undergraduate at Stanford University where she worked on the Gravity Probe-B experiment. She has worked at JPL since receiving her Ph.D. from the University of California, Santa Barbara. At JPL, she has been the cryogenic cognizant engineer and deputy Project Scientist on the Confined Helium Experiment (CHeX), the facility manager for the SIRTF telescope test facility, and a flight definition principle investigator on an experiment for the International Space Station. She is currently the Project Scientist for the first mission of the LTMPE.

**Dr. Talso Chui** is a Principal Technical Staff member at the Jet Propulsion Laboratory. He began his career at Stanford University co-developing the high-resolution thermometer, which, he later showed, to have reached the limited imposed by thermodynamic fluctuations. He participated in two successful flight experiments, the Lambda Point Experiment and the Confined Helium Experiment, to study the properties of helium very near the superfluid transition of 4He. After joining JPL he has continued his research on the dynamic properties of superfluid helium and participated, in various roles, in the development of the Low Temperature Microgravity Physics Experiment Facility. His achievements at JPL include, the theoretical prediction that the heat capacity of superfluid helium diverges under a heat flux, and the first observation of the Josephson effect in superfluid 4He. He graduated from Caltech with a B.S. degree and from Rutgers University with a Ph. D. degree in physics.

**Arvid Croonquist** has worked at JPL for 25 years. He was the Project Scientist for the Drop Physics Module. He is currently the System Engineer for the LTMPE project. He graduated from the California Institute of Technology.

**Dr. Warren Holmes** received his Ph.D in physics from University of California at Berkeley in 1998 working for Prof. P.L. Richards. After graduating, he worked briefly as post doctoral researcher for Prof. M.D. Fayer in the Chemistry Department at Stanford University before becoming a member of the technical staff at the Jet Propulsion Laboratory in Pasadena, CA in August 1998. His career work is focused on mid and far infrared measurement and cryogenic technology. Recently, he has developed a lightweight, high strength, thermomechanical platform for cryogenic experiments on the LTMPEF and adapted infrared bolometer technology to sense heat deposited by energetic particles in space. He is currently testing the bolometric detectors for the High Frequency Instrument of the ESA/NASA mission Planck to measure anisotropy of the Cosmic Microwave Background.

**Don Langford** is the Mission Manager for the first mission of the LTMPE. He has previously worked on the Confined Helium Experiment, the Infrared Astronomical Satellite (IRAS) and the Mars Atmospheric Water Detector (MAWD). He graduated from the University of Texas at Arlington.

**Dr. Feng-Chuan Liu** is the Deputy Project Manager for the LTMPE project. He has previously worked for the LTMPF, and he was Project Scientist for the DYNAMX project when DYNAMX was going to fly as a Space Shuttle mission. Dr. Liu received his Ph. D. from the University of Washington in low temperature physics. He then took a post doctoral appointment with Prof. G. Ahlers at the University of California, Santa Barbara. He left UCSB to work at JPL.
John Pensinger is the Project Manager of the Low Temperature Microgravity Physics Experiments (LTMPE) Project at JPL. He has also worked on the Shuttle Radar Topography Mission (SRTM), and Cassini for JPL. Prior to Cassini, he worked at TRW on communication satellite systems. He graduated from Texas A and M University.