Laser Cooled Atomic Clocks in Space

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Overview of LCAP Flight Projects

• PARCS (Primary Atomic Reference Clock in Space):
  Development of a laser cooled and trapped cesium clock for the realization of the unit of time, to operate continuously for at least 30 days. Use of orbiting clock for relativity experiments and global precise time distribution.

• RACE (Rubidium Atomic Clock Experiment):
  Development of a laser cooled and trapped Rubidium clock for ultrahigh accuracy (exceeding a part in $10^{16}$), to operate continuously for at least 30 days. Use of clock for relativity experiments and cold collision studies.

• GLACE (Glovebox Laser cooled Atomic Clock Experiment):
  Demonstration of laser technology for future LCAP flights, as well as a test of laser cooling techniques in microgravity, in particular those required for the LCAP clock experiments.
Space Clock 101

Source: Prepare cold sample of atoms, and launch along cavity axis

State Selection: Prepare atoms in a particular state

Microwave Clock Cavity: Induces atoms to make a transition from one atomic level to another

Detection region: Read out the state of atoms to determine whether they've undergone transition

Graph: Relative Microwave Freq. (MHz)

-5 0 5 10 15 20 25 30 35

0 10 20 30 40 50 60
LCAP Instrument Block Diagram

Laser and Optics Section

Electronics Package
- Laser Control
- Microprocessor
- Magnetic Field Control
- Clock Electronics

Physics Package
- MOT Collection Region
- Cooling and Launch
- add'l cooling, state selection
- Clock Cavity
- Detection
Physics with Clocks in microgravity

- Gravitational frequency shift
- Local Position Invariance
- Kennedy-Thorndike Experiment
LCAP Timeline

- JPL Laser Cooling Facility created (Mar 97)
- First trapped Cs images at JPL (Oct 97)
- PARCS project passes its SCR (Jan 99)
- JPL Laser Cooling Facility created (Mar 97)
- Two Flight definition projects selected from '96 NRA (PARCS and RACE) (Nov 97)
- Ground-based prototype clock operational (Sept 00)
- Flight Unit complete. Astronaut training begins (Sept 02)
- Engineering model complete (May 01)
- Space Qualification of components complete (May 03)
- Integration into Express Transportation Rack (Mar 03)
- Integration into Shuttle MPLM (May 03)
Collect: $N_0 = 8 \times 10^7$ cold atoms/ball
Launch: $N_{m=0} = 9 \times 10^6$ in $m=0$ with 2 balls/s
Detect: $N_D = 1.5 \times 10^4$
Ramsey Time: $T_R = 5$ s
Cycle Time: $T_c = 15$ s

Source “brightness” achieved so far:
1) $N_0 \sim 2 \times 10^8$ (in 1 sec.) in vapor cell molasses (Ch. Salomon, Paris)
2) $N_0 \sim 5 \times 10^7$ (in 1 sec.) in small beam filled molasses (NIST Fountain)
**GLACE: Glovebox Laser-cooled Atomic Clock Experiment**

**Principle Investigator:** K. Gibble (Yale)

**Goals:**
- First utilization of tunable, frequency-stabilized lasers (300 kHz @ 852 nm) in space.
- Demonstrate laser cooling and trapping in microgravity.
- Demonstrate longest ‘perturbation-free’ interaction time for a precision measurement on neutral atoms.
- Resolve Ramsey fringes 2–10 times narrower than achievable on Earth.

**Approach:**
- COTS components (HP 5071 cavity, commercial lasers and vacuum components).
- Utilize prototype hardware from LCAP flight definition experiments.

**Launch date:** Oct. 2002 (UF-3)
Space Qualification of Components

Shuttle requirements:
• Vibration Testing:

<table>
<thead>
<tr>
<th>Freq. Range</th>
<th>Design/Protoflight (PF)</th>
<th>Flight Acceptance (FA)</th>
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<tbody>
<tr>
<td>20 to 150 Hz</td>
<td>+6dB/Octave</td>
<td>+6dB/Octave</td>
</tr>
<tr>
<td>150 to 1000 Hz</td>
<td>0.06 g2/Hz</td>
<td>0.03 g2/Hz</td>
</tr>
<tr>
<td>1000 to 2000 Hz</td>
<td>-6dB/Octave</td>
<td>-6dB/Octave</td>
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Duration: Design: 2 minutes; PF or FA test: 1 minute

• Temperature:
Must survive over a -5 to 50°C range

New Focus Vortex laser on vibration test bed at JPL
ISS Science Platforms:

Express Pallet

• For External Payloads

Microgravity Science Glovebox (MSG)

• 260 liter working volume
Microgravity Science Glovebox

MSG specifications

- **Working volume:**
  260 liters (92 cm×65 cm×50 cm)

- **Vibrational isolation:**
  
<table>
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<tr>
<th>Frequency Range</th>
<th>RMS Acceleration</th>
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<tr>
<td>0.01–0.1 Hz</td>
<td>&lt; 0.21920 µg</td>
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<tr>
<td>0.1–100 Hz</td>
<td>&lt; f×0.21920 µg/Hz</td>
</tr>
<tr>
<td>100–300 Hz</td>
<td>&lt; 219.20 µg</td>
</tr>
</tbody>
</table>

- **Electrical power**
  1000 W (8.3 A @ 120 V, 7 A @ 28 V, 2 A @ ±12 V, 4 A @ 5 V)

- **Heat dissipation**
  1000 W (800 W via coldplate, 200 W via air flow)

- **Data I/O**
  RS-422, MIL STD 1553B, digital I/Os, analog outputs, ethernet.