Clock Technology Development in the Laser Cooling and Atomic Physics (LCAP) Program

Dave Seidel, R.J. Thompson, W.M. Klipstein, J. Kohel, L. Maleki

Time and Frequency Sciences and Technology Group
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
U.S.A.
Credits

**JPL:** LCAP program

Dave Seidel (Systems Engineer)
Rob Thompson (Instrument Manager)
Lute Maleki (Group Sup./Proj. Scientist)
Jim Kohel
Bill K lipstein

GPS Carrier Phase:
Larry Young
Sien Wu

Project Management:
Mike Devirian (Program Manager)
Gail Klein (Project Manager)
Ed Dobkowski (Quality Assurance)
Ulf Israelsson (Discipline Scientist)
Richard Beatty (ISS Program Engineer)

**Yale:** GLACE, RACE, LCATS

**Kurt Gibble**

**NIST:** PARCS, LCATS

Don Sullivan
Tom Heavner
Leo Hollberg
Steve Jefferts
John Kitching
David Lee
Judah Levine
Dawn Meekhof
Craig Nelson
Tom Parker
William Phillips
Hugh Robinson
Steve Rolston
Fred Walls
Andrea De Marchi (Torrino)

**CU:** PARCS, LCATS

Neil Ashby

**SAO:** PARCS

Bob Vessot
Ed Mattison
Overview of LCAP Flight Projects

International Space Station

• PARCS (Primary Atomic Reference Clock in Space): NIST/CU
  Laser-cooled cesium primary frequency standard (10^{-16} accuracy) operating continuously for at least 30 days, with GPS capability. Will perform relativity experiments and global precise time distribution.

• RACE (Rubidium Atomic Clock Experiment): Yale
  Laser-cooled 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.

Space Shuttle

• LCATS (Laser Cooled Atomic Timekeeping in Space): Joint PARCS/RACE team.
  Flight of laser-cooled microgravity atomic clock along with high stability ion clock/H maser and GPS capability for relativity experiments, tests of spatial isotropy. Tests time transfer and clock technology with some science return.
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)
Physics with Clocks in microgravity

• Gravitational frequency shift
  (requires stable frequency transfer to ground)

• Local Position Invariance
  (requires comparison to another oscillator)

• Kennedy-Thorndike Experiment
  (requires cavity oscillator such as SUMO)
Space Clock Challenges

Laser Cooling Source
- Lasers
- Optical Frequency Control
- Fibers
- Fluorescence detection
- Vacuum chamber
- Computer Control
- Electronics
- Magnetic field control
- Atom Source

Clock Parts
- Microwave electronics
- Local Oscillator
- Synthesizer
- Cavity
- More magnetic field control
- Thermal Control
- Light Baffling/Shutters
- Vacuum requirements
- Measurement System
LCAP Timeline

- JPL Laser Cooling Facility created: Mar 97
- First trapped Cs images at JPL: Oct 97
- Two Flight definition projects selected from '96 NRA (PARCS and RACE): Nov 97
- PARCS project passes its Science concept review: Jan 99
- Ground-based prototype clock operational: May 01
- Engineering model complete. Critical Design review: Sept 01
- Space Qualification of components complete
- Flight Unit complete. Astronaut training begins: Sept 02
- Integrated into Express Transportation Rack: Mar 03
- Launch: May 03
ISS Science Platforms

A) Centrifuge Accommodation Module
B) Columbus Orbiting Facility
C) Japanese Experiment Module (JEM)
D) JEM external facility
E) US Lab

Not shown: Russian Laboratories, Express Pallets
ISS Express Rack

Cesium Clock Package

- Physics Package (x 87cm)
- Electronics Package (x 80cm)
- Laser Package (x 80cm)
- Dimensions:
  - 26cm x 30cm
  - 46cm x 15cm
  - 46cm x 45cm

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Constraint</th>
<th>Reserve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>130Kg</td>
<td>195Kg</td>
</tr>
<tr>
<td>Power</td>
<td>&lt; 500W</td>
<td>&lt;2kW</td>
</tr>
<tr>
<td>Volume</td>
<td>162 liters</td>
<td>248 liters</td>
</tr>
<tr>
<td>length</td>
<td>87cm</td>
<td>90.7cm</td>
</tr>
<tr>
<td>depth</td>
<td>46cm</td>
<td>51.6cm</td>
</tr>
<tr>
<td>height</td>
<td>45cm</td>
<td>53.1cm</td>
</tr>
</tbody>
</table>

NOTE: SAMS interface available in ARIS Rack only.
Space Qualification of Components

Shuttle requirements:

• Vibration Testing:

Instrument should operate after exposure to:
Freq. Range   Design/Protoflight (PF)   Flight Acceptance (FA)
20 to 150 Hz   +6dB/Octave            +6dB/Octave
150 to 1000 Hz 0.06 g²/Hz            0.03 g²/Hz
1000 to 2000 Hz -6dB/Octave          -6dB/Octave

Duration: Design: 2 minutes; PF or FA test: 1 minute

• Environment:

Instrument should operate after exposure to:
Temperature: -5 to 50 C
Pressure: 786 torr to 204 torr (1240 torr/min Max Depressurization rate)
Humidity: 20 to 70%

• Radiation:
~100x Earth dose

New Focus Vortex laser on vibration test bed at JPL
Laser Configuration

First layer: master laser and frequency control

second layer: repump and laser lock

38 cm

46 cm
Clock Rate Comparisons: GPS Carrier Phase Frequency Transfer
GPS Carrier Phase Frequency Transfer

GPS carrier phase technique expected to give:
- 100 ps resolution
- < 10 cm position information
- < 1mm/s velocity information

Issues:
- Need external antennae
- No high quality rf/optical link between interior/exterior
- Multipath worrisome (need ~-70 dBm)
- Visibility of satellites (desire ~12 in view)

Existing GPS antennae will see between 3-6 satellites
Give Position Information to 100 m
ISS Model Views

“Normal” View

Another “Normal” View

Centrifuge Accomodation Module (CAM)

US lab

ESA Module

JEM

JPL