U.S.A.
Pasadena, CA 91109
California Institute of Technology
Jet Propulsion Laboratory

Technology Group
Time and Frequency Sciences and

J. Kohel, I. Maleki
Dave Seidel, R.J. Thompson, W.M. Kipplestein,

Laser Cooling and Atomic Physics (LCAP) Program
Clock Technology Development in the
ED Matison
Bob Vespoli

SAO: PARCS
Neil Ashby

CU: PARCS, LCATS
 Andrea De Marchi (Tomino)
 Fred Walls
 Steve Rolison
 Hugh Roppinson
 William Phillips
 Tom Parker
 Craig Nelson
 Dawn Meekham
 Judith Levine
 David Lee
 John Kichling
 Steve Jeffers
 Leo Hohidel
 Tom Heaver
 Don Sullivan

Kurt Gibble

NIST: PARCS, LCATS
Yale: GLACE, RACE, LCATS

Credits

Richard Beatty (ISS Program Engineer)
ULI Israelsson (Discipline Scientist)
ED Dobkowski (Quality Assurance)
Gail Kizia (Project Manager)
Mike DeVincent (Program Manager)
Project Management:

Steven Wu
Larry Young

GPS Career Phase:

Bill Kippen
Jim Kohel

Luci Mellek (Group Sup/Proj. Scientist)
Rob Thompson (Instruments Manager)
Dave Slejd (Systems Engineer)

JPL: LAP Program
With some science return.
capability for relativistic experiments, less of spatial isotropy. Tests time transfer and clock technology.
FLIGHT of laser-cooled microgravity atomic clock along with high stability ion clock/H maser and GPS.

Space Shuttle

For at least 30 days use of clock for relativistic experiments and cold collision studies.
laser-cooled Rubidium clock for ultra-high accuracy (exceeding a part in 10^16) to operate continuously.
RACE (Rubidium Atomic Clock Experiment): Yale.

PARCS (Primary Atomic Reference Clock in Space): NIST/CU.

International Space Station

Overview of LCRP Flight Projects
SUMO
(requires cavity oscillator such as
Kennedy-Thorneike Experiment

(oscillator)
(requires comparison to another
Local Position Invariance

(Ground
(requires stable frequency transfer to
Gravitational Frequency Shift

Physics with Clocks in Microgravity
Space Clock Challenges

Clock Parts

- Microwaves Electronics
- Synthesizer
- Local Oscillator
- Cavity
- More magnetic field control
- Thermal Control
- Light Baffling/Shutters
- Vacuum Requirements
- Measurement System

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

Parts

JP
LCAP Timeline

- **Launch**: Mar 03
- **Transportation**: May 03
- **Integration into Rack**: Sept 02
- **Training Begins**: Sept 02
- **Complete Critical Design Review**: Sept 01
- **Complete Rack**: May 01
- **Satellite Specifications**: Jan 99
- **Two Flight Definition**: Oct 97
- **69 MAE (RACE)**: Nov 97
- **FIRST Laser Cylinder**: Dec 97
- **JPL/Laser Created**: Jan 97
- **Cylindrical Radiating Energy (CARE)**: Feb 97
- **2010**: Mar 10
- **Space Qualification Complete**: May 10
- **First Trapped Cs Images at JPL**: Oct 01
- **Complete Concept Review**: Jan 00
- **Ground-based Prototype Cock**: Sept 00
- **Destructive Model**: May 00
- **Launch**: Sept 00
<table>
<thead>
<tr>
<th>Requirement</th>
<th>Constraint</th>
<th>Reserve</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1 cm</td>
<td>5.6 cm</td>
<td>3.7 cm</td>
</tr>
<tr>
<td>51.6 cm</td>
<td>90.7 cm</td>
<td>45 cm</td>
</tr>
<tr>
<td>248 liters</td>
<td>162 liters</td>
<td>&gt; 500W</td>
</tr>
<tr>
<td>1.5 kW</td>
<td>&gt; 2 kW</td>
<td>1300 kg</td>
</tr>
<tr>
<td>65 kg</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Specifications:***
- Height: 45 cm
- Depth: 46 cm
- Length: 87 cm
- Volume: > 500 liters
- Power: > 2 kW
- Mass: 1300 kg

**Diagram Notes:***
- Master
- SAV
- Clock
- Cesium
- 46 cm
- 45 cm
- 30 cm
- 20 cm
- 26 cm
- 20 cm
- 80 cm
- 80 cm
- 87 cm

**ISS Express Rack**

**PARCS**
Vibration Test Bed at JPL
New Focus Vortex Laser on Space Qualification of Components

Radiation:

-100x Earth dose

Environment:

Humidity: 20 to 70%
Pressure: 78 Torr to 204 Torr (1240 Torr/min Max Depressurization Rate)
Temperature: -5 to 50°C
Instrument should operate after exposure to:

Duration: Design: 2 minutes; PP or PA test: 1 minute

-6dB/Decade
0.03 Hz
0.06 Hz
150 Hz
20 Hz

Freq. Range: Design/Prototype (PP) Flight Acceptance (PA)

Instrument should operate after exposure to:

Vibration Testing:

Shuttle Requirements:
Clock Rate Comparisons: GPS Carrier Phase Frequency Transfer
Give Position Information to 100 m
Existing GPS antenna will see between 3-6 satellites

Visibility of satellites (desire ~ 12 in view)
Multipath Worumome (need ~ 70 dBm)
No high quality RF/optical link between interior/exterior
Need external antenna

Issues:

> 1 m/s velocity Information
> 10 cm position Information
100 ps Resolution

GPS carrier phase technique expected to give: GPS Carrier Phase Frequency Transfer