Engineering Developments for the Primary Atomic Reference Clock in Space (PARCS) Experiment

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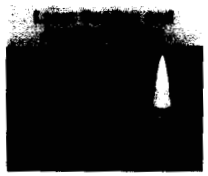
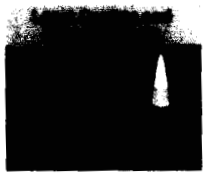


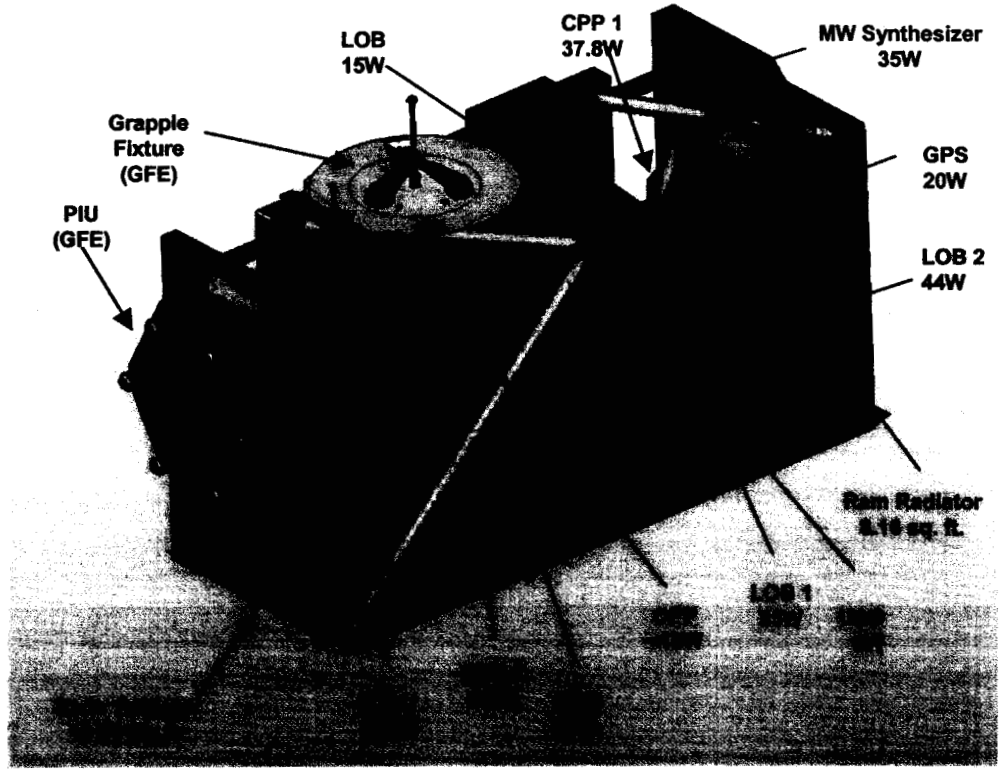
PARCS Development Overview

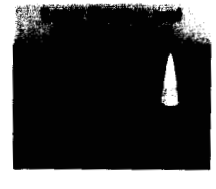
- **PARCS Description**
  - PARCS Configuration
  - System Block Diagram
  - PARCS/SUMO Link
- **PARCS Development Approach**
  - "Rapid Prototyping"
  - Technology Readiness Levels
- **PARCS Major Subsystem Developments**
  - Laser Optical Subsystem
  - Cesium Physics Package



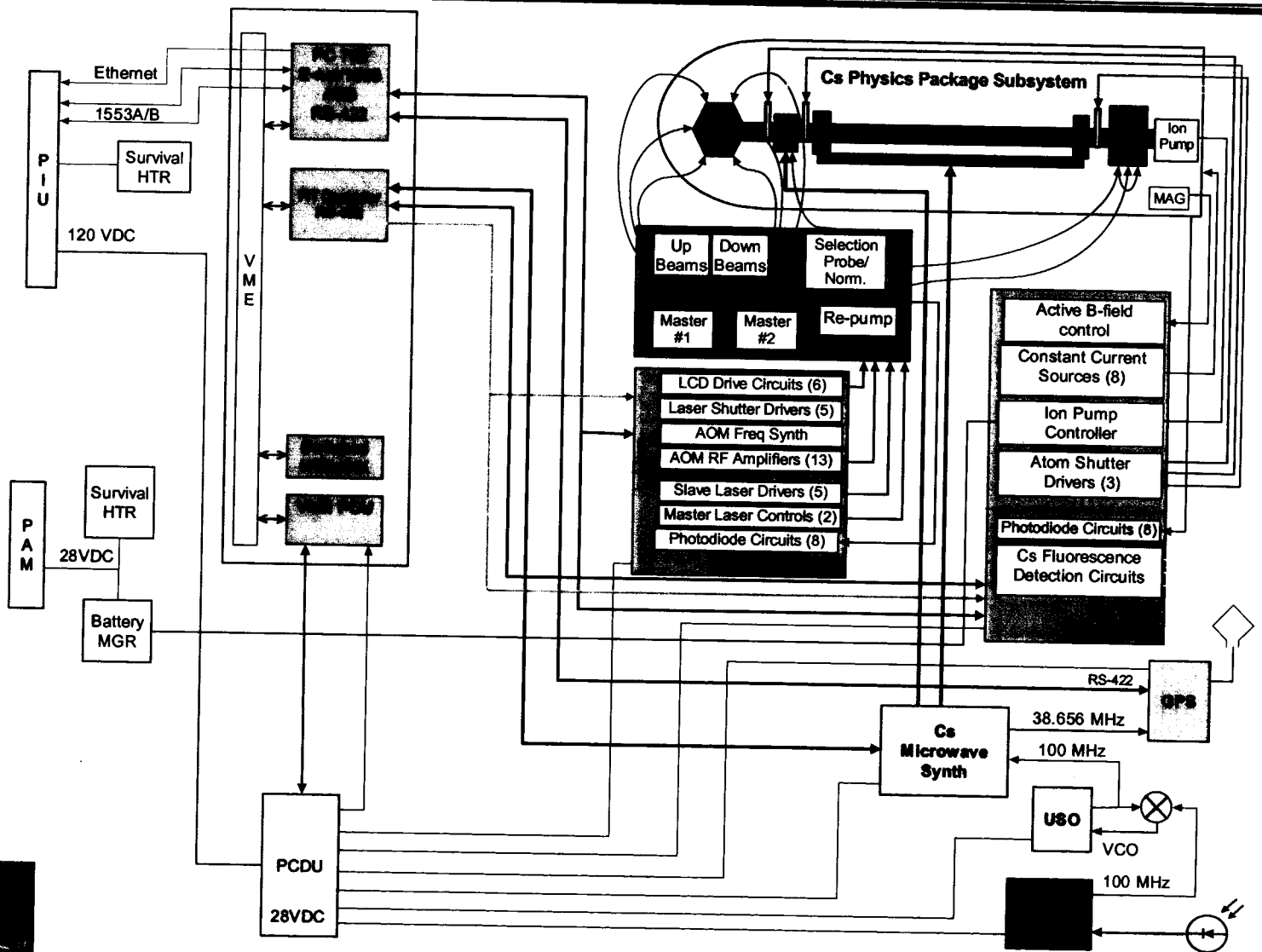
PARCS Configuration

- **PARCS Flight System**
  - Mass: 450 kg (CBE)
  - Power: 400W (CBE)
  - Size: 1 m x 0.8 m x 1.8 m
  - Ram (or Zenith) facing JEM-EF module
- **Major Subsystems:**
  - Laser Optical Bench (LOB)
  - Cs Physics Package (CPP)
  - Microwave Synthesizer
  - GPS Receiver
  - Avionics
  - Instrument Electronics
  - Structure/Thermal Control



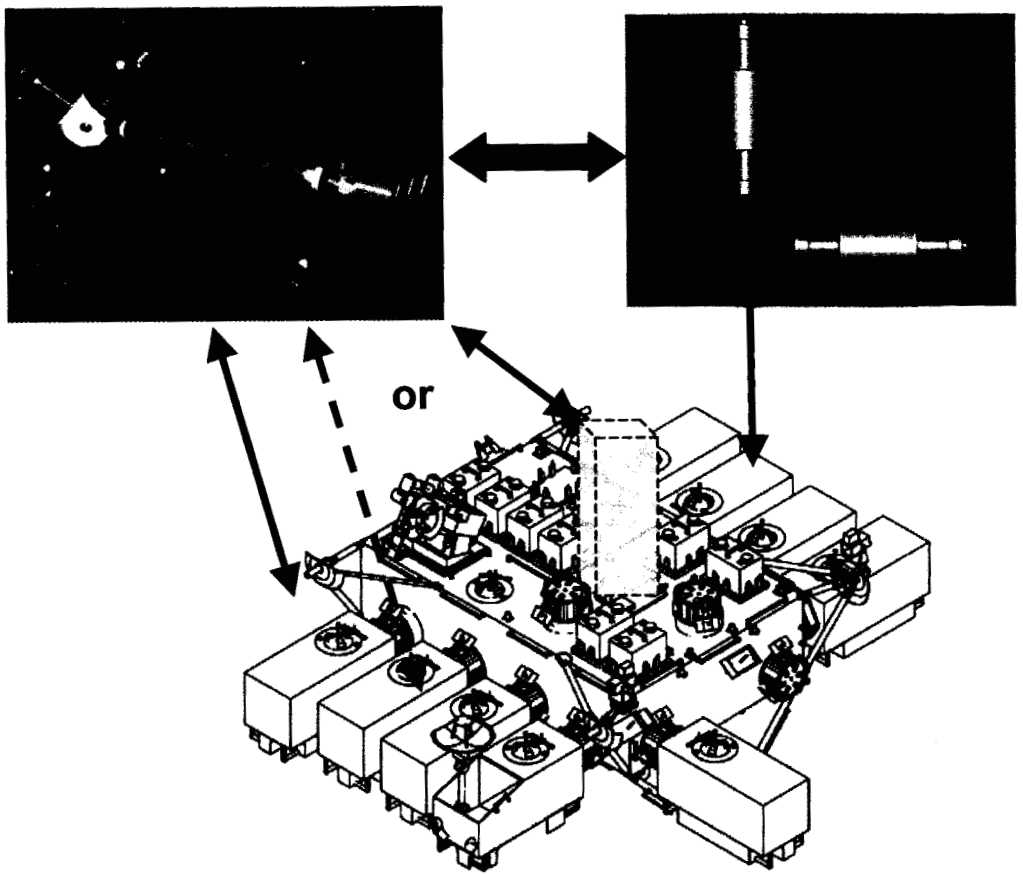


PARCS Block Diagram

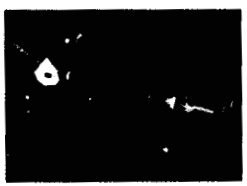


PARCS/SUMO Connection

- **PARCS/SUMO Link**
  - Ultra-high quality RF signal
  - Allan deviation < $3 \times 10^{-14}/\tau$
  - Reject motion-induced path changes, multi-path effects (two-way link required)
- **Link Options**
  - Direct optical fiber
  - Direct coaxial cable
  - Free-space optical beam
  - Unshielded wire link (within JEM-EF)
  - Omni-directional RF link
  - Affected by PARCS location (EFU #1, #5, or #11)

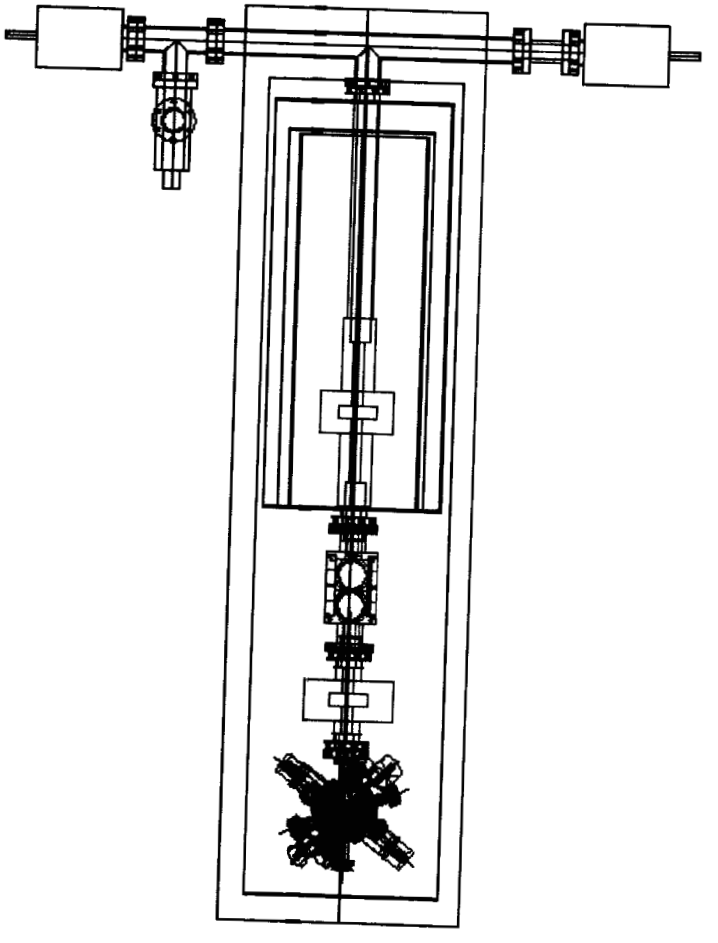


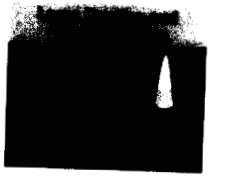
View of JEM-EF from top side
(RAM direction is toward the left)



PARCS Development Approach

- "Rapid Prototyping" paradigm:
  - "Build a little, test a little" for developing new technology items
  - Evaluate risks & mitigation schemes
    - Technology Insertion and Maturity Assessment (TIMA) process using Defect Detection Prevention (DDP) risk analysis tool
  - JPL Cs Fountain (PARCS-like testbed)
    - Status: state-selected cold atoms produced
  - Extensive use of models, simulators breadboards, prototypes and engineering model hardware during concurrent subsystem development
    - Early validation of subsystem/system support equipment
  - Concurrent LabVIEW flight software development at NI and at JPL
- Avoid surprises in System-level integration and test!

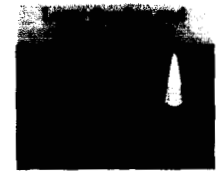




Technology Readiness Level (TRL) Assessment

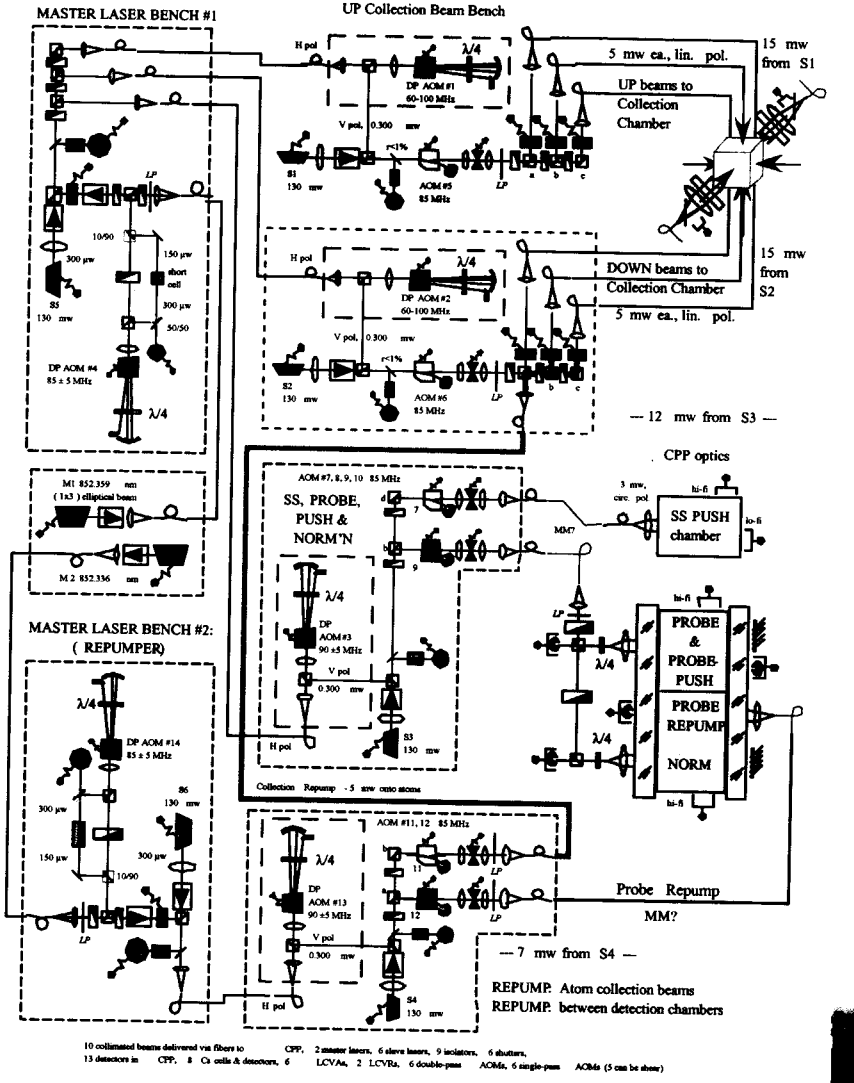
- **PARCS Component TRL's**
  - **TRL 7 or higher:** GPS, USO
  - **TRL 6**
    - 120VDC converters
    - MPC750 266 MHz PowerPC SBC
  - **TRL 5:** Magnetic shields
  - **TRL 4**
    - **Master Laser, AOMs, Laser Shutters,** Beam Delivery Collimators, LCD attenuators
    - Laser Cooling Technique, **MW cavities,** magnetics control
    - MW Synthesizer, Laser/AOM control electronics, fluorescence collection optics, Cs MW feed
  - **TRL 3 → 4**
    - **Atom shutters**

TRL	NASA Technology Readiness Level Definition
1	Basic Principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof-of-concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
7	System prototype demonstration in a space environment
8	Actual system completed and "flight qualified" through test and demonstration (ground or space)
9	Actual system "flight proven" through successful mission operations

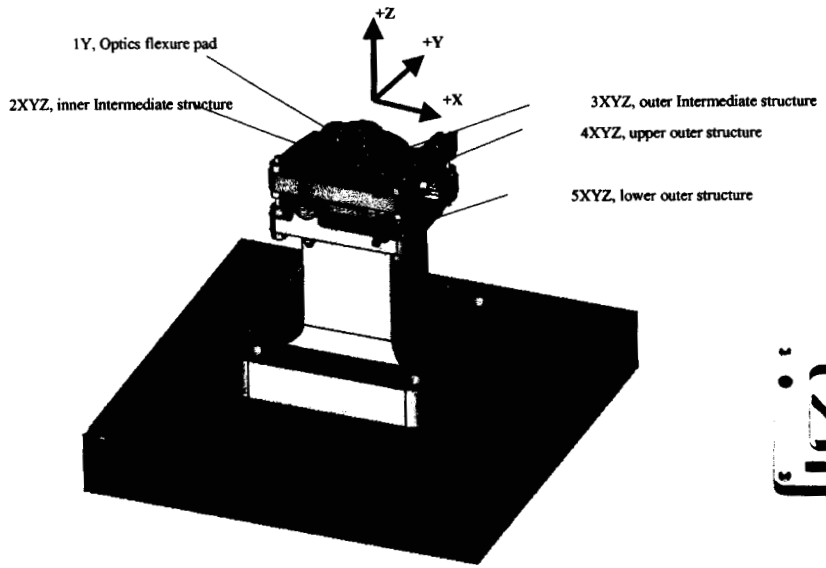


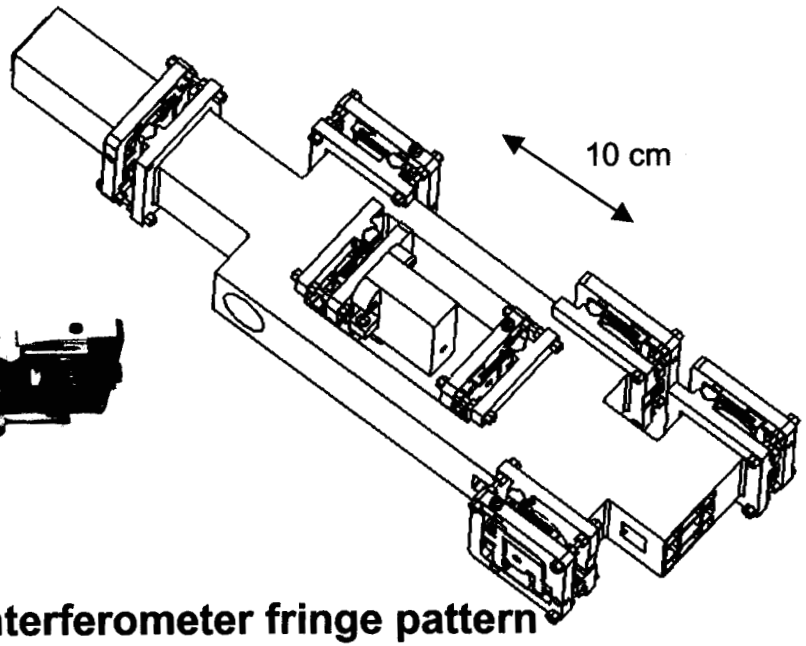
Laser/Optical Bench

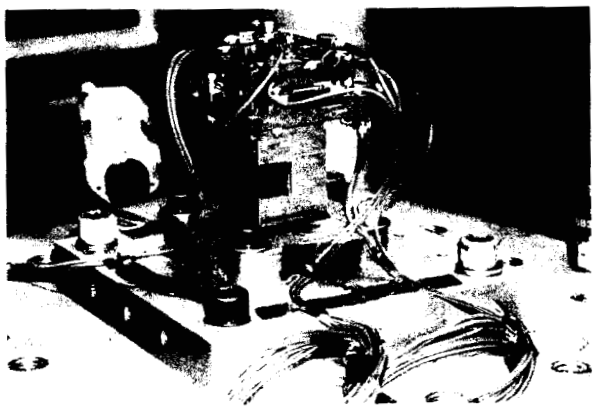
- Generate laser beams for:
  - Collection, Launch and Post-cool region (6 beams plus repump)
  - State selection (push beam)
  - Detection (probe/push, normalization plus repump)
- Each beam has specified:
  - Stabilized power
  - Controlled frequency
  - Polarization
  - Spatial profile
- LOB utilizes modular design
  - "Building-block" approach
  - UP Collection Beam Bench EM



PARCS LOB Opto-mechanical Design: SM fiber-coupling 4-DOF adjustable mounts

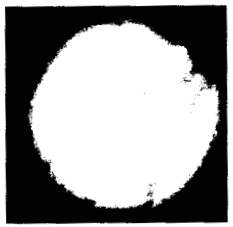






Zygo Interferometer fringe pattern

Baseline



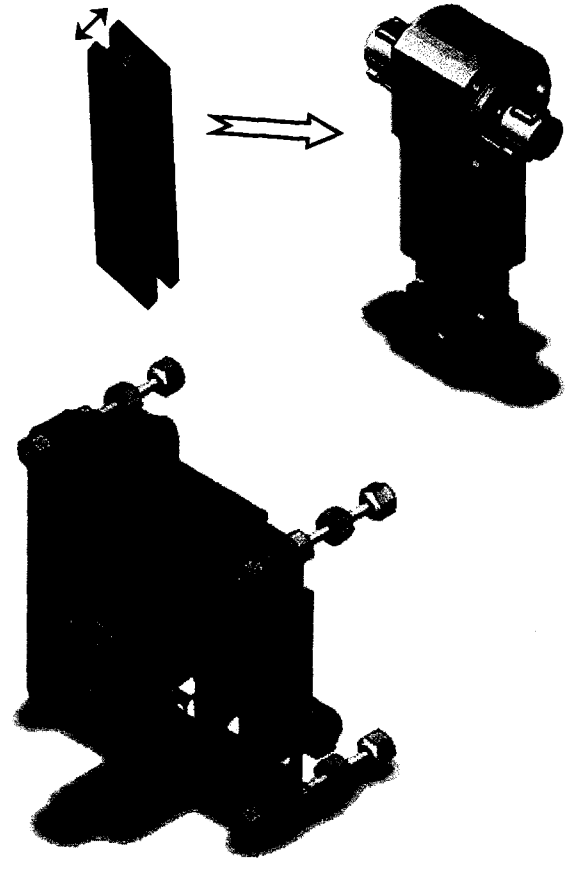
Post z-axis shake

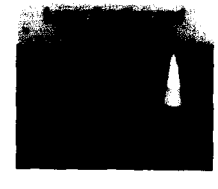
Post y-axis shake

Single fringe change: ~ 32 micro-radians (<7 arc seconds) of tilt.
Approx. 1% fiber coupling loss

Laser Shutters

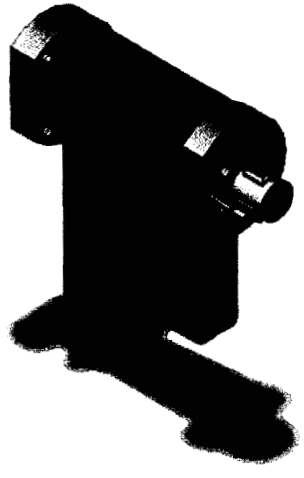
- Shutters with rapid response (< 3 msec), high attenuation (> 10^7) with very low mechanical disturbance and long-life are needed in PARCS
- Novel concept developed using PZT "benders" with optical "flags" positioned at a fast waist in the laser beam
- Initial prototype has been operated for over 60 million cycles (3x operational life)
- High-speed video imaging performed to analyze shutter motion – low jitter

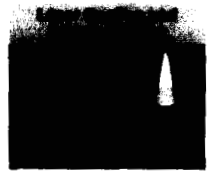




Acousto-Optical Modulators

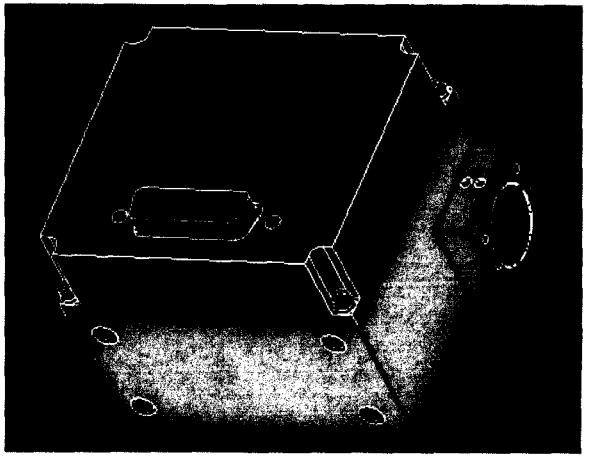
- PARCS utilizes various AOMs for laser frequency and amplitude control
- A phased-array AOM is in development for nearly constant diffraction efficiency over wide frequency range
- Flight AOMs are repackaged for attachment to 4-DOF mount with balanced thermal conductance from the crystal to an external heatsink

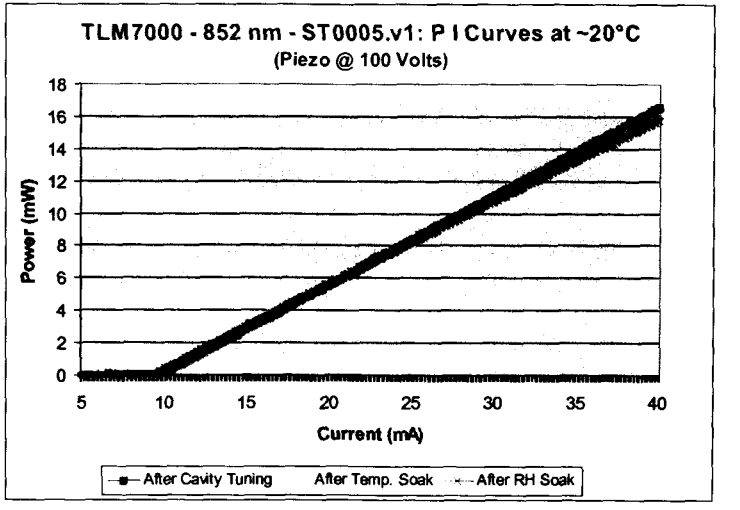


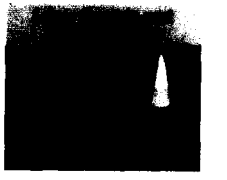


Master Laser

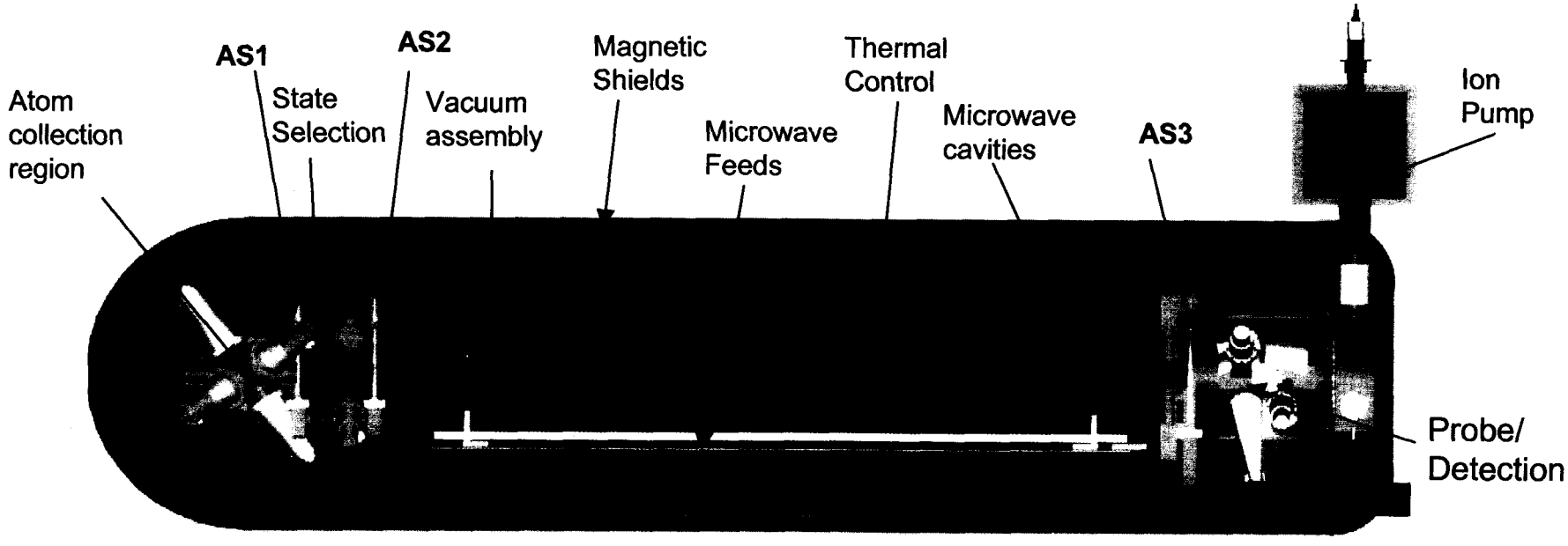
- **New Focus, Inc. External Cavity Diode Laser (ECDL)**
  - Modifications to existing New Focus platform
  - Tunable to Cs transitions in air and vacuum
  - Linewidth performance comparable to commercial Vortex laser used extensively on the ground.
  - Development reports exceeded goals for optical power, thermal performance.
  - Prototype delivered in late March 2003.
  - Vibration (launch survival and milli-g disturbance) and thermal cycle tests in work





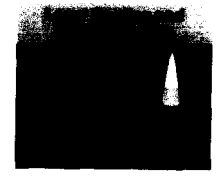


PARCS Cesium Physics Package



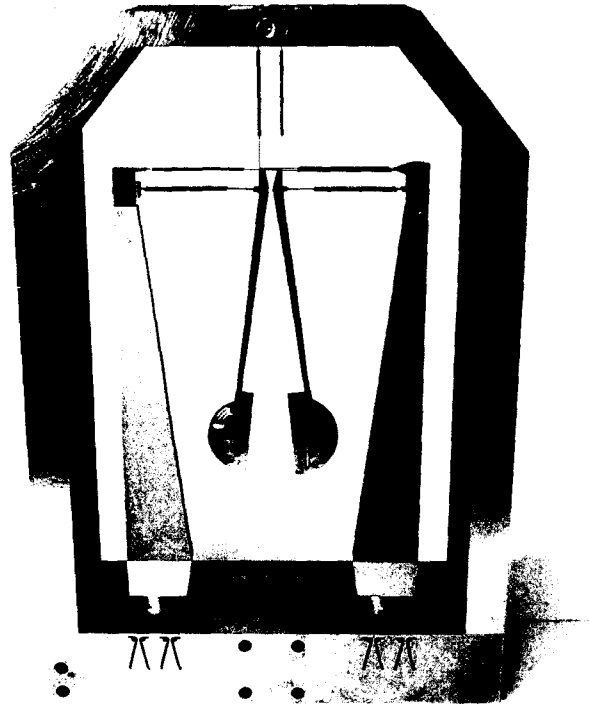
Major Components:

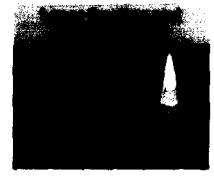
- 10 optical collimators
- **3 atom shutters (AS)**
- **3 microwave cavities (2 hi-fi)**
- **1 Ramsey microwave coupling structure**
- 1 SS microwave coupling structure
- 10-12 ceramic microwave coupling windows
- 17 optical windows
- 1 ion pump
- **Evaporative Getter Film**
- 1 Cs source
- 3 sets of atom fluorescence collection optics
- 6 DC coils (SS ,follow, C, R1, R2, P)
- 3 AC or variable coils (Z, Shield, Degauss)
- 1 field-control fluxgate magnetometer
- 4 magnetic shields
- 3 hi-fi fluorescence detectors
- 10 lo-fi laser power level detectors
- 3 heaters (3 zones)
- 3 control temperature sensors
- >5 monitor temperature sensors



PARCS Atom Shutter

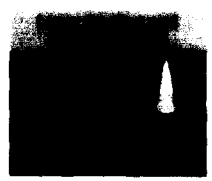
- PARCS uses atom shutters to exclude light from the Ramsey region and ballistic Cs from the detection zone
  - 1.5 cm clear aperture
  - >10^6 light attenuation
  - Fast response (<15 msec)
  - Long operating life
  - UHV compatible
  - Low disturbance mechanism
  - Non-magnetic materials, actuator
- Flexure-based, high motion amplification (>700x), PZT-driven shutter prototype developed
- Initial mechanical characterization performed (high-speed imaging)
- Optimized drivers in development
- Environmental test plans in work

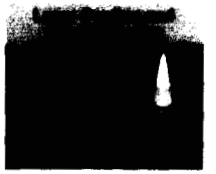




Summary

- New technology developments have been quite successful in meeting PARCS performance needs
- PARCS functional requirements and subsystem designs are rapidly maturing
- Subsystem "peer design reviews" this summer, system preliminary design review in the fall
- Parallel development plan in place through integration and test of the PARCS flight system to meet funding and schedule constraints



PARCS Team

- Principal Investigator: Donald Sullivan, NIST
- Project Manager: David Seidel
- Project Scientist: William Klipstein
- Flight System Manager: David Brinza
- Subsystem Leads:
  - Cs Physics Package: Eric Burt
  - Laser Optical Bench: Eric Hochberg
  - GPS: Ian Harris
  - Avionics: Phil Yates
  - Instrument Electronics: Tom Radey
  - Mechanical Systems: Wes Schmitigal
  - Thermal Control: Robert Krylo
- NIST Development Support:
  - Steve Jefferts, Tom Heavner, Leo Hollberg, Elizabeth Donley, Neil Ashby
- JPL Development Support:
  - Daphna Enzer, Bob Glaser, Don Moore, Ted Ozawa, Robb Thompson, Michelle Coleman, Cesar Sepulveda, Andy Stone, Eric Kurzweil, Steve Cole, Boris Lurie, Albert Chen, Chris Smith (Swales), Rudy Vargas, JPL MTC, and many others