Environmental Testing of Lasers for JPL's Cold Atom Laboratory (CAL)

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What is CAL?

- CAL is a new, multi-user facility being developed for the International Space Station (ISS) at JPL.
- CAL will study ultra-cold quantum gases in the microgravity environment of space, leading to temperatures possibly as low as 10 picokelvin!
  -- At this point, matter stops behaving as particles and instead as macroscopic matter waves.
- CAL will be installed in an express rack and remotely operated by a team of scientists at JPL for at least 1 year.
- CAL is currently in the design-development stage and is scheduled to launch in 2016.

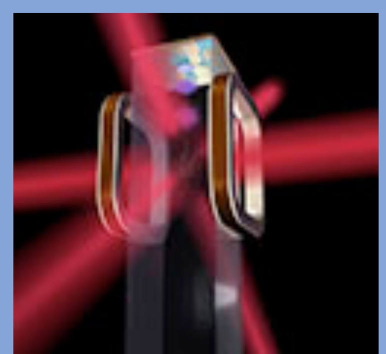

Figure 1: As part of the cooling process, CAL fires lasers from all six directions on neutral atoms in a vacuum-filled chamber. (Image source: http://coldatomlab.jpl.nasa.gov/)

How CAL Works

1. Laser Cooling
- Lasers from all 6 directions ("optical molasses"), tuned just below the target atoms' absorption point, fire on neutral atoms in a small vacuum-filled chamber.
- The Doppler Effect allows photons to excite and slow down the fastest atoms and pass right through all the others.
- Atom speed goes from ~200 m/s → ~1 cm/s

2. Trapping – The Magneto-Optical Trap (MOT)
- An inhomogeneous magnetic field is applied to the trapping region and is adjusted to shift laser color as needed.
- Optical molasses + magnetic field = MOT
- Number of trapped atoms is proportional to laser power

3. Evaporative Cooling
- The most energetic atoms are allowed to escape the magnetic trap.
- When the trap contains the most atoms at the coldest temperature, you have **Bose-Einstein Condensate (BEC)**.

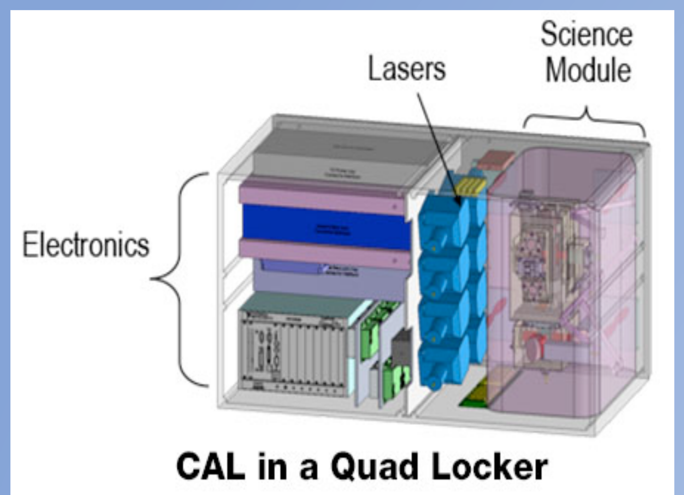

Figure 2: The setup of CAL on the ISS: electronics on the left, science module and laser assembly on the right. (Image source: http://coldatomlab.jpl.nasa.gov/instrument/)

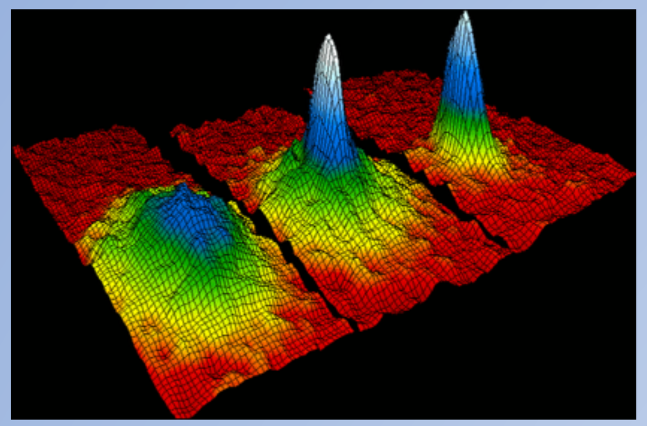

Figure 3: Density plots illustrating the BEC transition. (Image source: NIST/JILA/CU-Boulder)

Question

How do lasers behave at higher temperatures and increased vibration?

Goal

To test the performance of commercial and JPL-developed lasers under launch and post-launch conditions.

Environmental Testing Methods

Thermal	Vibrational
▪ Necessary test because diode lasers tune with temperature. ▪ Laser cavity temperature and power output are tracked as temperature is increased from 24°C (room temperature) to 42°C in 2- to 3-degree increments.	▪ Necessary because of laser's high sensitivity to movement. ▪ Involves other subsystems, including electronics and optomechanical.

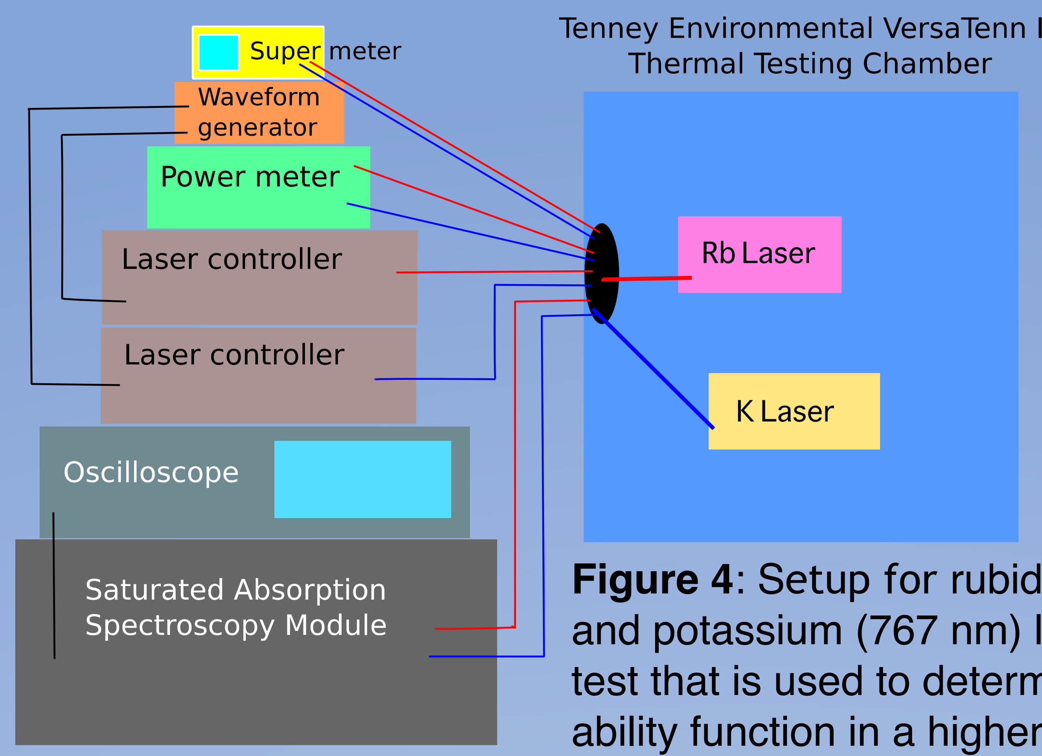

Figure 4: Setup for rubidium (780 nm) and potassium (767 nm) laser thermal test that is used to determine a laser's ability function in a higher-temperature environment.

Laser Diagnostic Measurements

1. Saturated Absorption Spectroscopy
- Used to verify the precise laser frequency or wavelength.
- Two counter-propagating laser beams (the *pump* and *probe* beams) at the same frequency interact with the same velocity subgroup of atoms in a vapor cell (see Figure 5 below).
- When the laser is on resonance with the atoms, there is a sharp decrease in absorption signal since many of these atoms have been pumped out of the ground state and will not be able to absorb any photons from the resonant probe beam (see Figure 6 below).

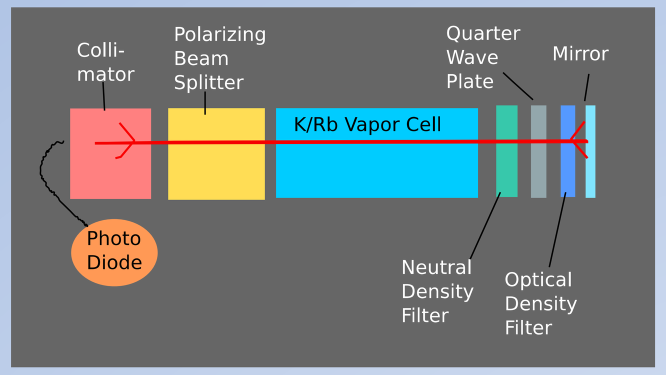

Figure 5: Saturated absorption spectroscopy module used to verify laser frequency or wavelength.

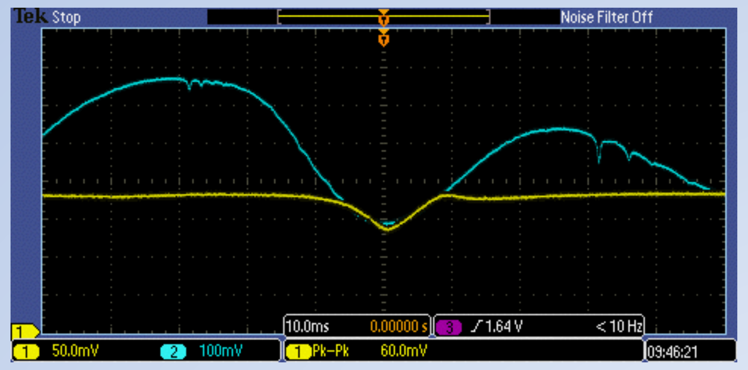

Figure 6: Screen grab from the oscilloscope. The dip indicates resonance of atoms in the vapor cell with the laser.

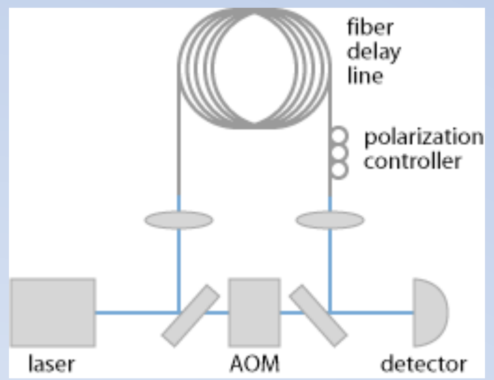

Figure 7: Setup for self-heterodyne test, which is used to verify laser linewidth.

2. Laser Linewidth Measurements
- Heterodyne Method: The generation of new frequencies, including a beatnote, by mixing two oscillating waveforms (see Figure 9).
- Delayed Self-Heterodyne Method: The generation of a beatnote between a laser beam and a delayed version of itself in order to measure the short-term laser linewidth, as in Figure 7.
- The laser linewidth, or breadth of laser frequencies, should be less than or equal to 1 MHz for laser cooling and detection of atoms.

Results

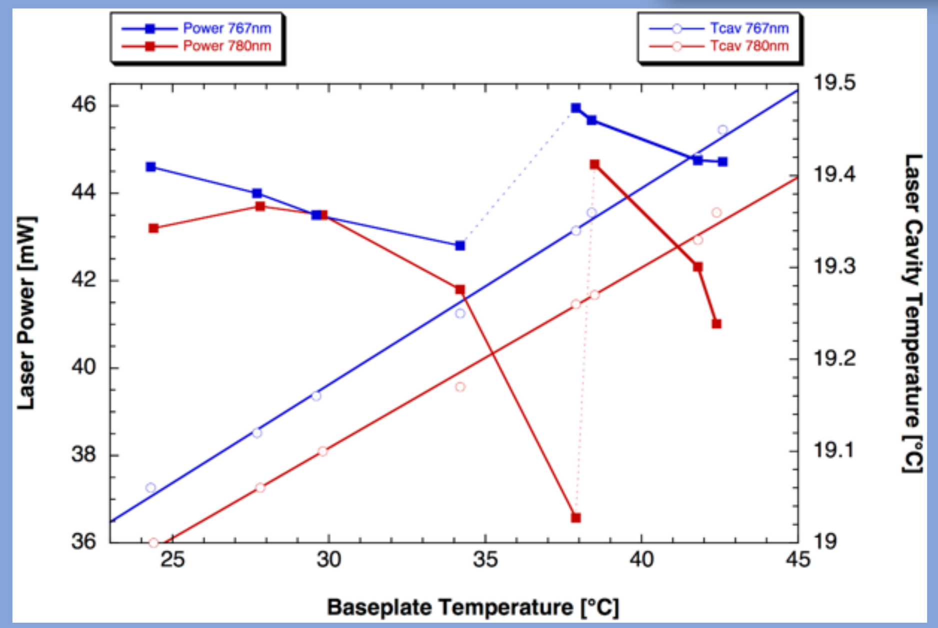

Figure 6: Thermal test results show a gradual decrease in laser power until just above 35°C, where laser frequencies jumped several GHz and laser power suddenly increased, indicating mode hops. CAL is expected to operate without mode hops up to and beyond the allowable flight temperature (AFT) of 35°C for the heat exchanger plate, where lasers reside.

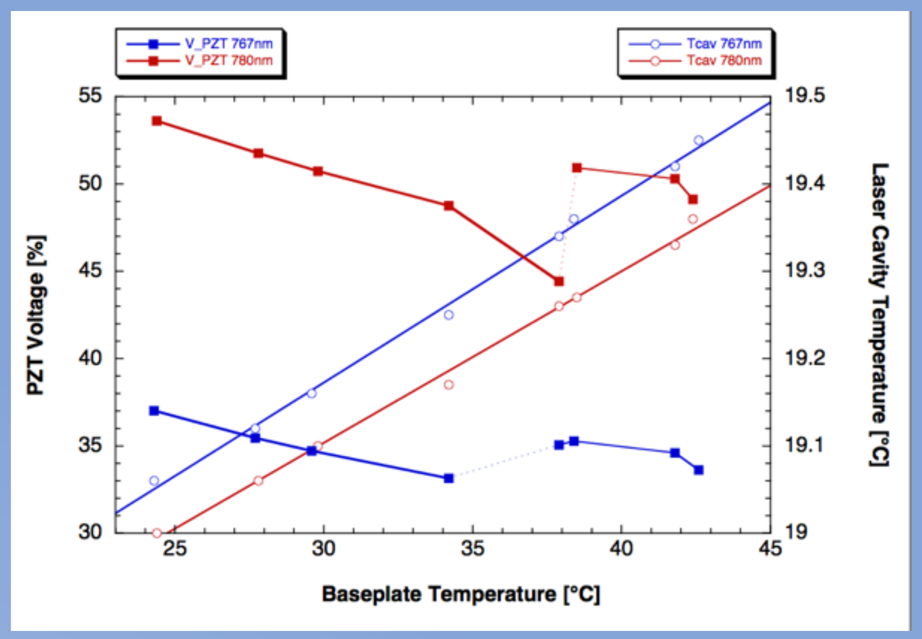

Figure 7: A second look at the above results, this time confirming that the power jump above is indeed a mode hop, as indicated by the jump in PZT voltage at the same temperatures. The PZT Voltage jumps because it's trying to maintain a constant laser frequency.

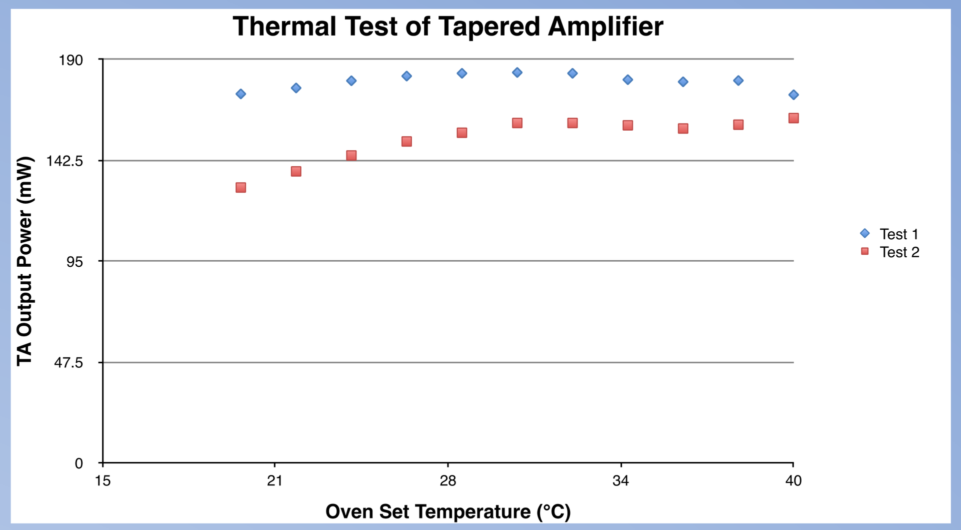

Figure 8: Thermal test results for a commercial tapered amplifier, showing that output is less than laser input and thus indicating a malfunction.

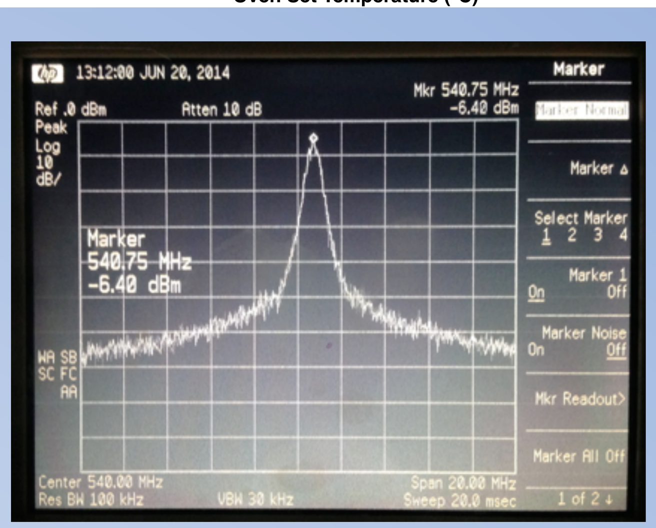

Figure 9: The optical beatnote observed between two lasers using the heterodyne technique, in which two lasers are combined to produce new frequencies. The linewidth observed is the sum of the individual laser linewidths.

What's to Come

- The development of a comprehensive environmental test plan for lasers that simulates vibrations in the on-orbit environment and involves multiple instrument subsystems, including:
  - Lasers & optics
  - Electronics
  - Optomechanical
  - Thermal
- Additional environmental testing of lasers is scheduled for Fall 2014 and will employ laser diagnostic techniques developed during this research program.

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