Spectroscopy of the Hg clock transition

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Motivation

The coherent excitation, control, and measurement of atomic and molecular systems with light is of fundamental interest in many fields of physics from precision frequency metrology to quantum information science. Similar to other alkaline earth-like atoms such as Sr and Yb, the long lived intercombination transition in Hg ($^1S_0$- $^3P_0$) can provide an extremely high resonance Q needed for an optically based atomic clock. A key advantage of the Hg clock transition is the potential for reduced uncertainty in the UV transition due to black-body induced Stark shifts, estimated to be smaller than Yb or Sr by an order of magnitude or more [1,2]. As a result, an improved optical atomic clock based on neutral Hg is being actively pursued by several international laboratories [2-6]. A key challenge in evaluating the potential of a Hg-based optical clock is the UV laser systems required for cooling, trapping, and probing.

Key directions of this research program are:

- Precision measurement of $^1S_0$- $^3P_0$ clock transition
- Evaluation of an optical lattice based Hg clock
- Investigation of direct frequency comb excitation of clock transition

Key properties of Hg

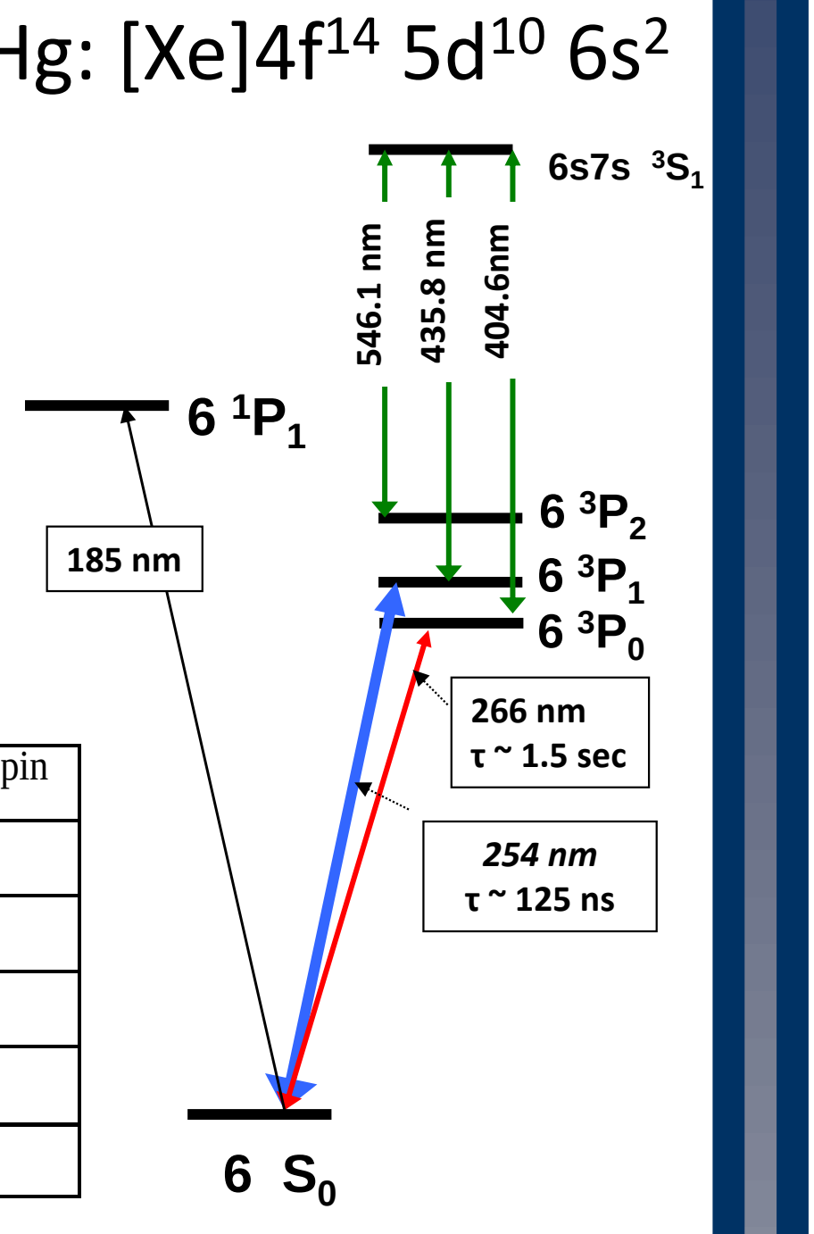
- fermionic and bosonic isotopes (I=3/2 and I=0).
- single stage cooling on $^1S_0$- $^3P_1$ transition to 30 μK.
- no repumping laser needed.
- Low sensitivity to BBR shifts.
- high vapor pressure.

Hg: [Xe]$4f^{14}$ $5d^{10}$ $6s^2$

Saturation intensity of $^1S_o - {}^3P_1$:

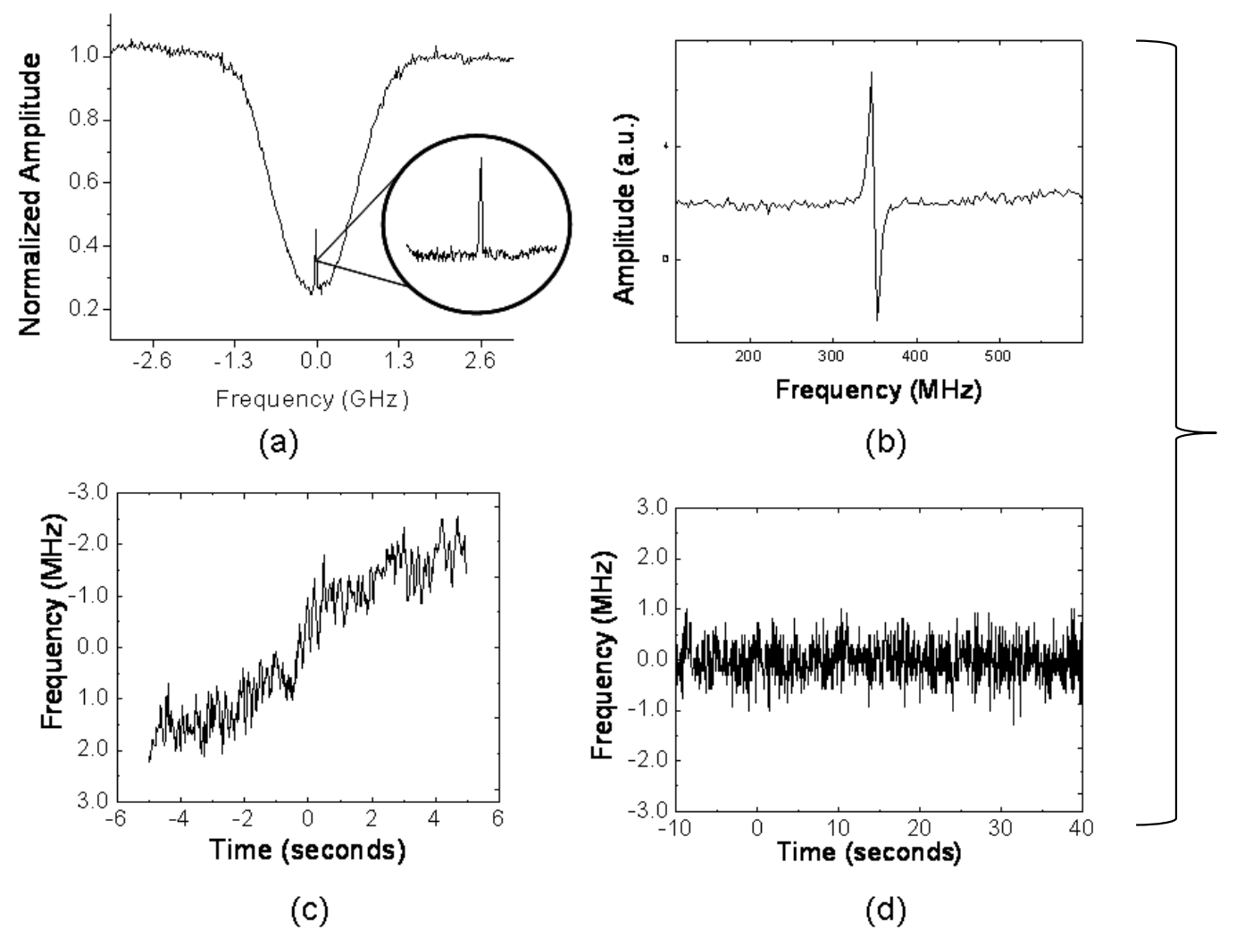
$$I_s = \frac{\pi hc}{3\lambda^3 \tau} \approx 10\,\frac{mW}{cm^2}$$

Isotope	% Natural Abundance	Nuclear Spin
^{198}Hg	9.97%	0
^{199}Hg	16.9%	1/2
^{200}Hg	23.1%	0
^{201}Hg	13.2%	3/2
^{202}Hg	30%	0



Hg MOT characterization and spectroscopy

FM spectroscopy of the cooling transition



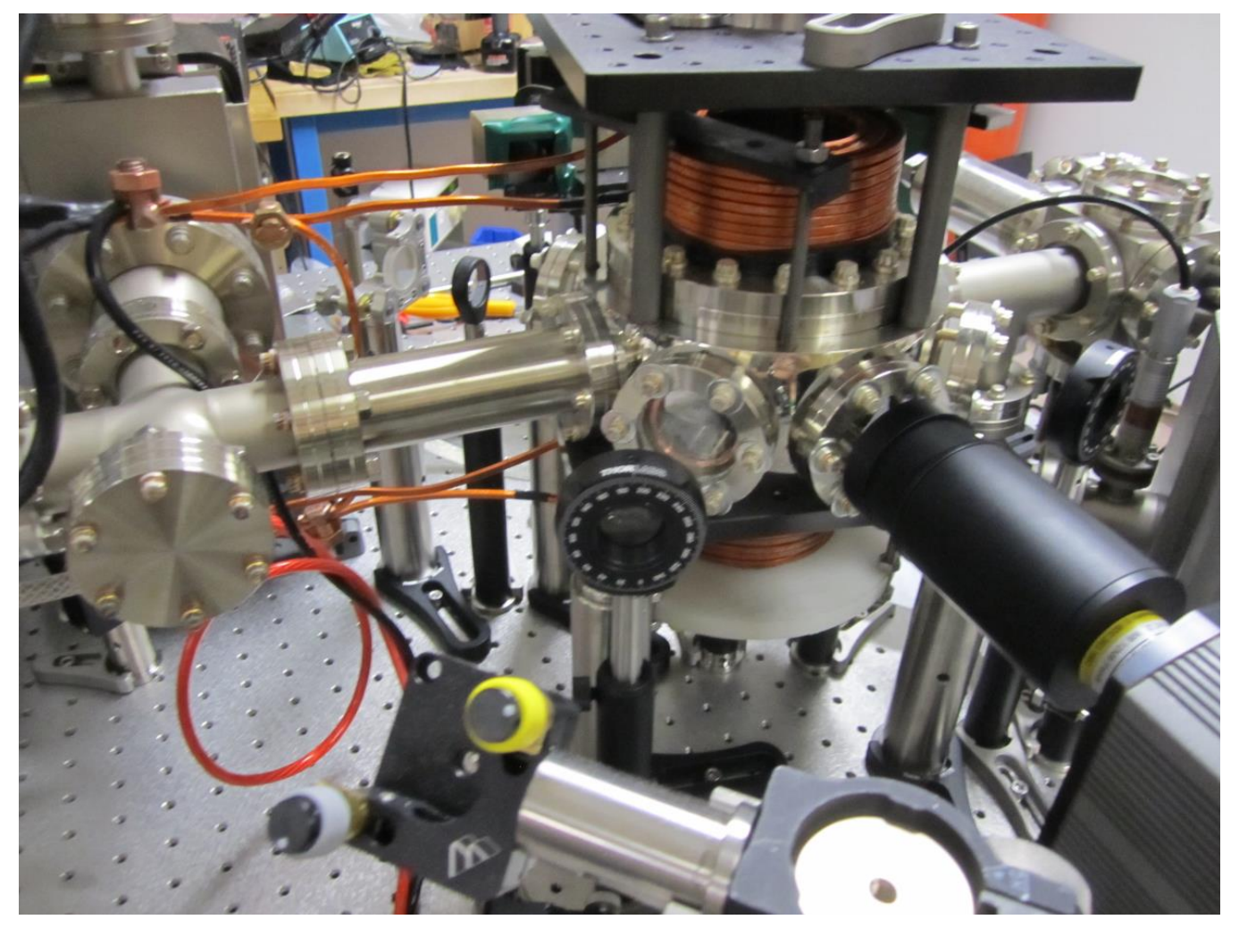
(a) Saturated absorption peak of $^1S_0$- $^3P_1$ in ^{200}Hg obtained scanning reference cavity.

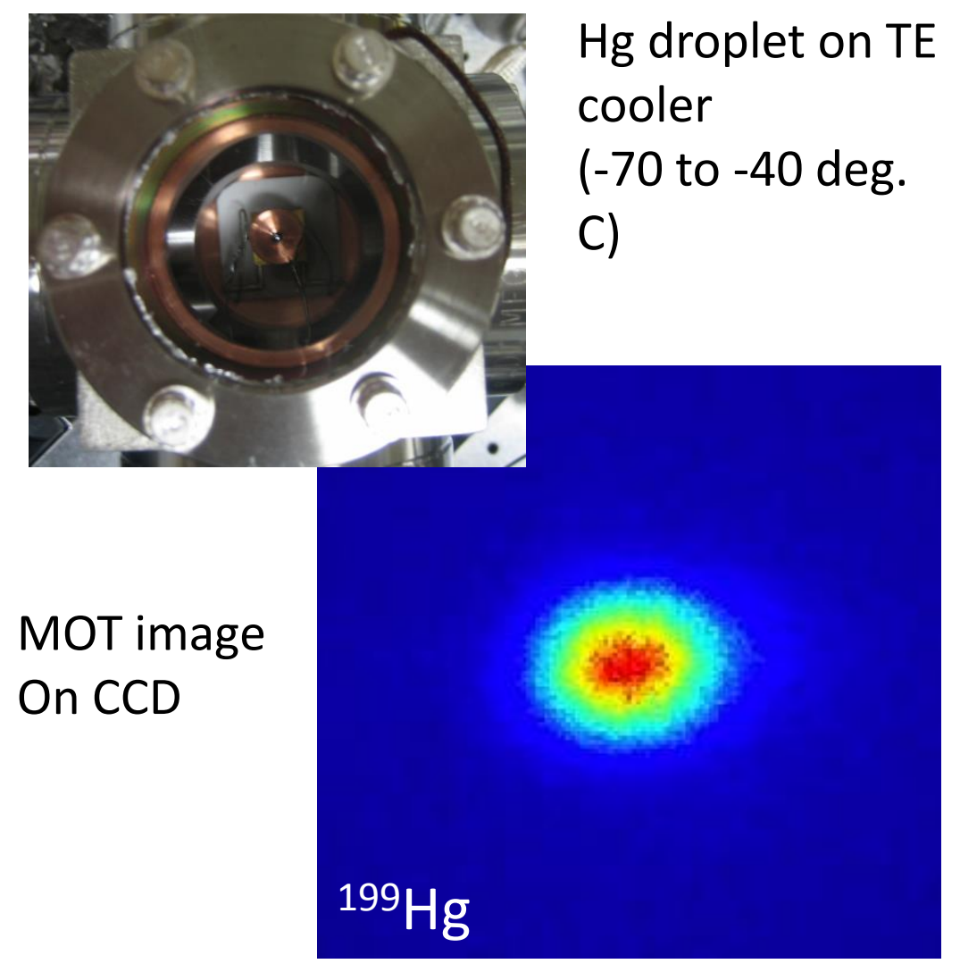
(b) Error signal from lock-in amplifier.

(c) Residual drift of cavity stabilized laser system without lock to Hg transition.

(d) Residual noise when locked to $^1S_0$- $^3P_1$.

Temperature measurements



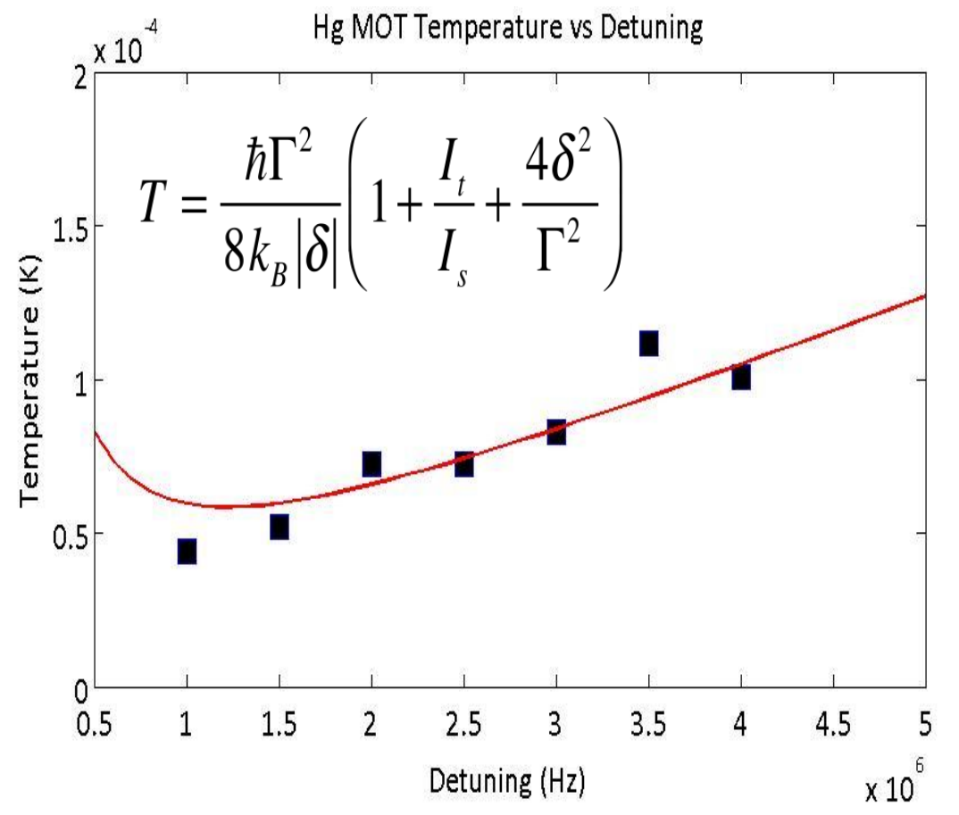


Hg droplet on TE cooler (-70 to -40 deg. C)

MOT image On CCD

- Temperature characterization based on ballistic expansion measurements imaged with EMCCD
- 40μK reached at Δ =1MHz
- Doppler-limited temperatures in ^{200}Hg agree well with theory.
- Atom # trapped:
  ^{200}Hg ~ 2 × 10^6
  ^{199}Hg ~ 0.6 × 10^6
- 16 G/cm axial magnetic field

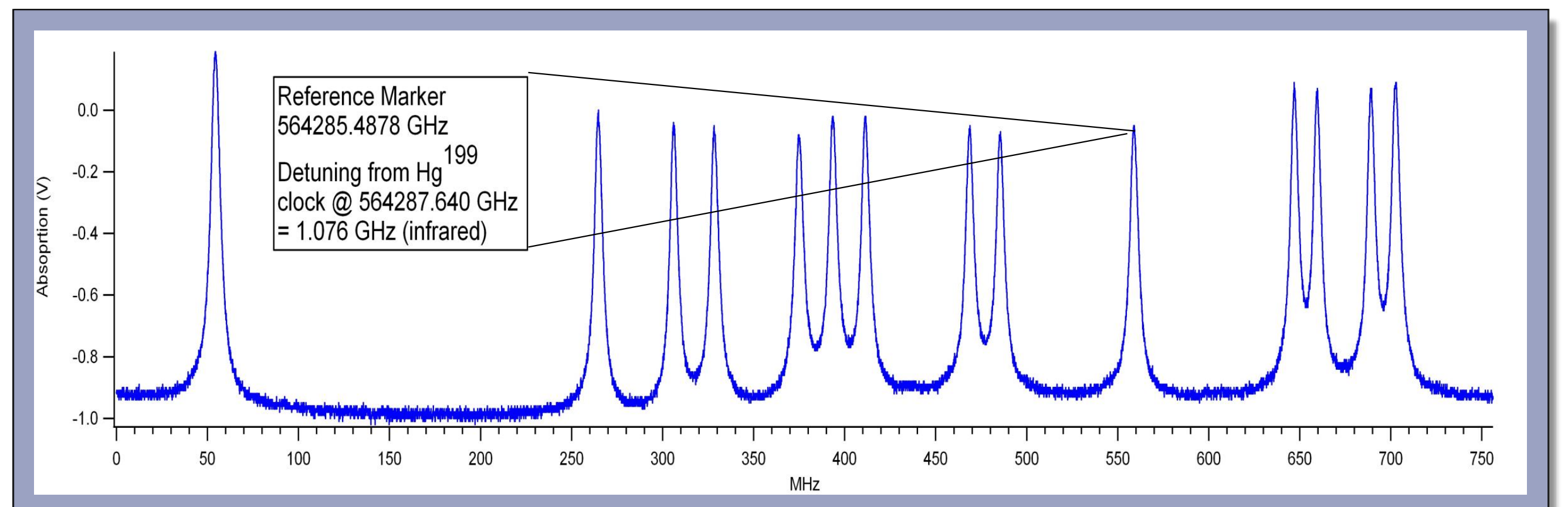
P. *Lett et. al.*, JOSA B **6**, 2084 (1989)



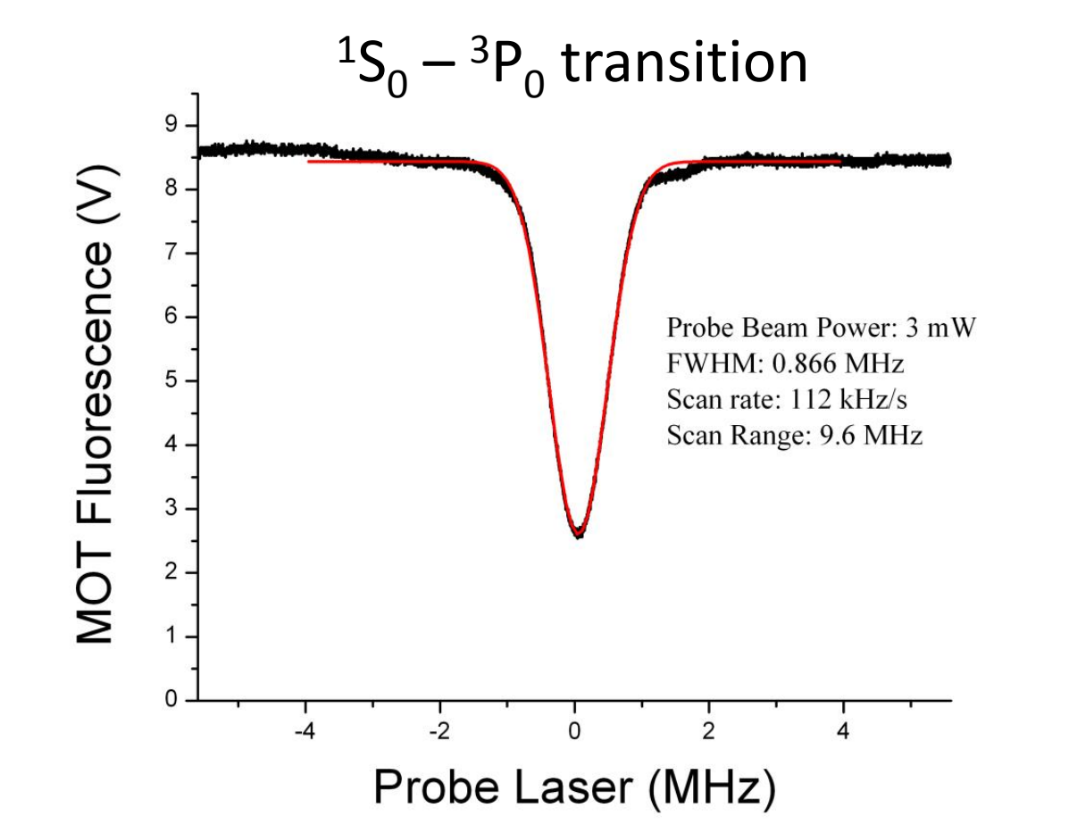
$$T = \frac{\hbar\Gamma^2}{8k_B|\delta|}\left(1+\frac{I_t}{I_s}+\frac{4\delta^2}{\Gamma^2}\right)$$

Clock transition measurement

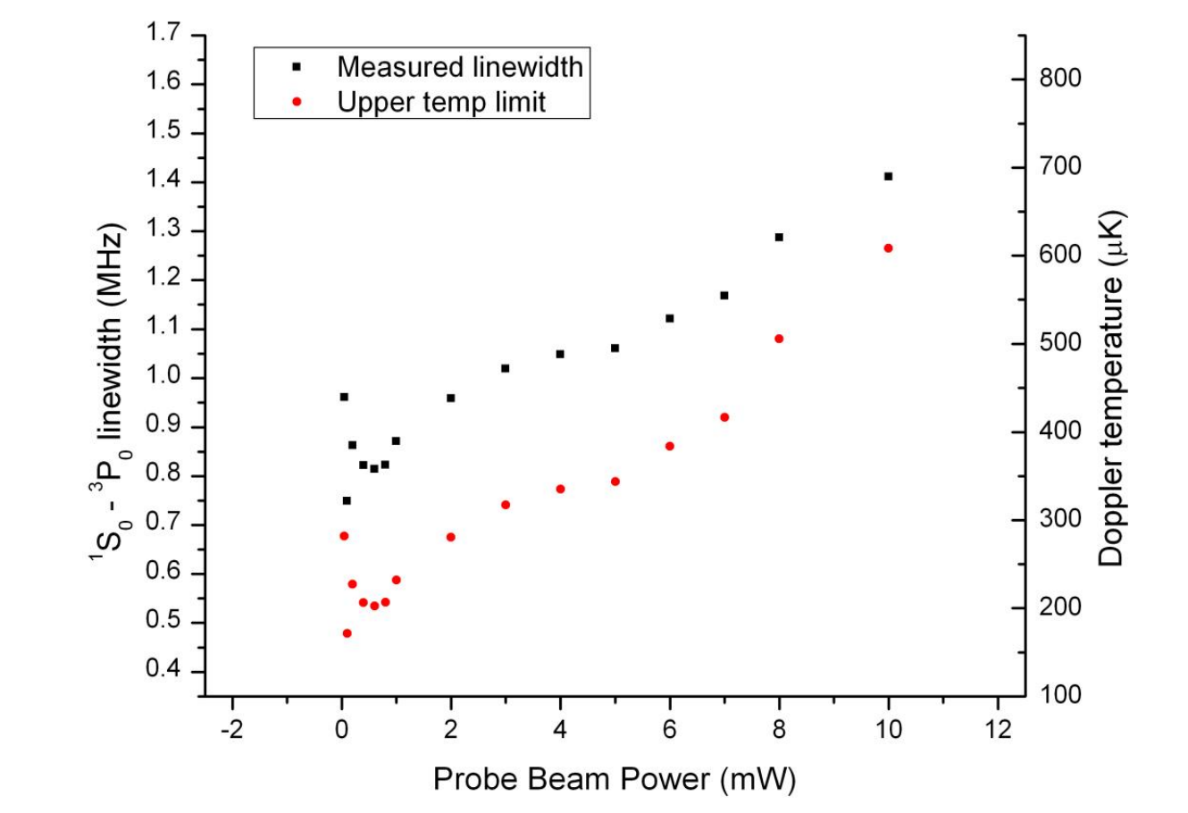
- Initial detection of the Hg $^1S_0 - {}^3P_0$ clock transition requires a known absolute reference and a detuning scheme for that reference.
- A visible molecular iodine line 1.1 GHz from the Hg line in the IR serves as the absolute reference for the UV probe laser.
- Precision scanning of the probe laser across the clock transition is enabled by an optical phase lock to a ULE cavity-stabilized ECDL. The ULE cavity has a finesse of 630,000 and drifts ~ 250 kHz/hr.
- We observed 70% depletion of the MOT fluorescence intensity with 3 mW of probe beam power incident on the MOT.
- Doppler temperatures corresponding to measured linewidth give an upper limit for the MOT temperature. We need to measure the linewidth unperturbed by the MOT beams to confirm the temperature.



Molecular iodine reference spectrum. Fiber laser is initially tuned to the marked absorption line, 1.1 GHz away from the Hg line in the IR.

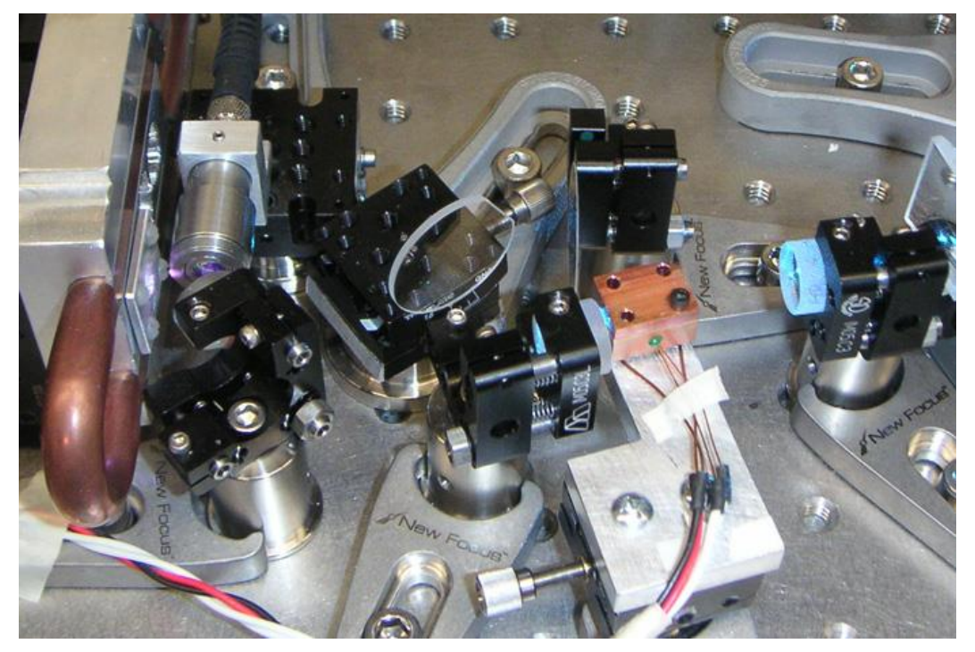


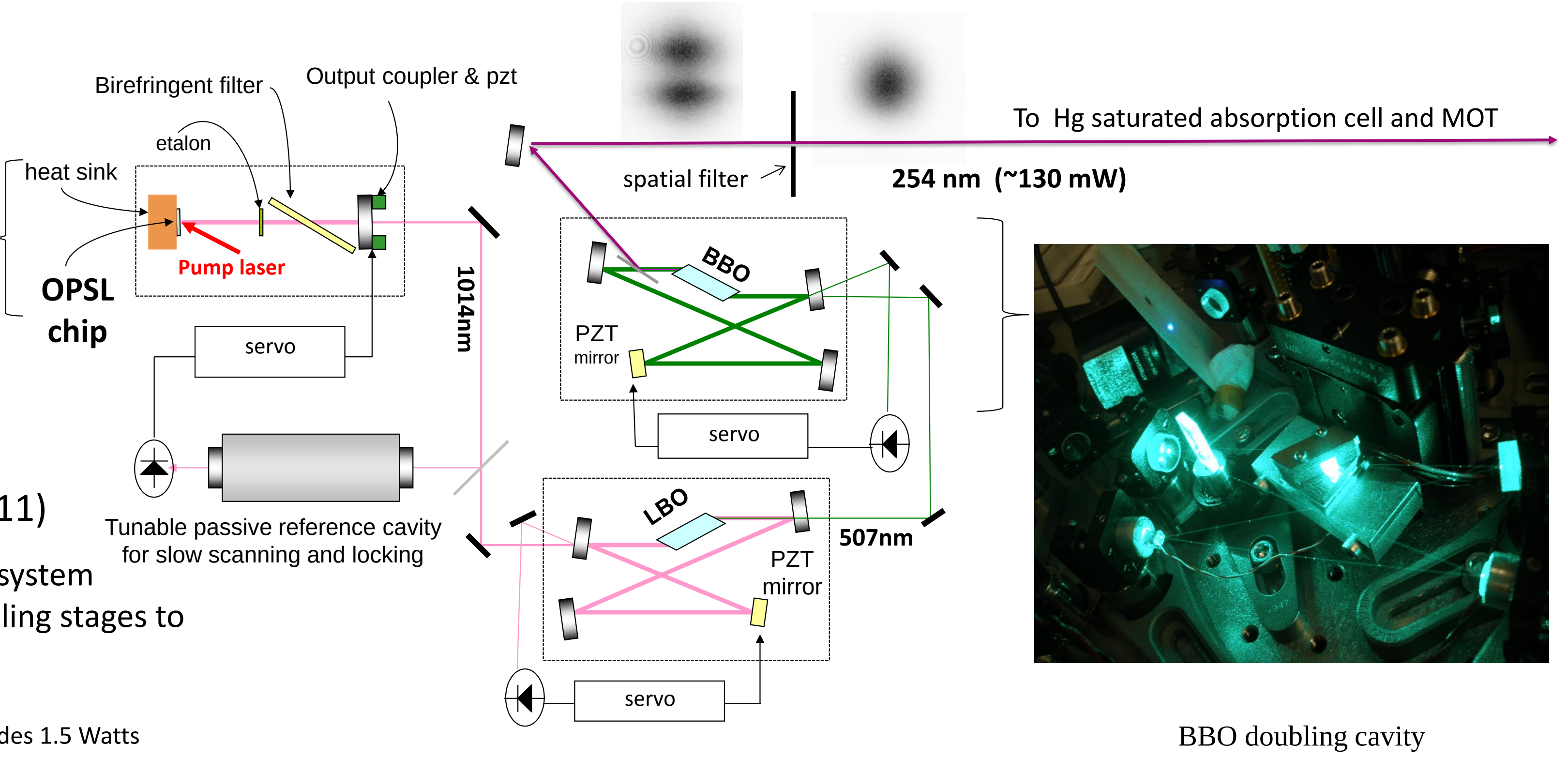
The phase lock with the ECDL allows us to tune an exact amount towards the Hg transition. The ULE cavity minimizes the drift of the ECDL.



UV laser systems

Optically pumped semiconductor laser (OPSEL) for cooling (254 nm)





BBO doubling cavity

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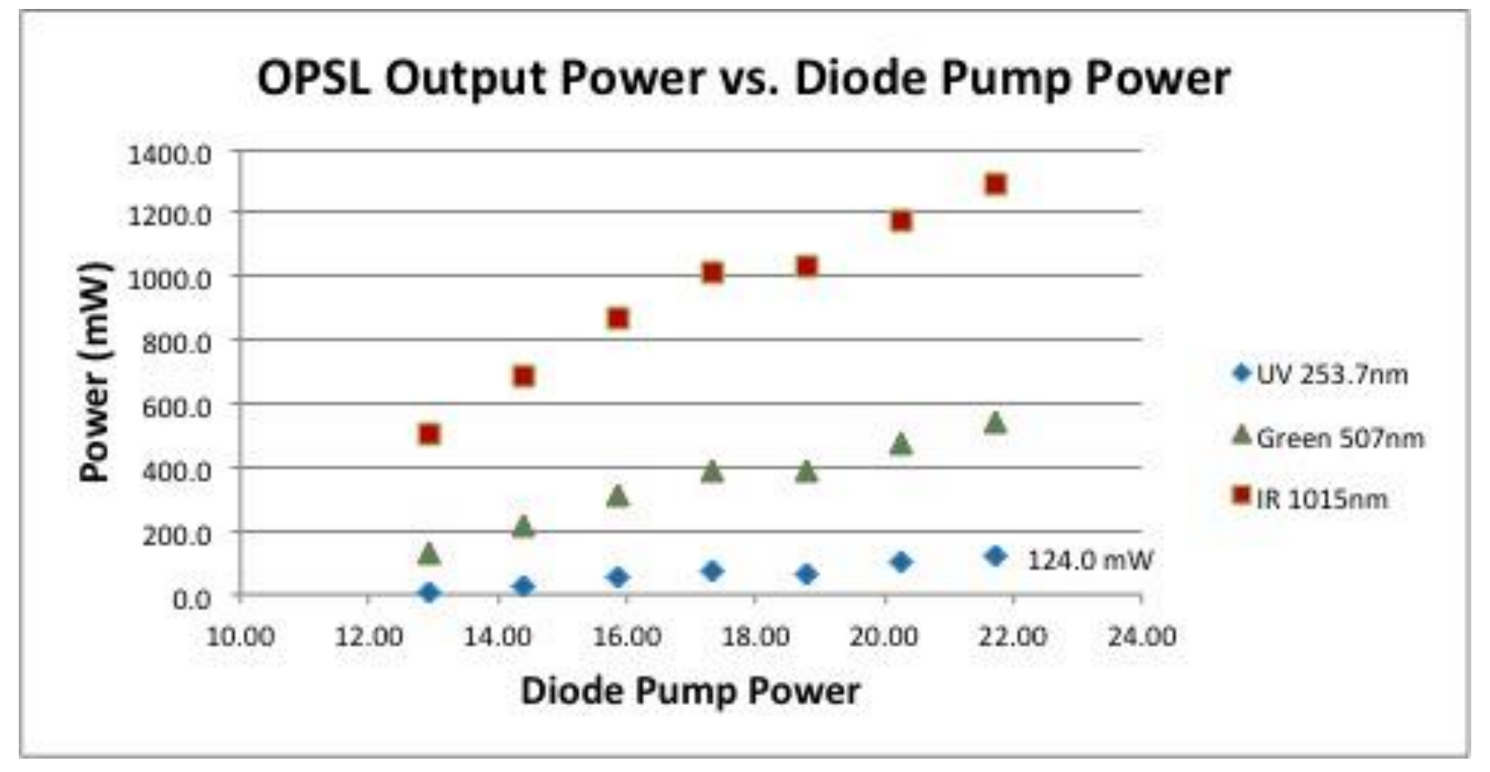
- Optically-pumped semiconductor laser system developed at 1014 nm [7] with two doubling stages to reach cooling transition at 254 nm.

→ Birefringent filter and 750 micron etalon provides 1.5 Watts single frequency in IR with continuous scanning ~ 3GHz
→ Narrow free running linewidth (~ 50 kHz) limited by technical noise at low Fourier frequencies
→ System pre-stabilized to tunable reference cavity

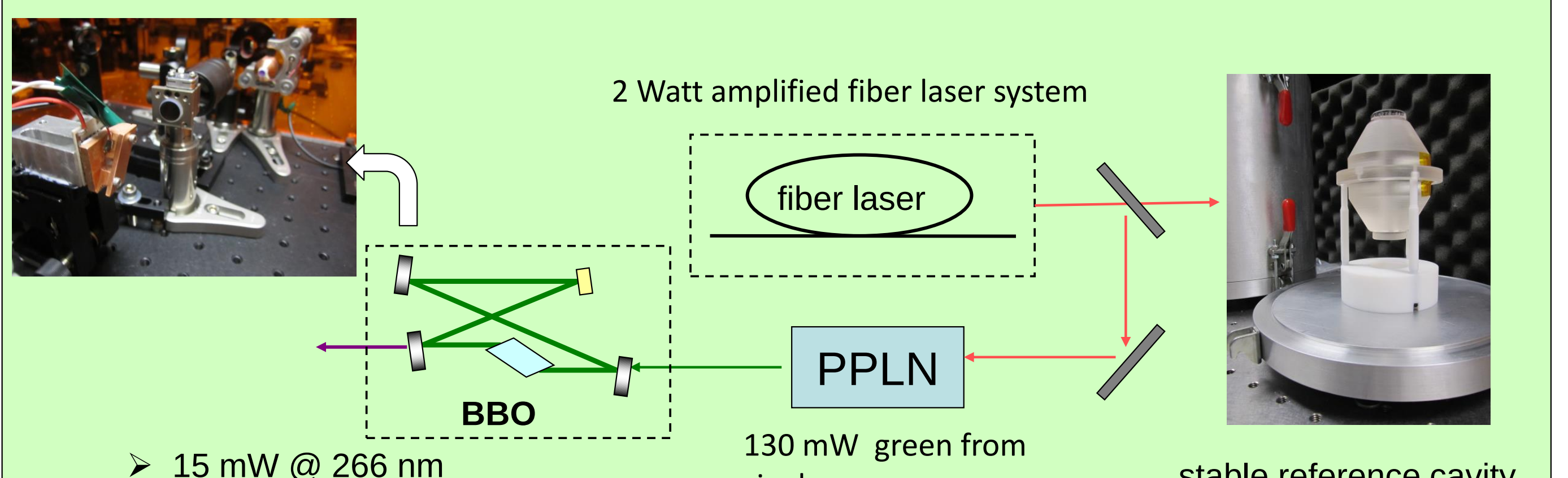


- OPSL technology is ideal for precision spectroscopy, providing an attractive alternative to ECDL's in atomic, molecular, and optical physics research.

→ High efficiency IR sources pumped with inexpensive single diode emitters or bars.
→ 1-D geometry provides efficient heat extraction for high powers.
→ Versatile wavelength range compared to solid state systems.
→ Intrinsically narrow quantum limited free-running linewidths compared to ECDL's.

Ultrastable cw probe laser (266 nm)

- Fourth harmonic of cw fiber laser for spectroscopy of the $^1S_0 \rightarrow {}^3P_0$ clock transition
- Short term stability provided by frequency lock to an ultrastable ULE reference cavity



- 15 mW @ 266 nm
- (> 10% conversion efficiency)

130 mW green from single pass

stable reference cavity

Current & future work

- Optical lattice based precision spectroscopy
  Stark-shift free "magic wavelength" optical lattice recently determined at λ=362.5nm [6].
- Investigate direct frequency comb spectroscopy and EIT based schemes for deep UV spectroscopy utilizing long coherence time of clock transition [9-10].

References

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