Quantum Computing with Trapped Ions

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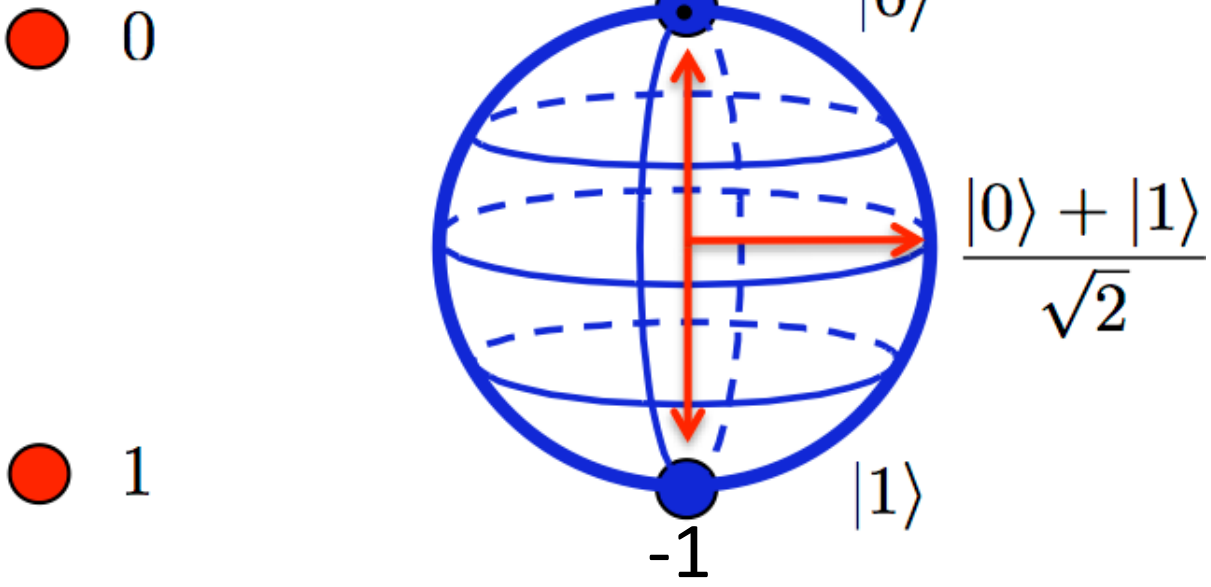
Outline

- Quantum Computing
- Ion Trapping Theory
- Building a 493nm Laser
- Ion Trapping Experimental

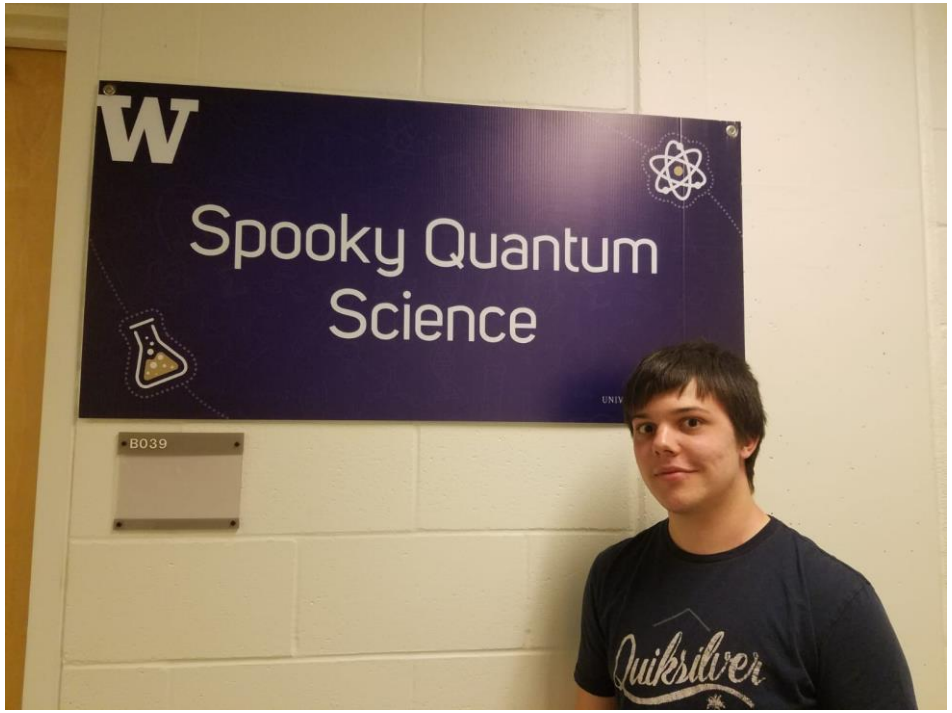
The Quantum Advantage

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$



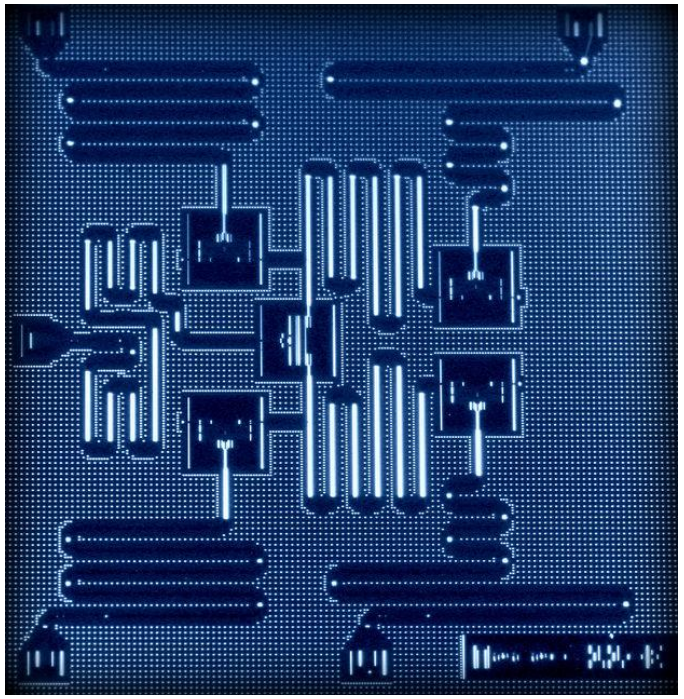
Classical Bit vs **Qubit**

[1]



Quantum Entanglement

Types of Qubits



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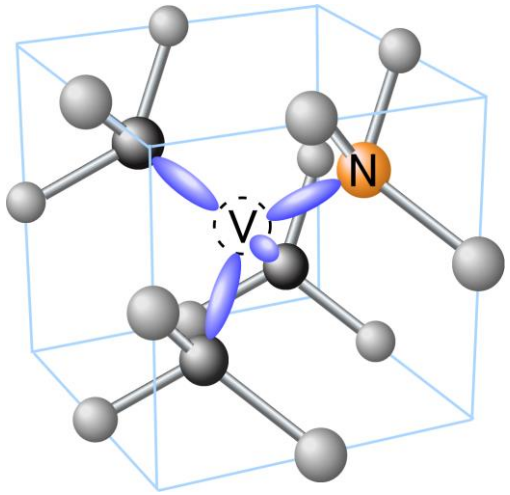
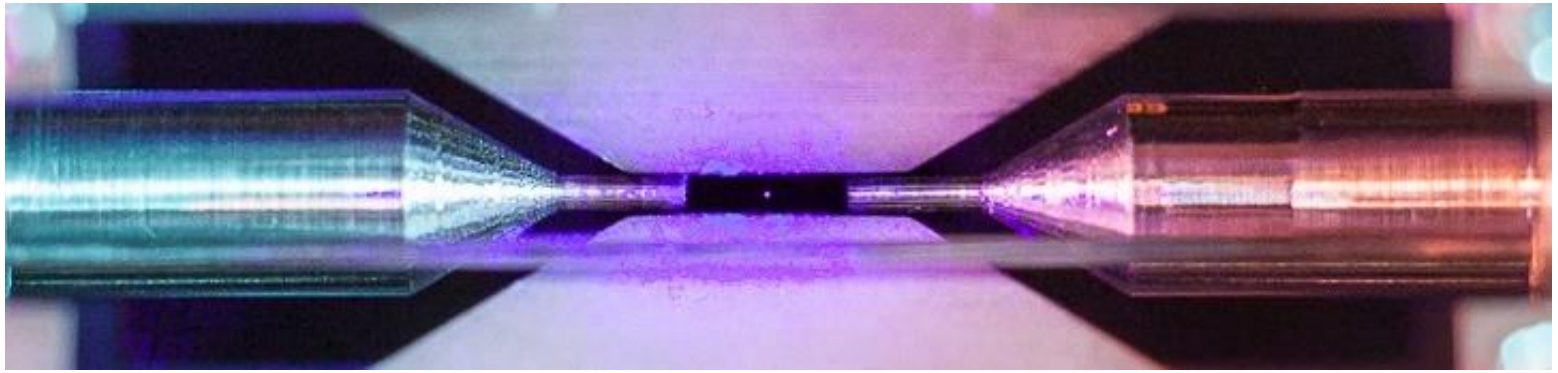
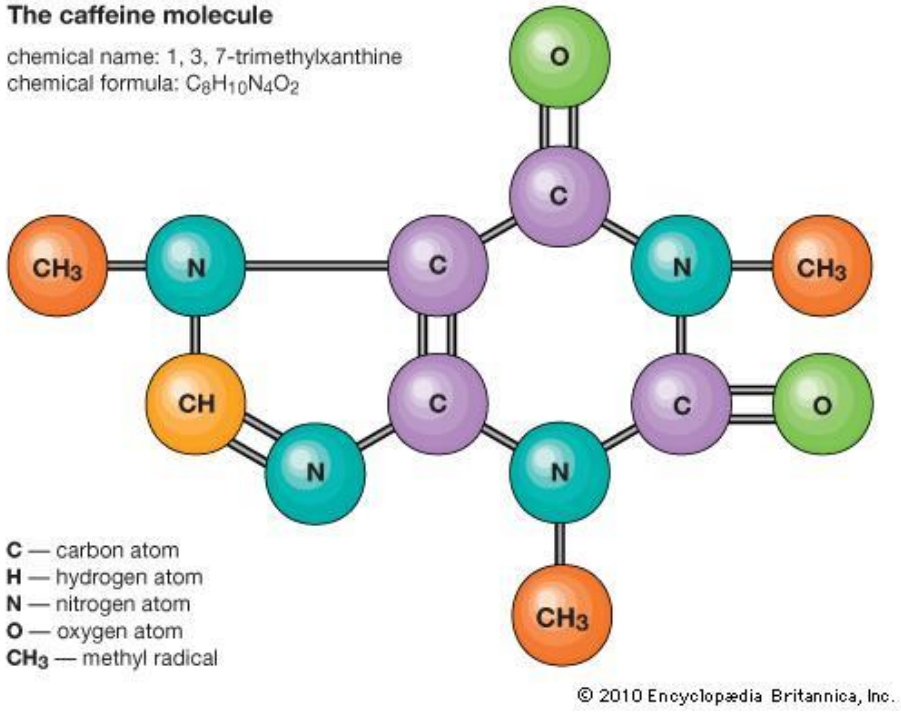


[3]



[4]

Applications: According to IBMQ



[5]

[6]

[7]

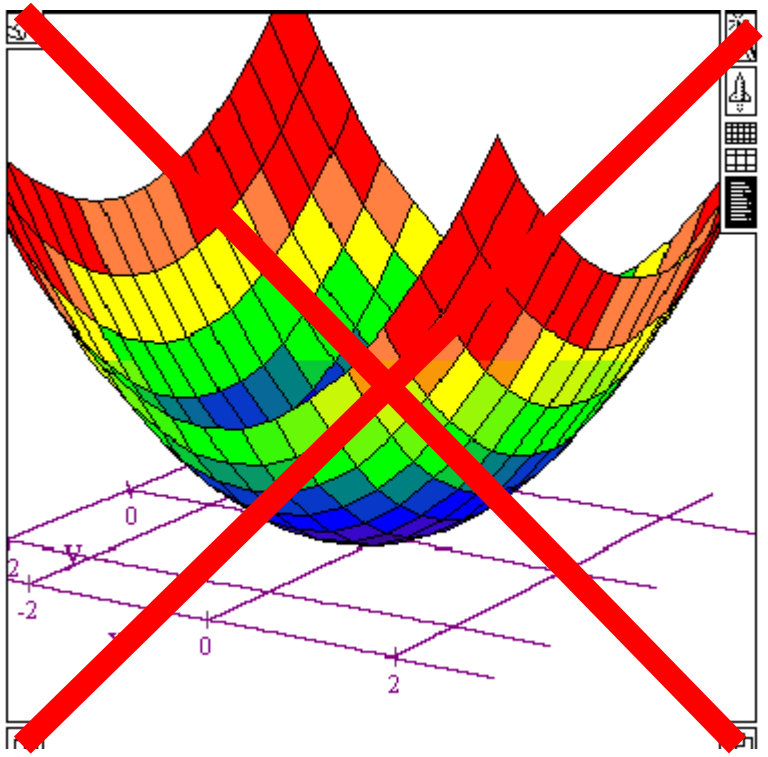
ABC's of Trapping an Ion

$$\nabla \cdot E = \frac{\rho}{\varepsilon_0}$$

$$E = -\nabla V$$

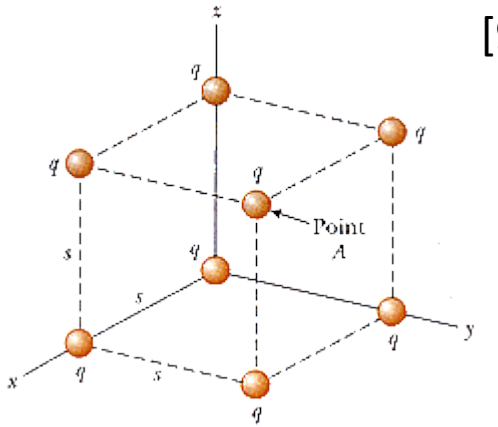
$$\nabla^2 V = 0$$

Static electric field =



[9]

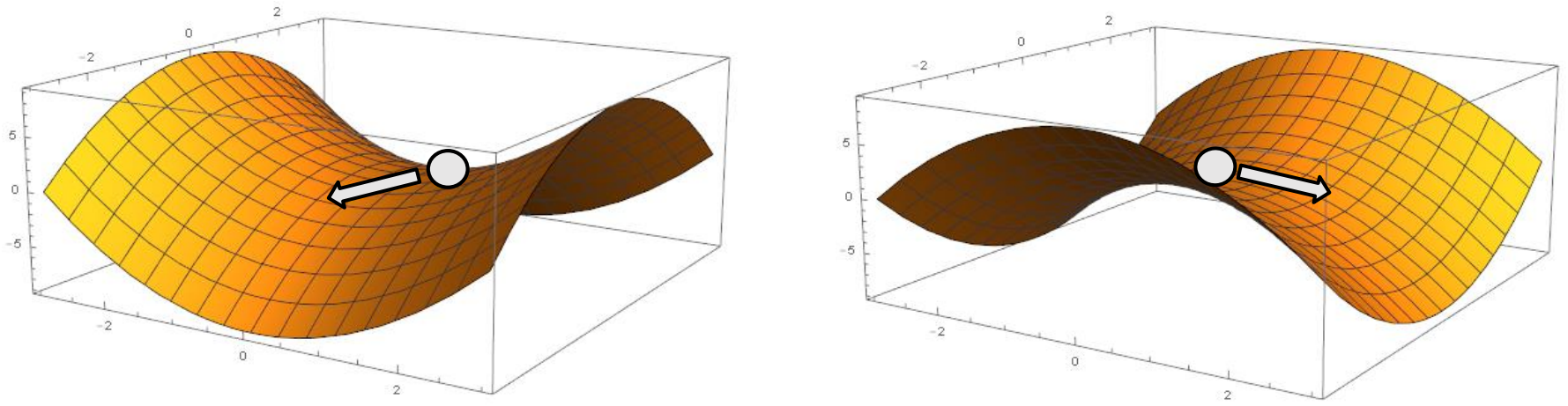
$$\begin{aligned} \nabla^2 V &= \nabla^2 \left(\alpha x^2/2 + \beta y^2/2 + \gamma z^2/2 \right) \\ &= \alpha + \beta + \gamma \\ &= 0 \end{aligned}$$



[10]

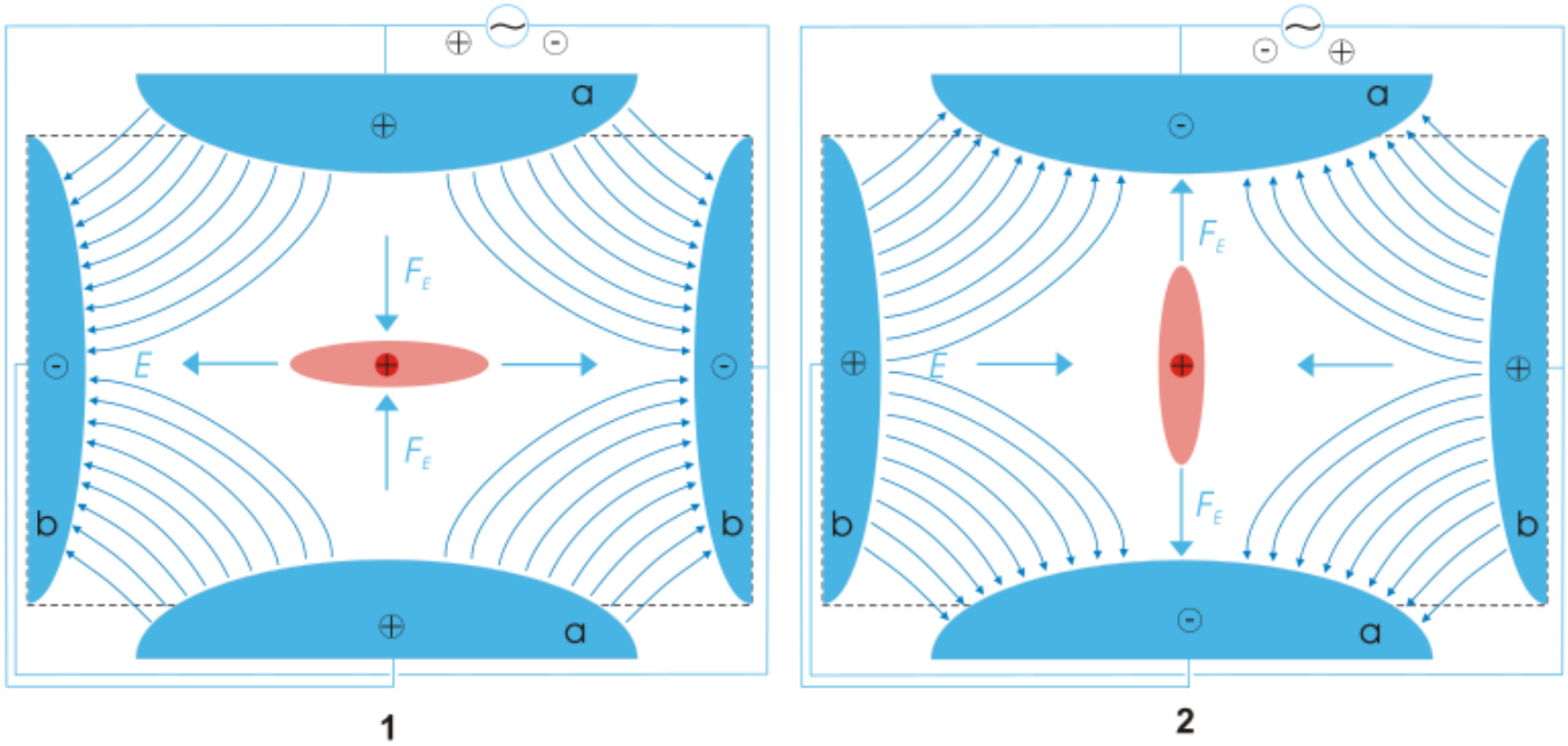
Pseudo-Potential

Time average is a minimum



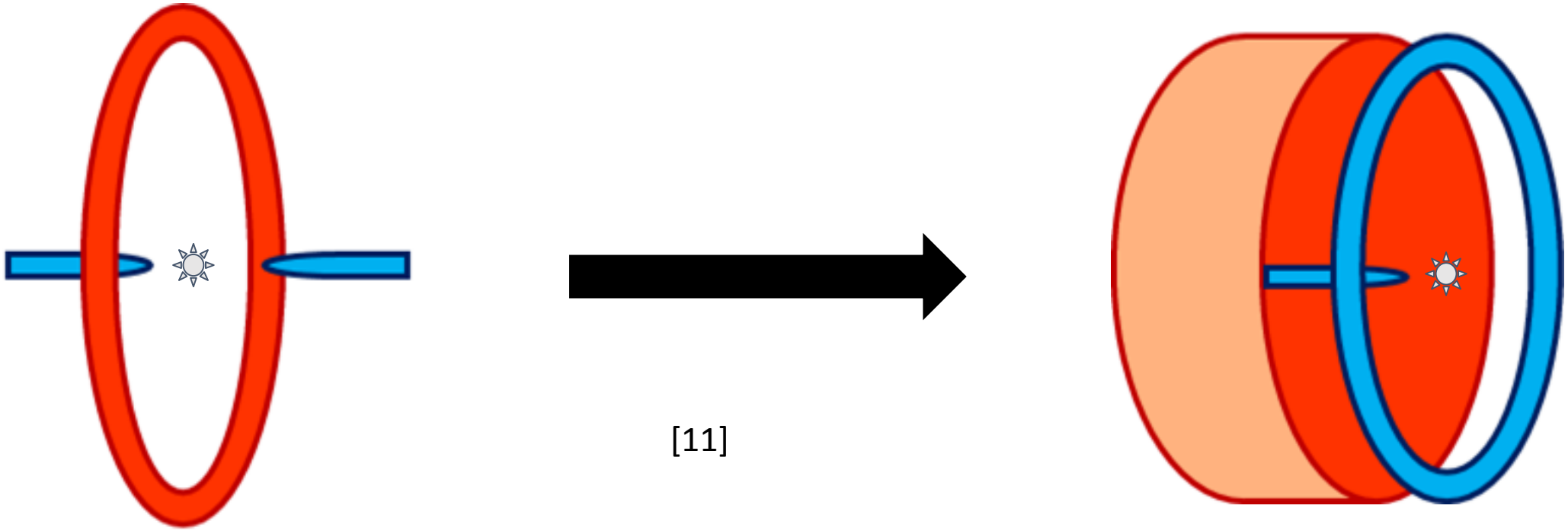
[11]

Quadrupole / Paul Trap



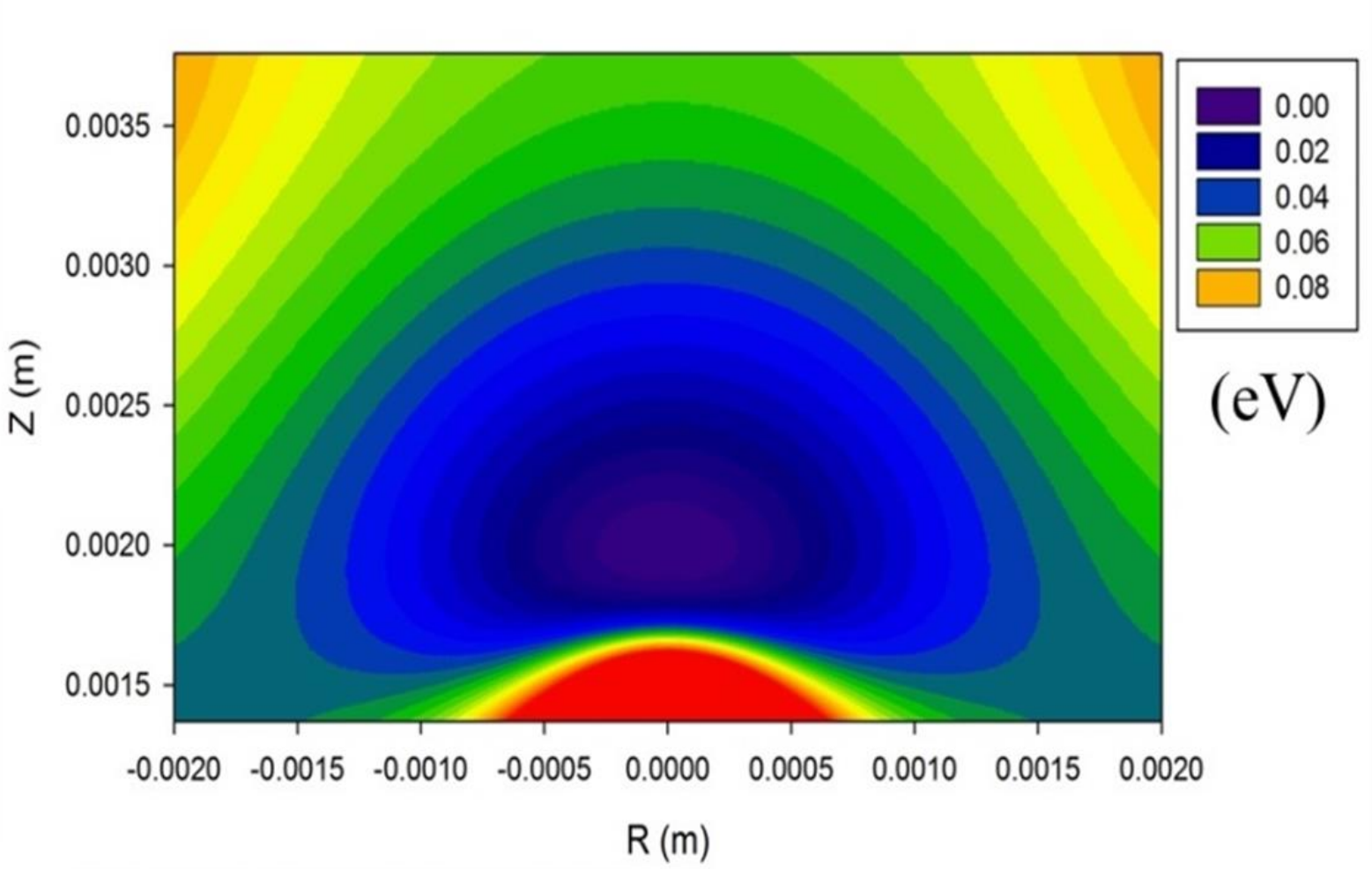
[12]

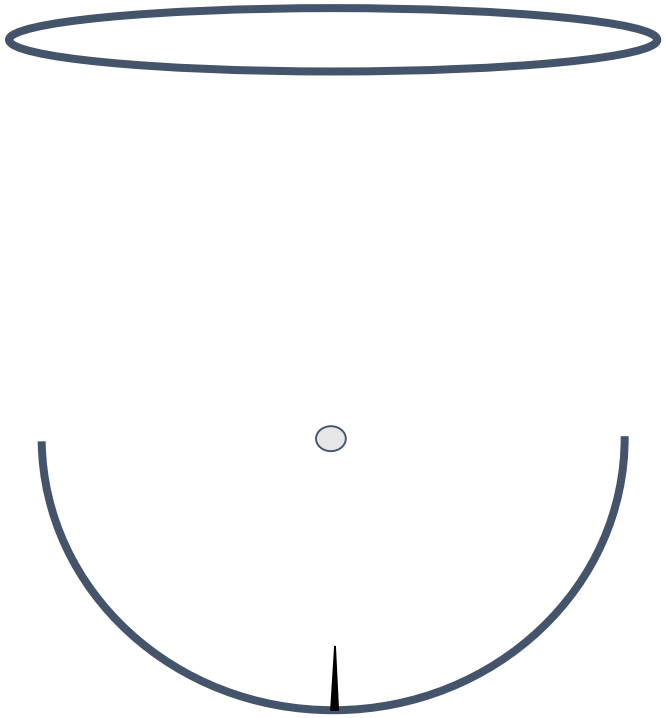
Parabolic Mirror Ion Trap



[11]

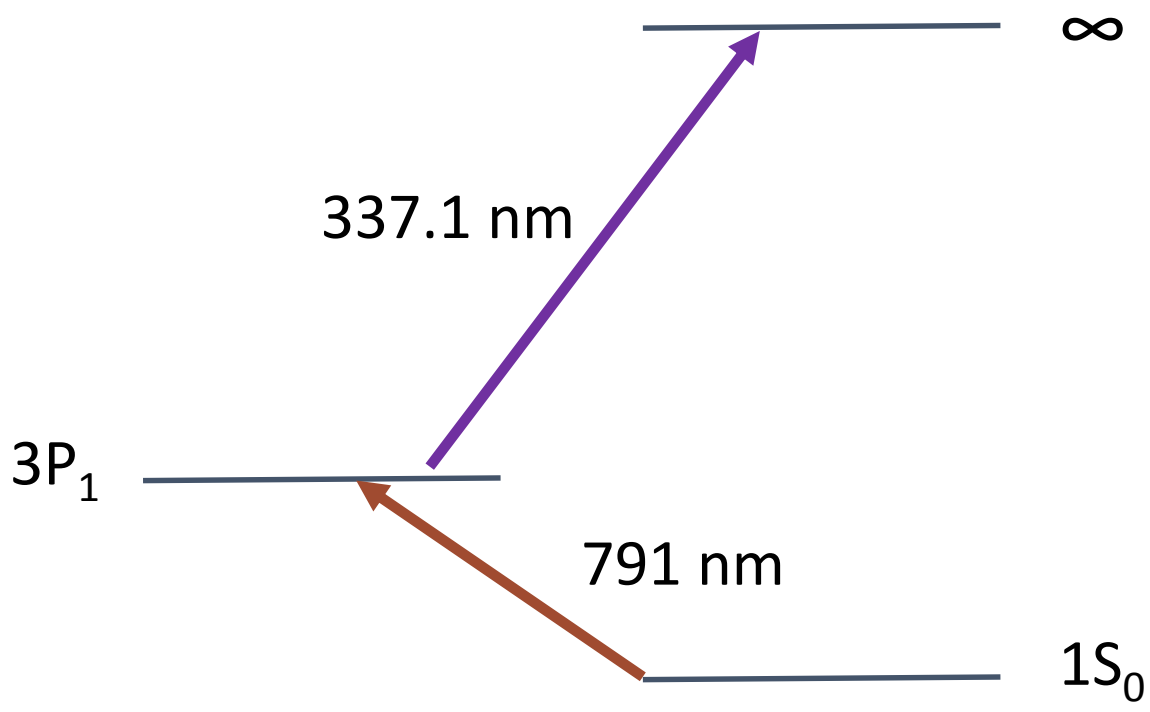
Generated Pseudo-Potential

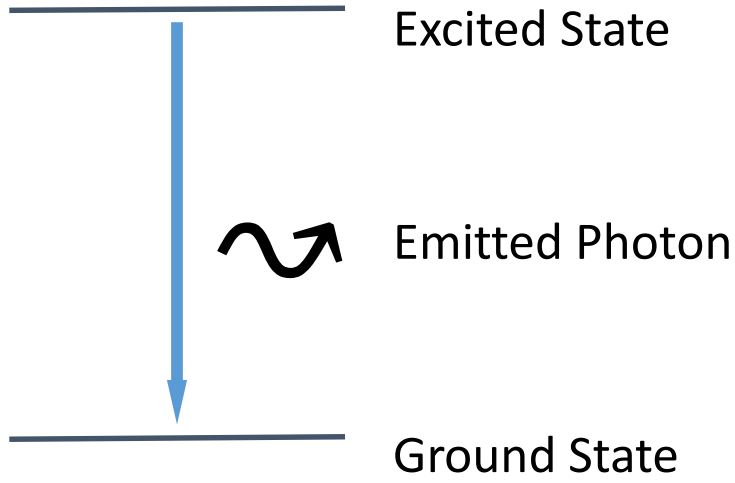




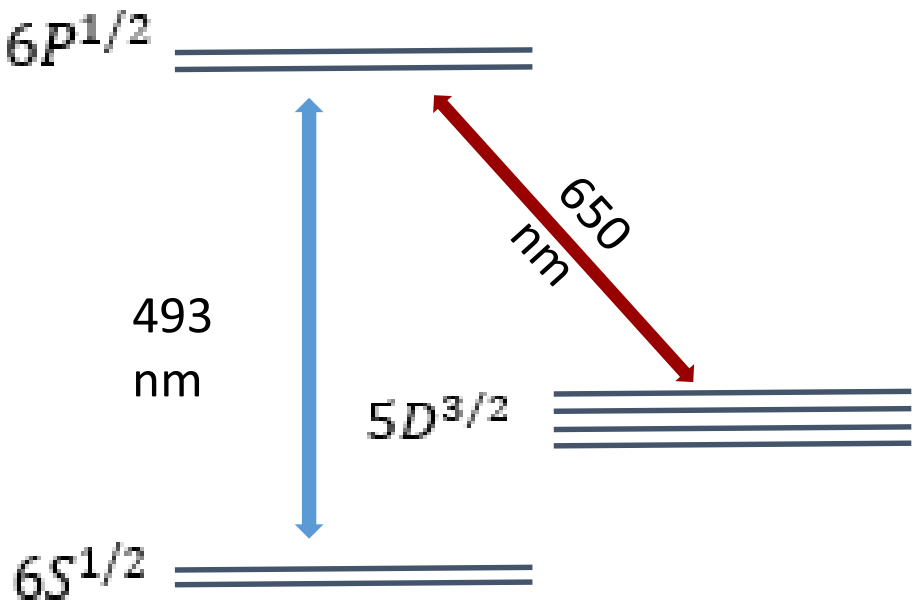
Trap architecture (not to scale)

Ionization Scheme





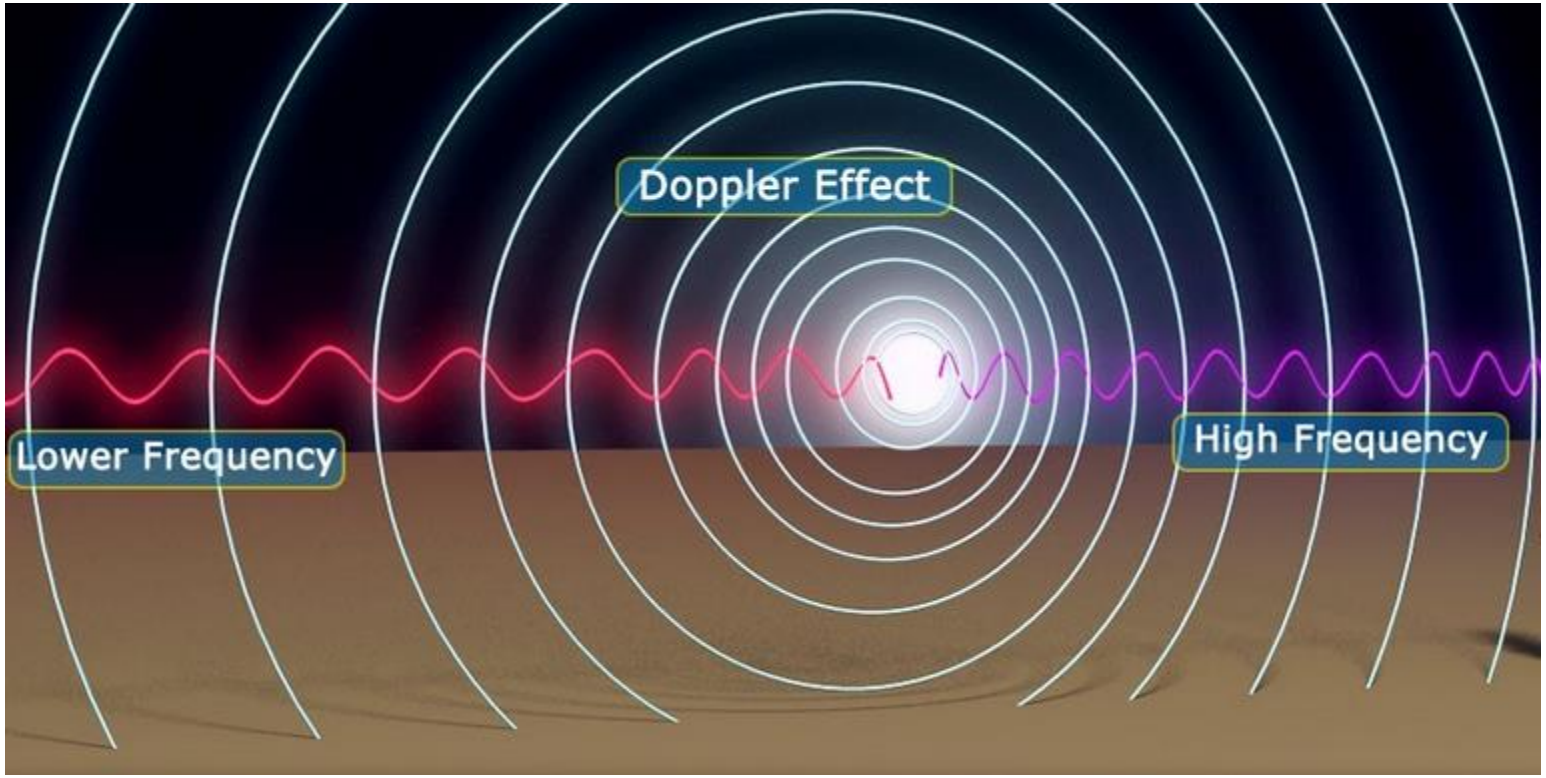
Cooling Cycle



[11]

Doppler Cooling

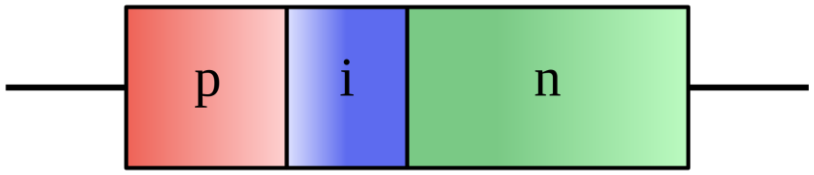
[13]



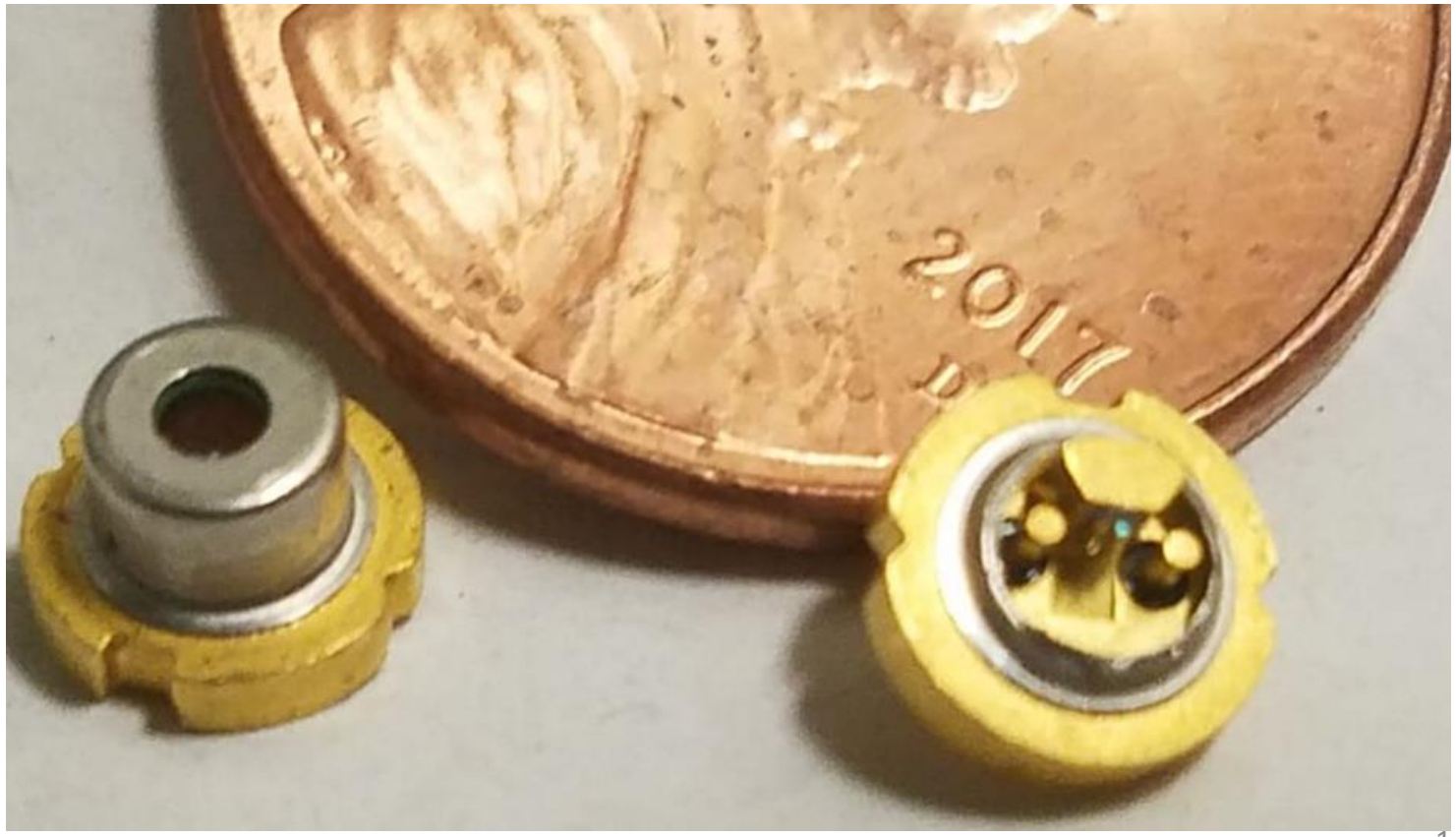
[14]

Blue Light: Laser Diode (new!)

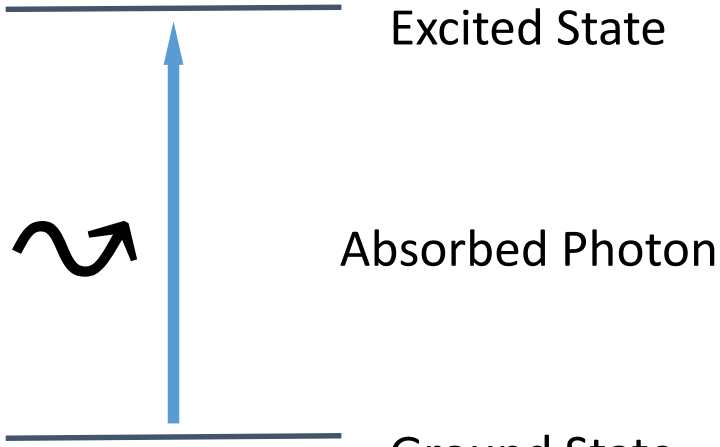
- Before in this lab: 986nm laser, doubling crystal
- Now: laser diodes
- PIN junction



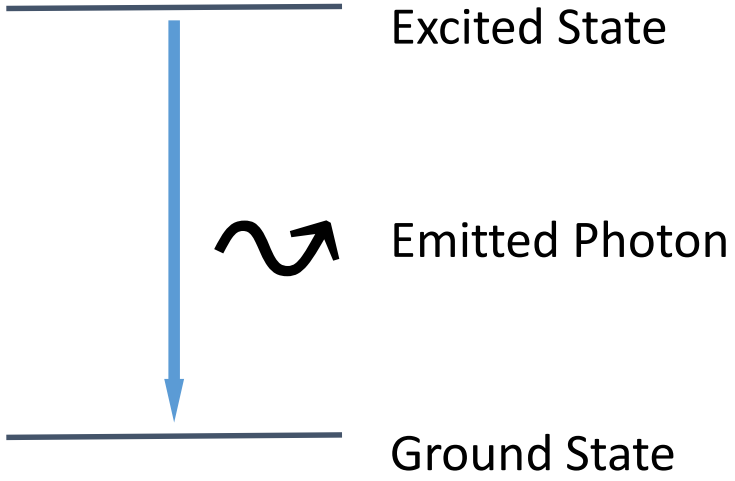
[15]



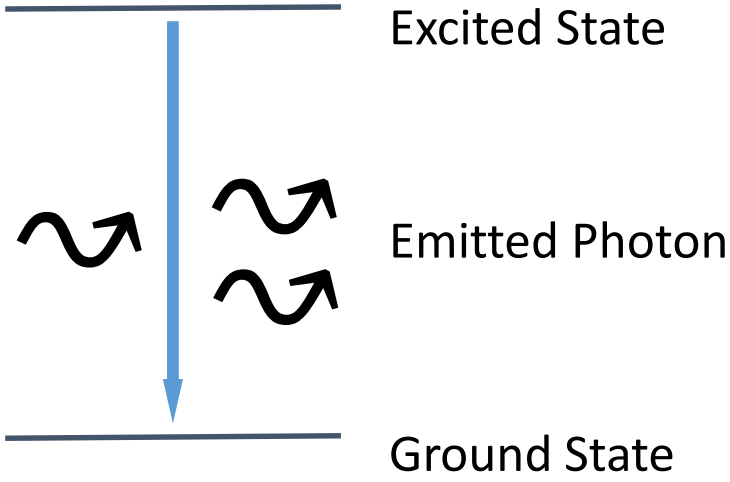
Stimulated Emission



Absorption

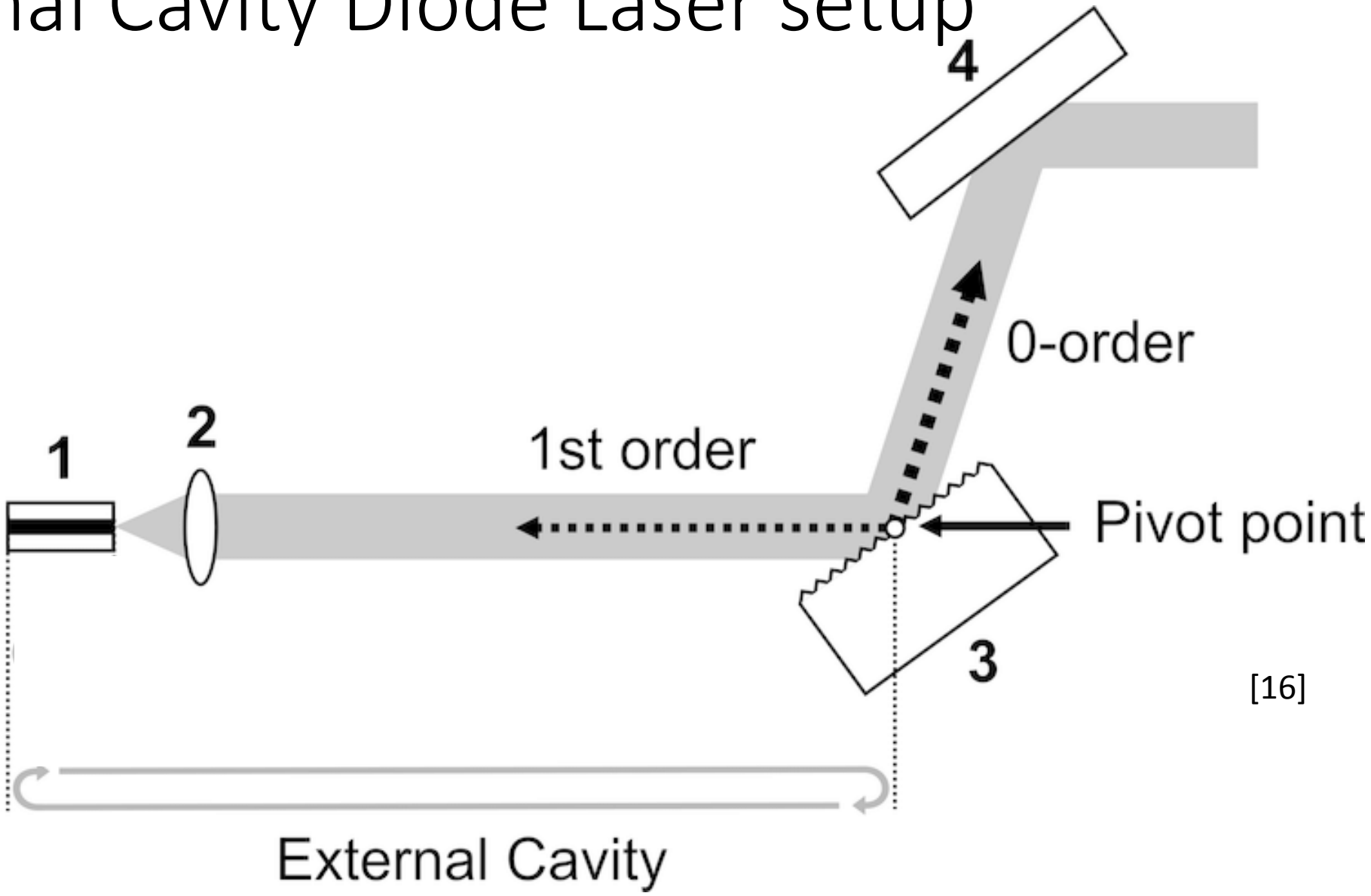


Spontaneous Emission



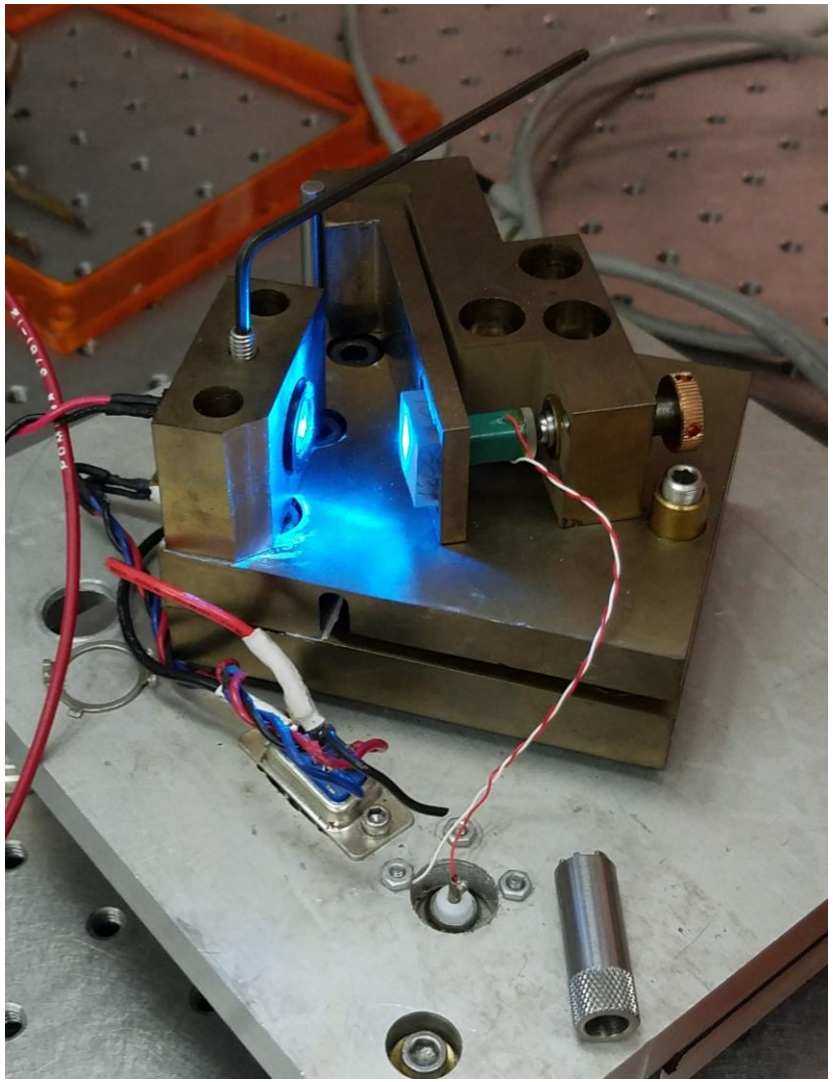
Stimulated Emission

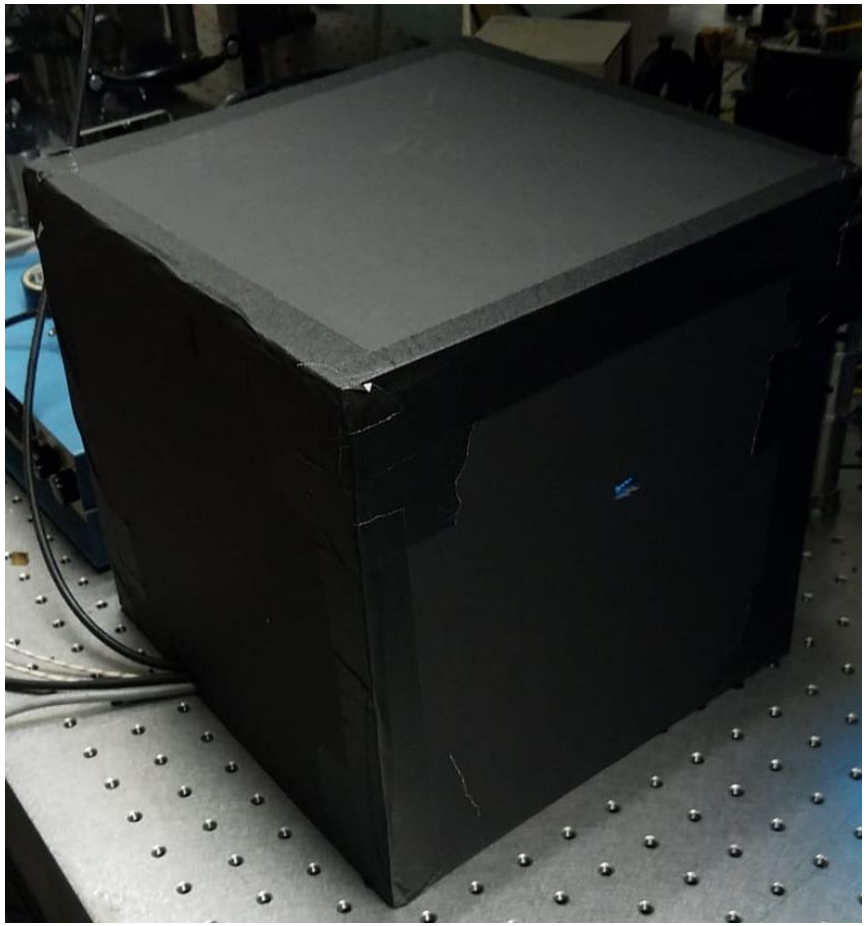
External Cavity Diode Laser setup



[16]

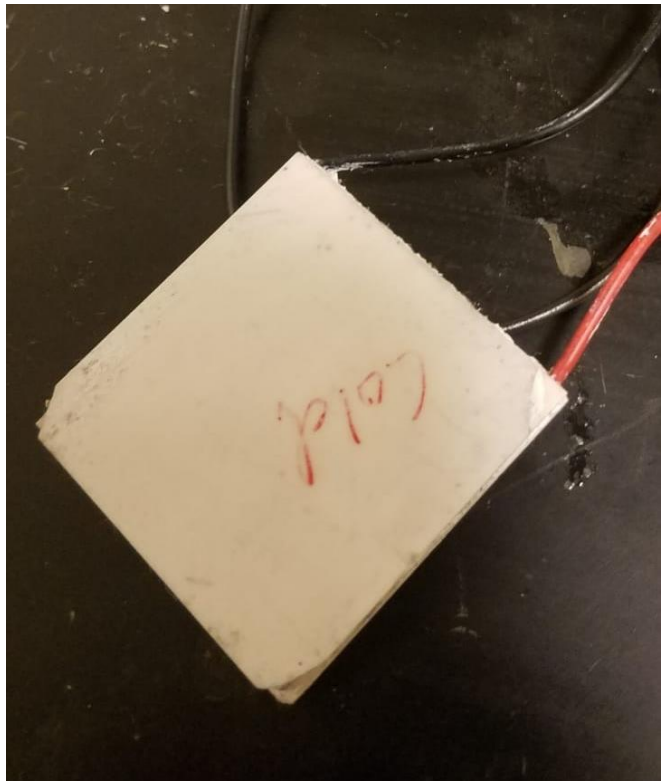
Laser Setup

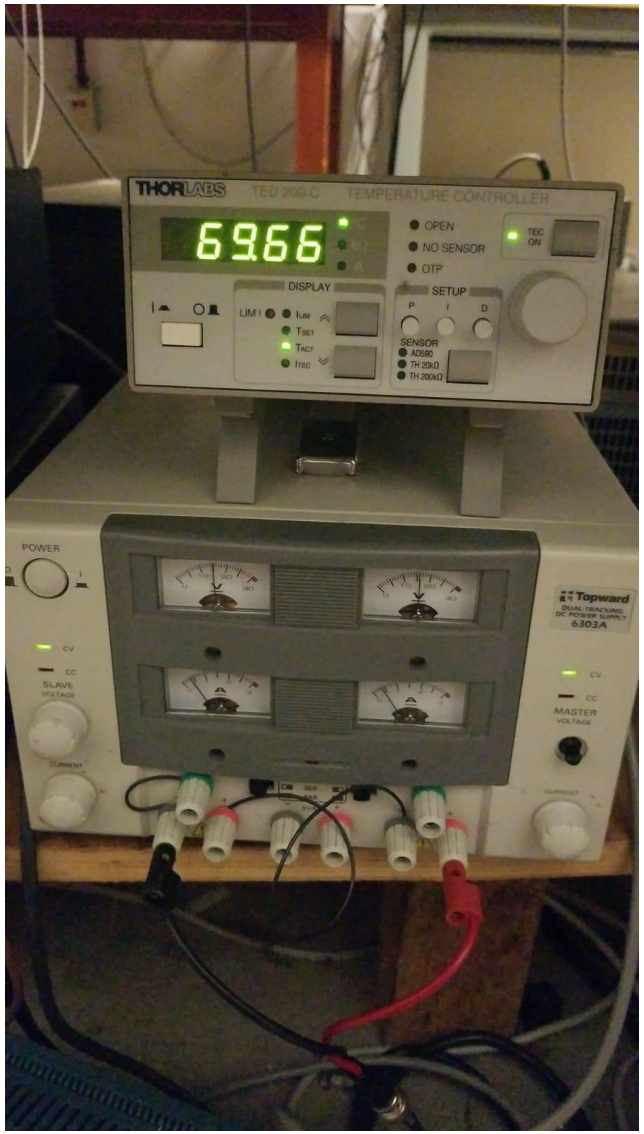




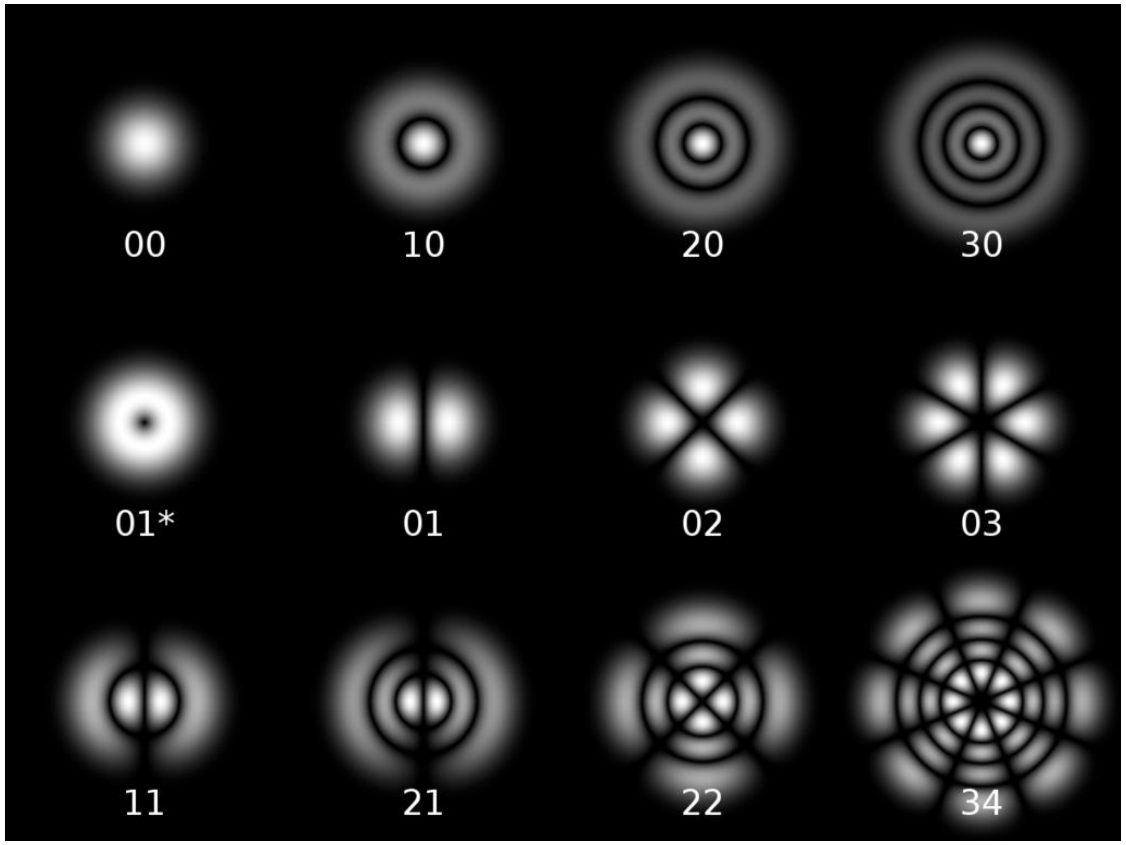
Temperature stabilization

- Thorlabs TED200C (4th attempt)
- Resistive Heater
- TEC

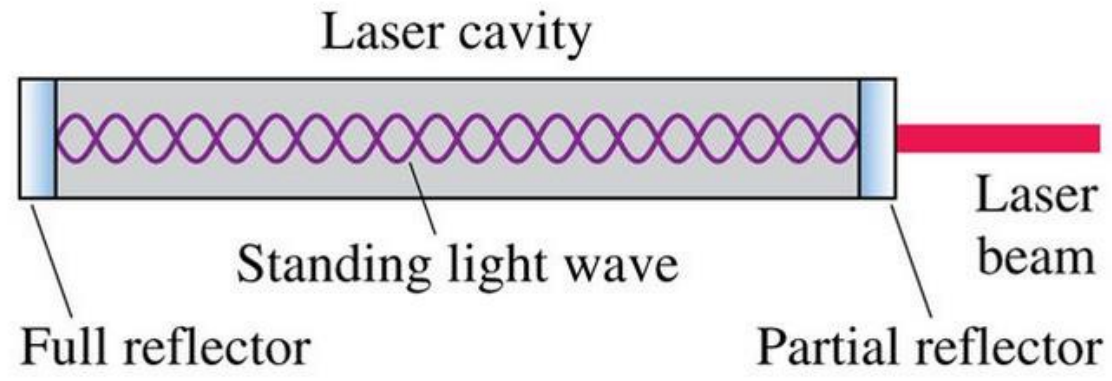


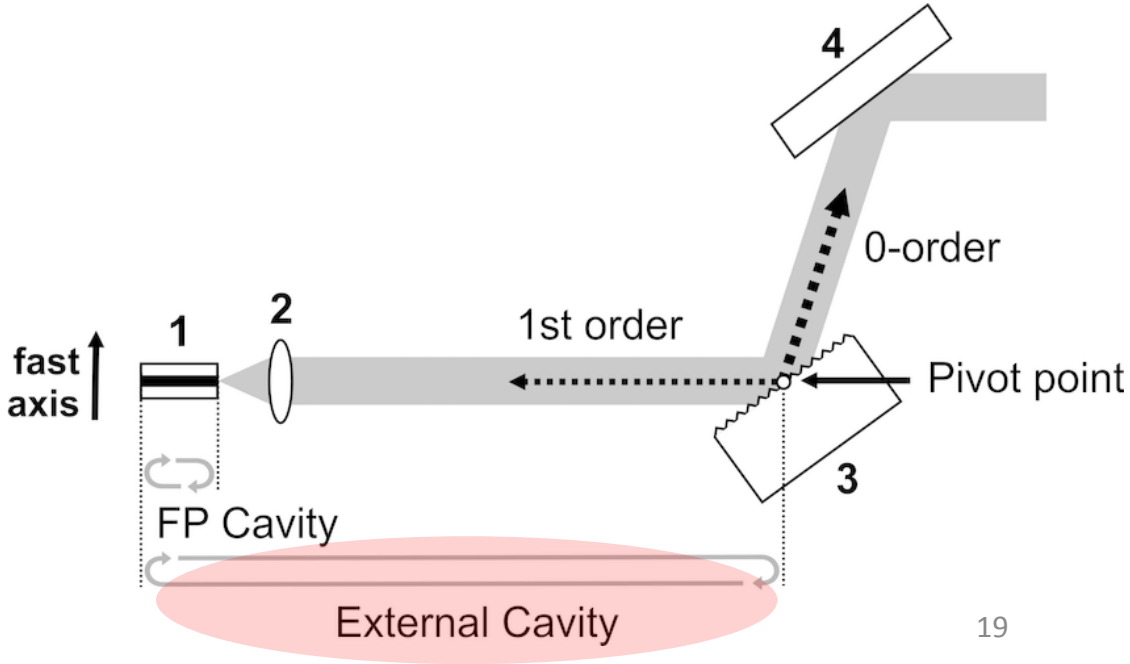


Laser modes

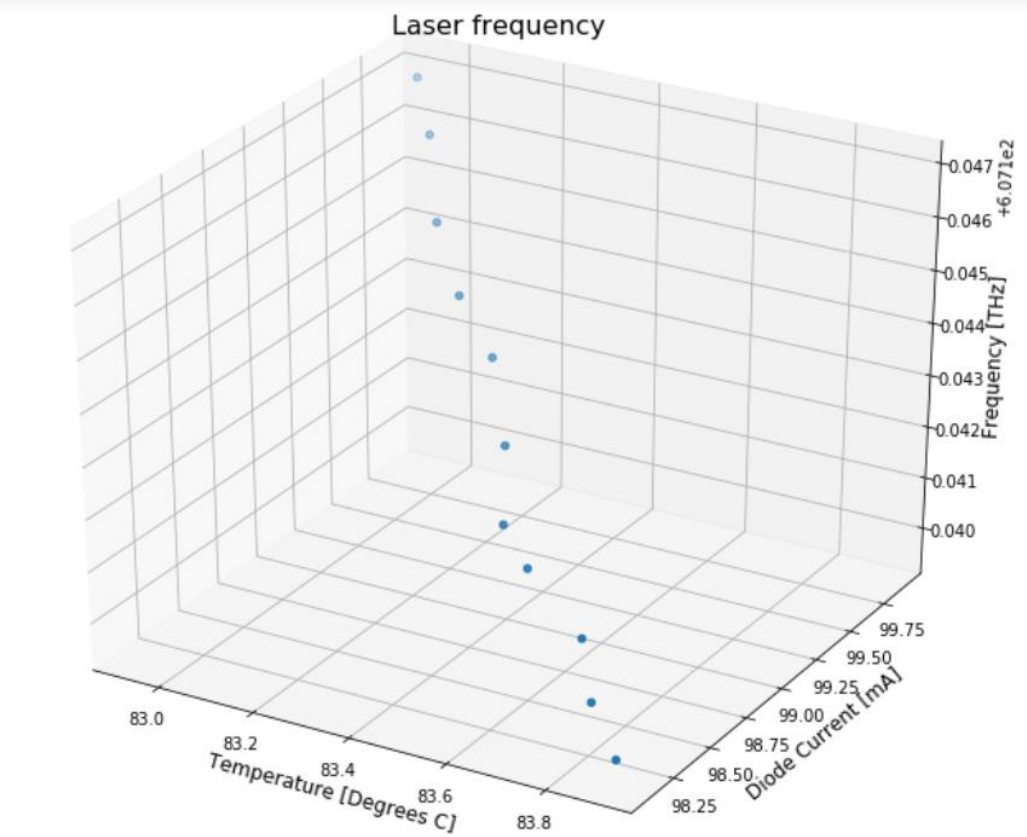


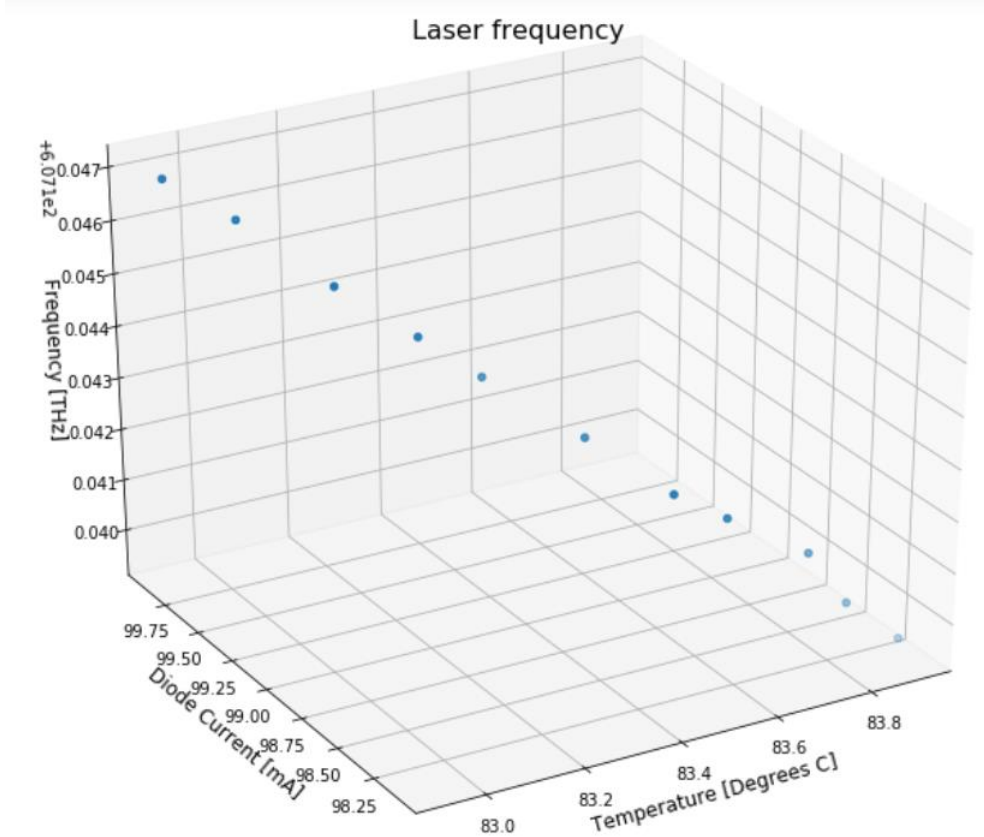
[17]



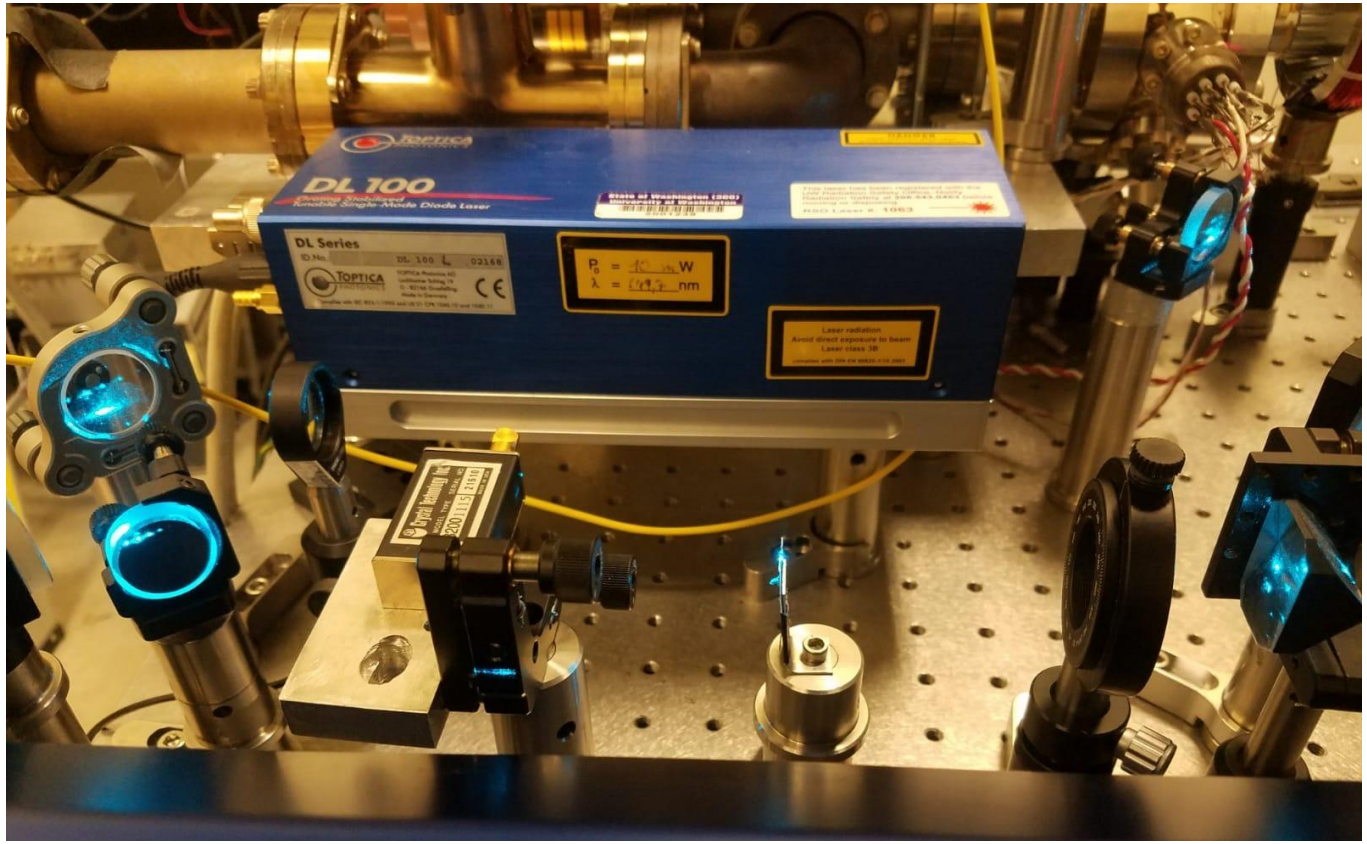


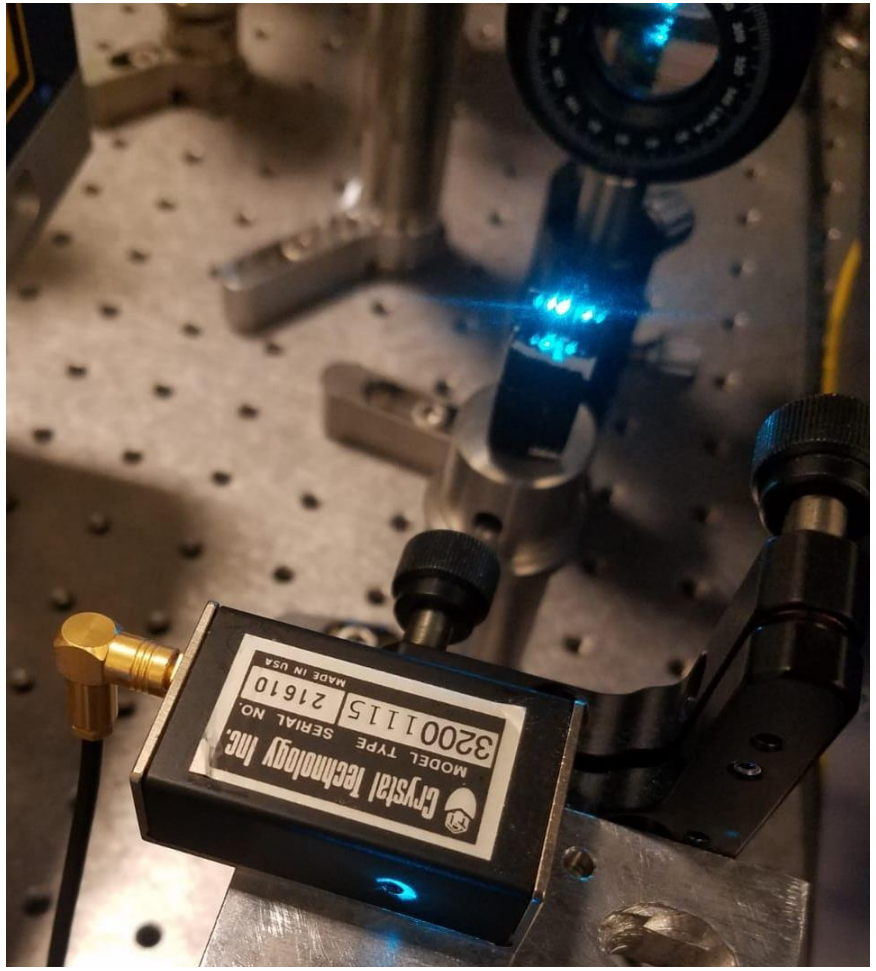
Temperature and Current Dependence



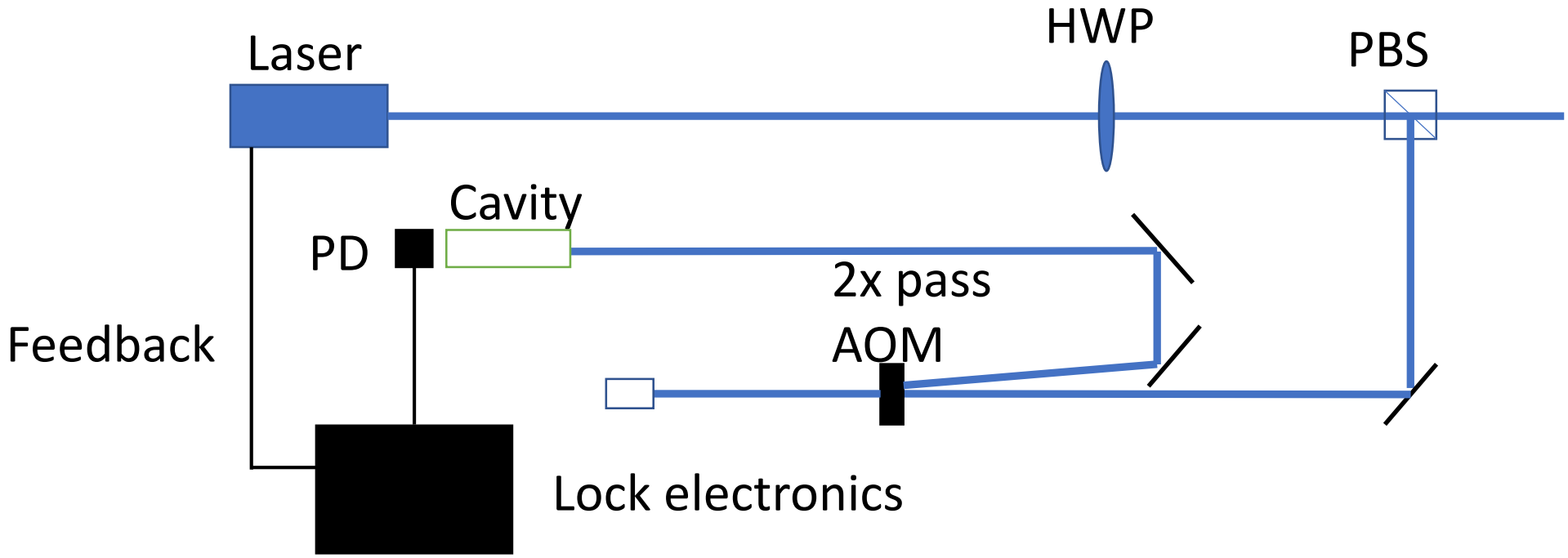


Laser Locking

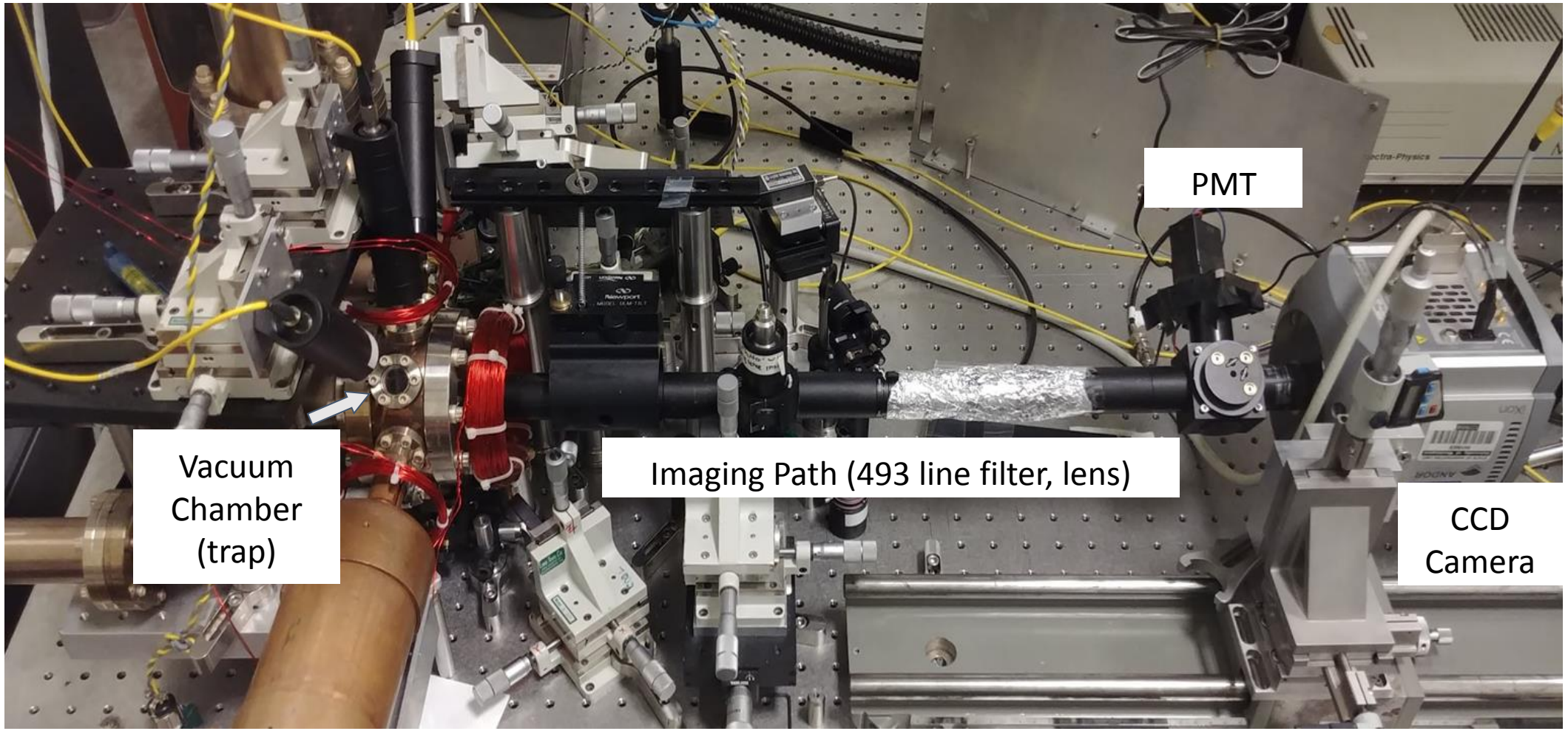




Locking Scheme

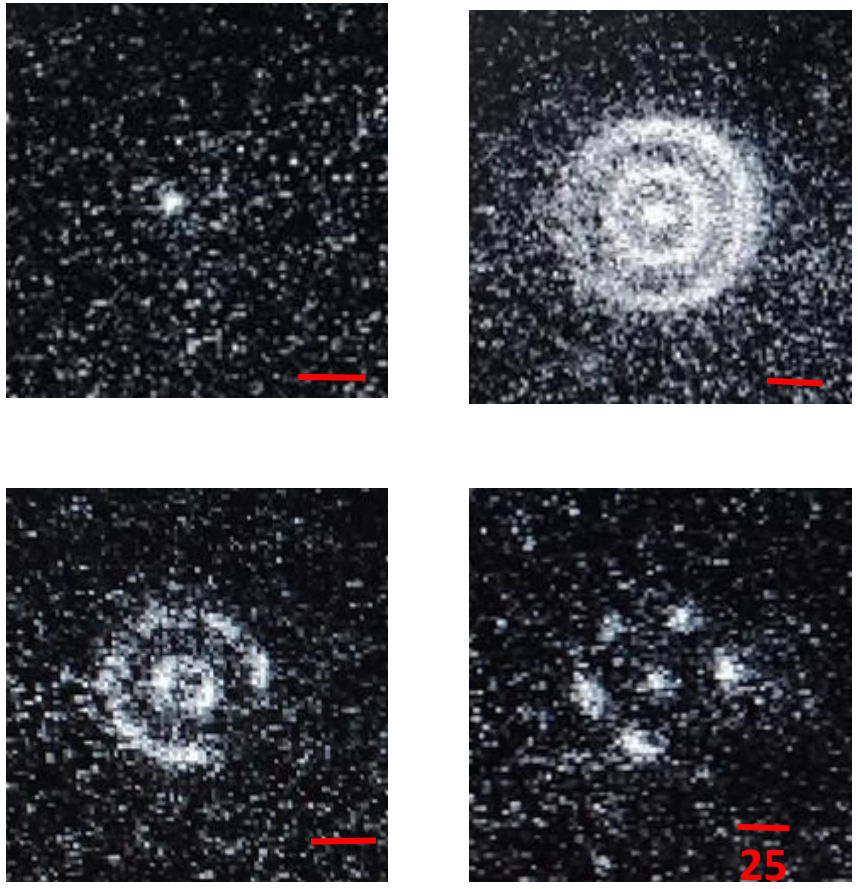


Ion trapping experimental Setup



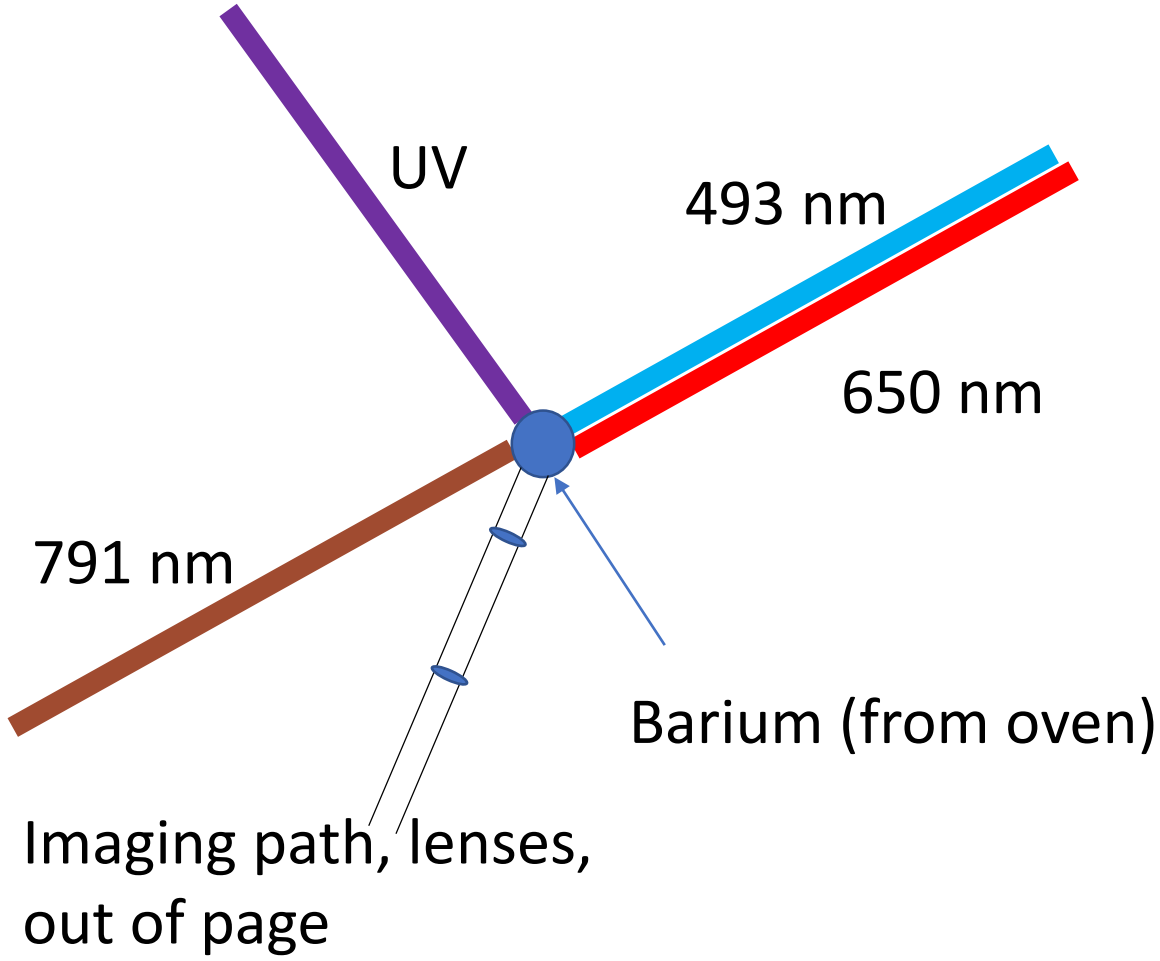
[11]

Ion pictures



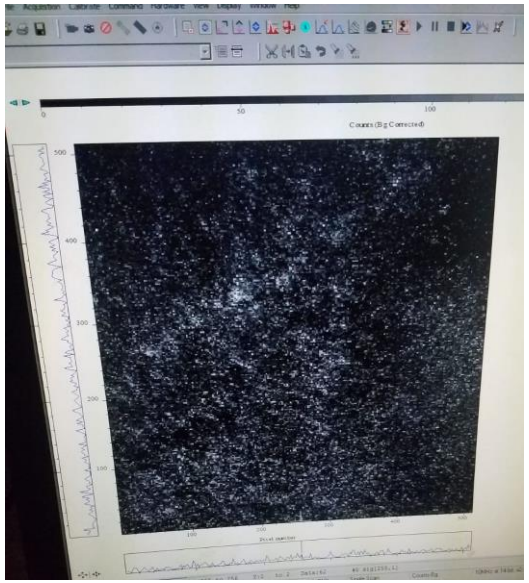
[11]

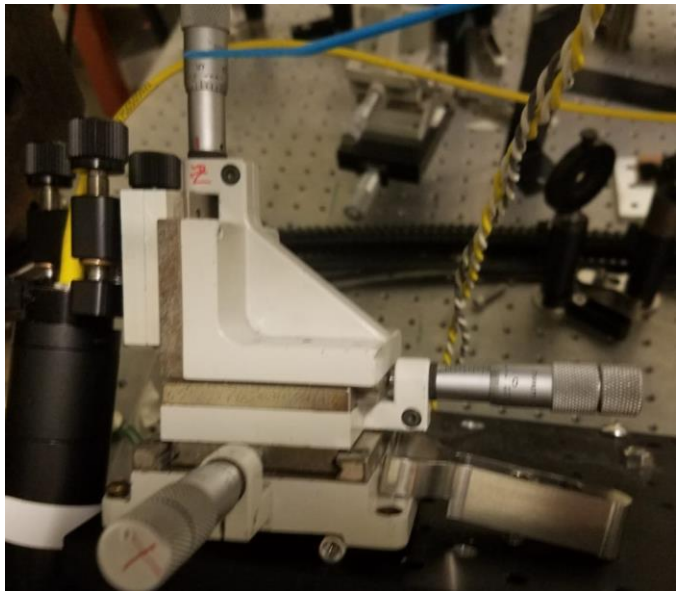
The Perfect Combination

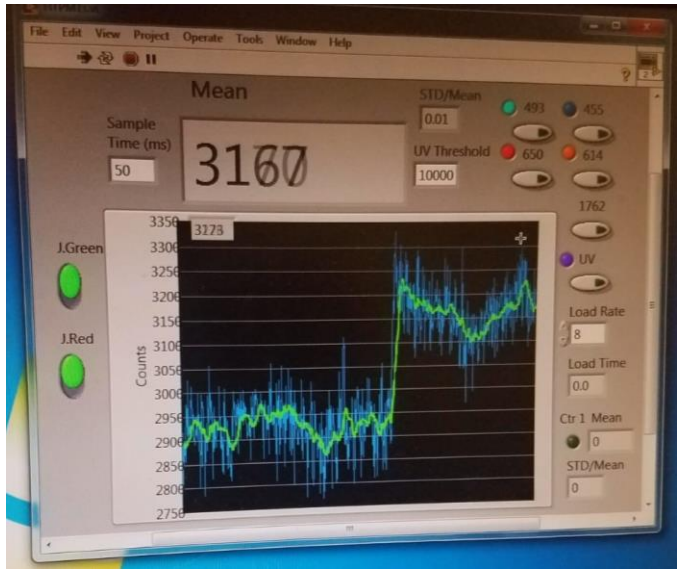


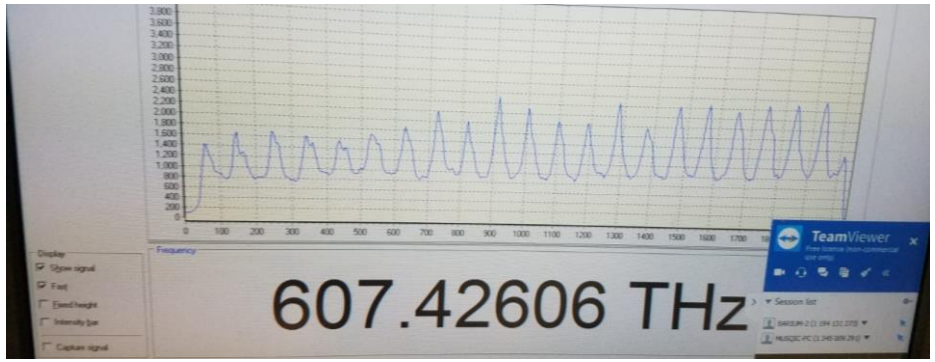
= RF minimum

Searching for ions









Conclusion

- Ion trapping is non-trivial
- My laser allowed:
  - 2 orders of magnitude more power sent to the to trap
  - Will allow better visualization of ions, less sensitive to frequency shifts
  - Wider section of space can be visualized

Acknowledgments

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- Cheryl McDaniel and Linda Vilett
- Alex Kato, Jennifer Lilieholm and Mila Zhukas
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- The Institute of Nuclear Theory

National Science Foundation
WHERE DISCOVERIES BEGIN

INSTITUTE for NUCLEAR THEORY

DEPARTMENT OF PHYSICS
UNIVERSITY of WASHINGTON

Citations and References

[1] http://qoqms.phys.strath.ac.uk/figures/qubit.png

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[3] http://mizuochilab.kuicr.kyoto-u.ac.jp/image/NV9.png

[4] https://www2.physics.ox.ac.uk/sites/default/files/imce/248/TrapIonzoom.jpg

[5] https://media1.britannica.com/eb-media/28/105428-004-13BB2171.jpg

[6] http://media.beam.usnews.com/8a/18/3d2e4ea543d19fcc9db29f724bb9/141016-stockmarket-stock.jpg

[7] https://hmslade5.files.wordpress.com/2012/02/terminator_movies_cyborg_movie_desktop_2000x2829_wallpaper-2281151.jpg

[8] Barium Ions for Quantum Computation, Matt Dietrich, PhD Thesis, 2009.

[9] http://www.comfsm.fm/~dleeling/t3/reports/comfsm5.gif

[10] http://www.webassign.net/pse/p23-69.gif

[11] Jennifer Lilieholm, General Exam Slides, 2019.

[12] https://upload.wikimedia.org/wikipedia/commons/thumb/1/11/Paul-Trap.svg/800px-Paul-Trap.svg.png

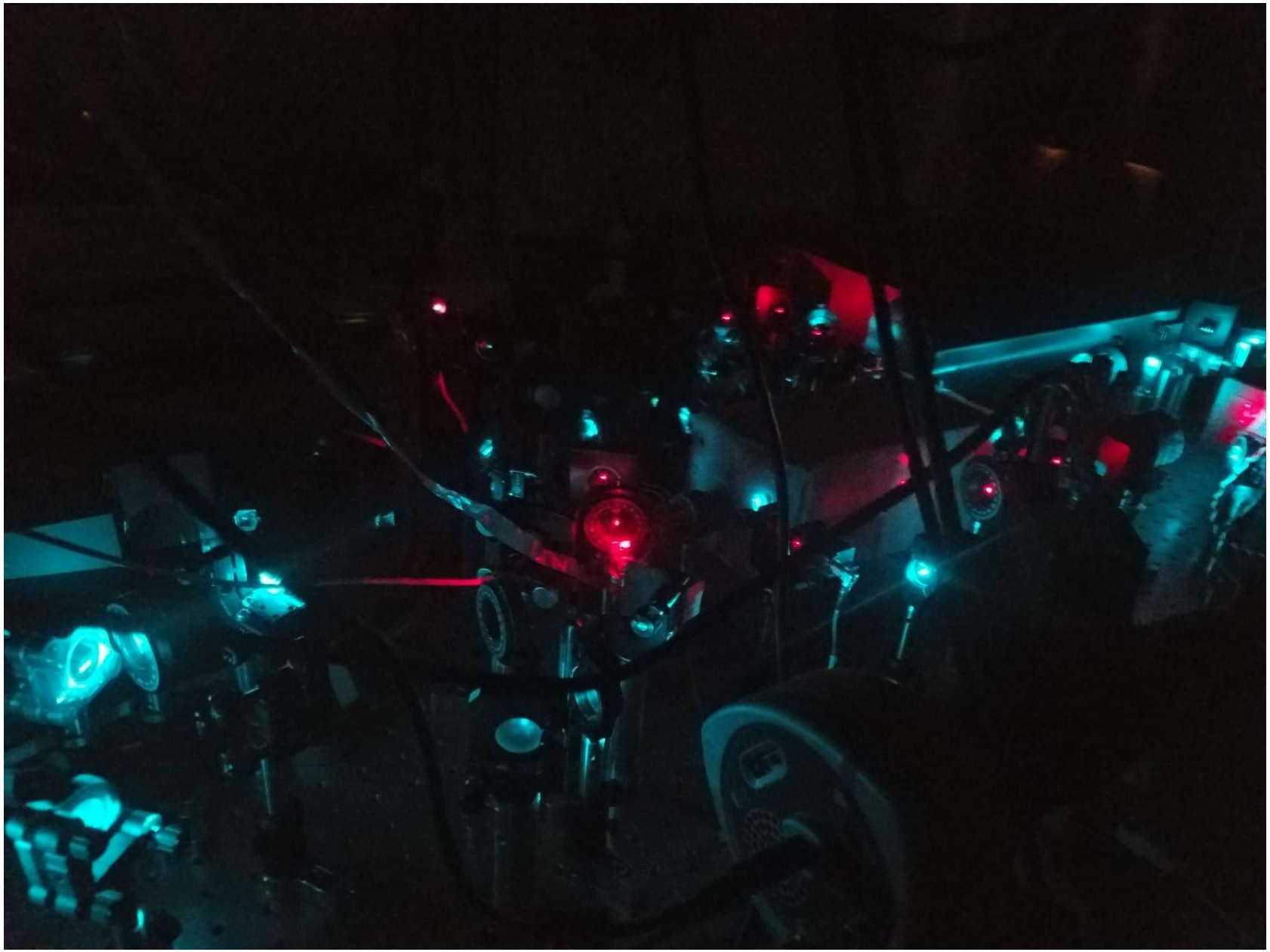
[13] https://i.ytimg.com/vi/z0EaoilzgGE/maxresdefault.jpg

[14] https://i.ytimg.com/vi/vDvIhiCnatE/maxresdefault.jpg

[15] https://upload.wikimedia.org/wikipedia/commons/thumb/a/ab/Pin-Diode.svg/1920px-Pin-Diode.svg.png

[16] https://www.researchgate.net/publication/263516767/figure/fig1/AS:422163762159618@1477663092718/Schematic-view-top-view-of-the-ECDL-setup-in-Littrow-configuration-1-FP-laser-diode.png

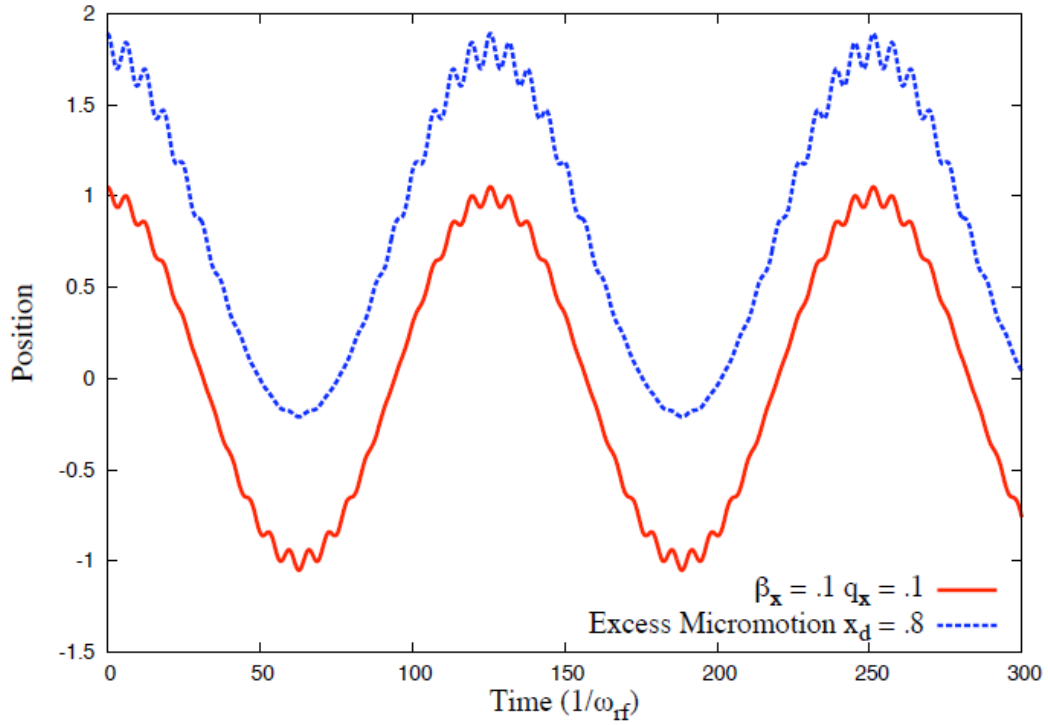
[17] https://upload.wikimedia.org/wikipedia/commons/thumb/9/97/Laguerre-gaussian.png/1024px-Laguerre-gaussian.png



Secular and Micro Motions

$$x(t) = 2AC_0 \cos\left(\beta_x \frac{\omega_{\mathrm{rf}}}{2} t\right)\left[1 - \frac{q_x}{2}\cos\left(\omega_{\mathrm{rf}} t\right)\right]$$

$$\beta_x = \sqrt{a_x + q_x^2/2},$$



[8]