Precision Atomic Spectroscopy of Lithium

Mike Rowan

We study atoms because…

- Atoms are relatively simple

  Good theoretical understanding of atoms

  We can make models and calculations

- We can control them well by use of lasers

  Extreme accuracy of measurements serve as tests of our understanding

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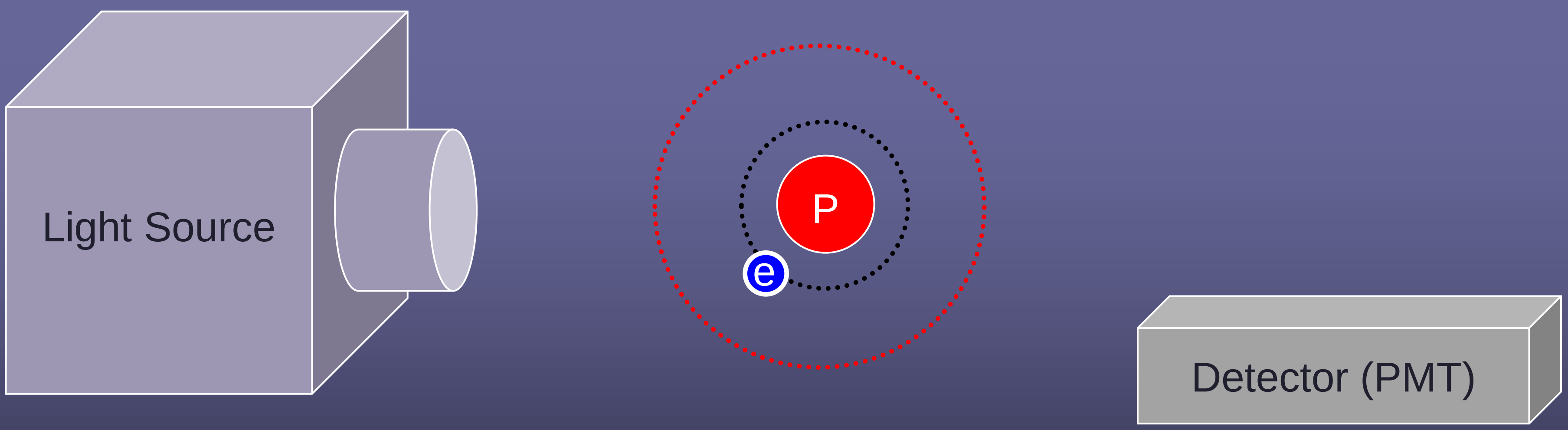
High-precision experiments provide tests of fundamental physics

- Fundamental constants – are they changing?
- General relativity
- Weak interaction
- Quantum electrodynamics

How do we study atoms?

- Spectroscopy – how light interacts with atoms
- Energy of a photon proportional to frequency (color); $E=h\nu$
- First, we excite an atom using light
- The atom then decays back to the ground state
- We detect fluorescence with a PMT



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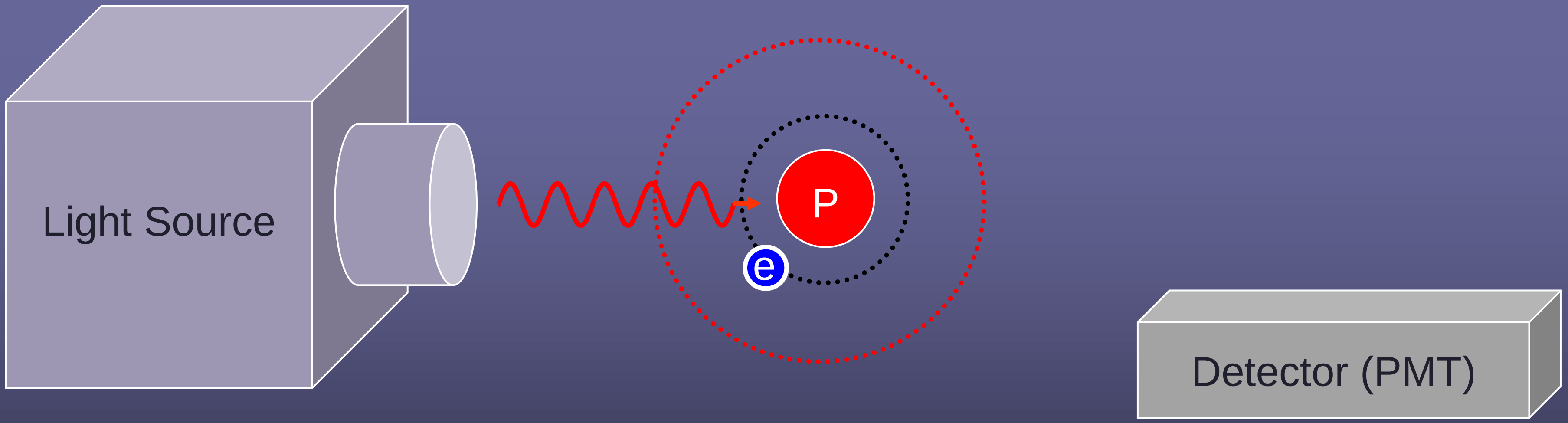

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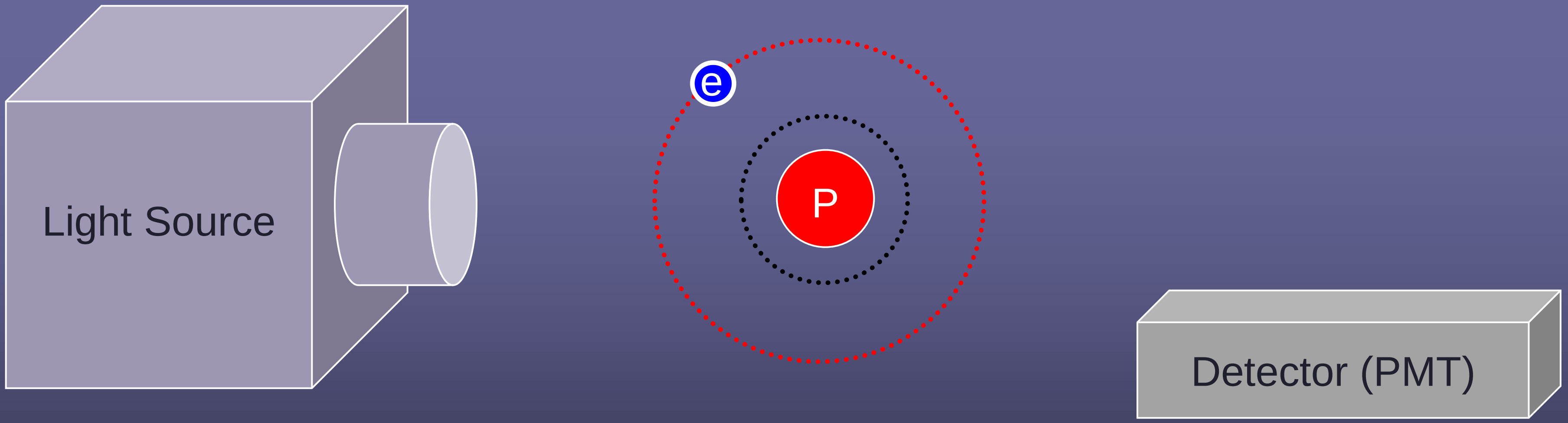

Transition!

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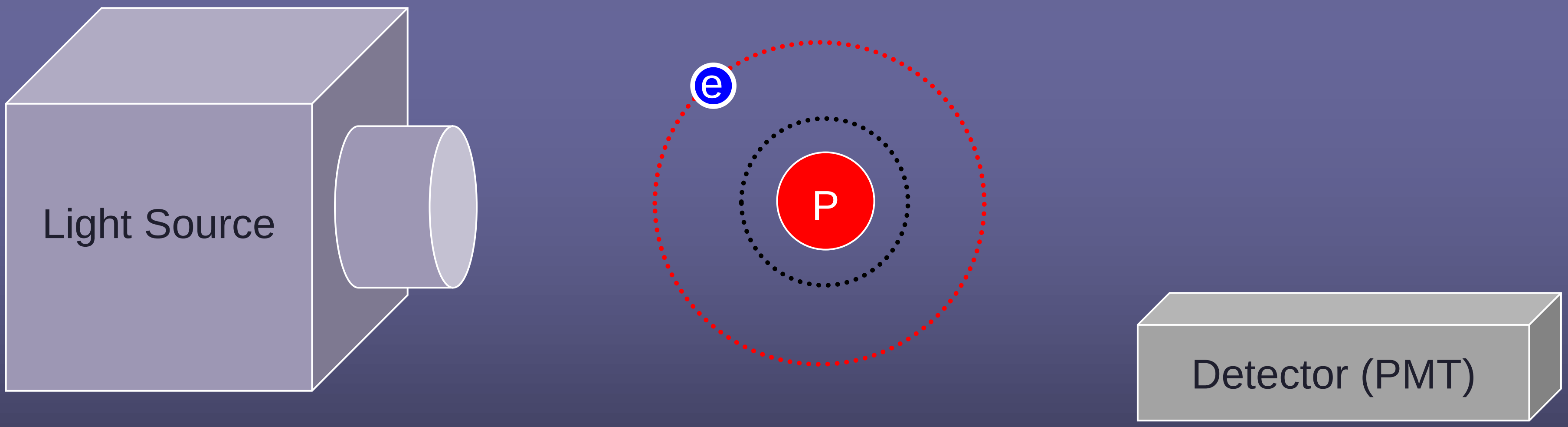

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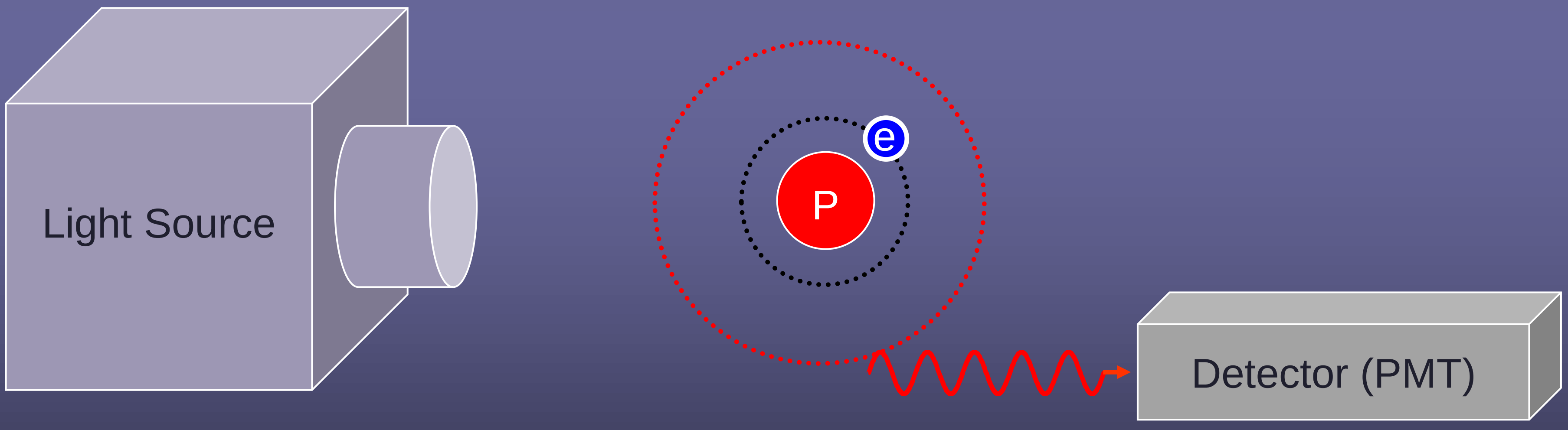

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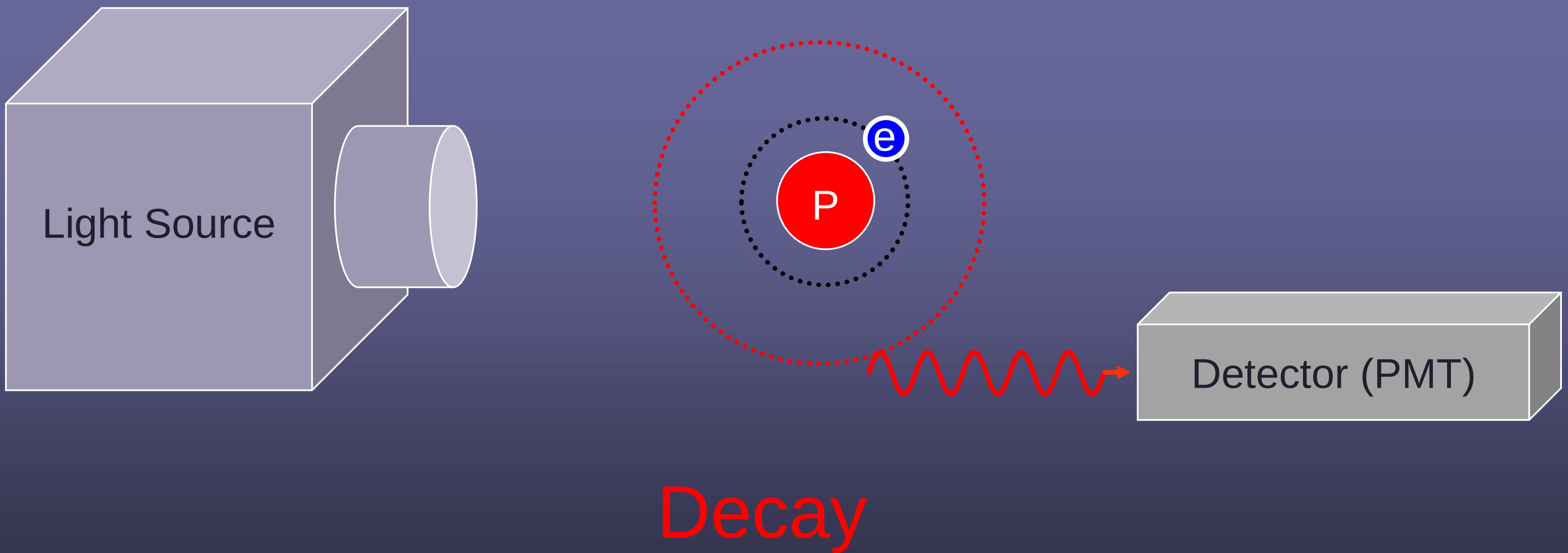

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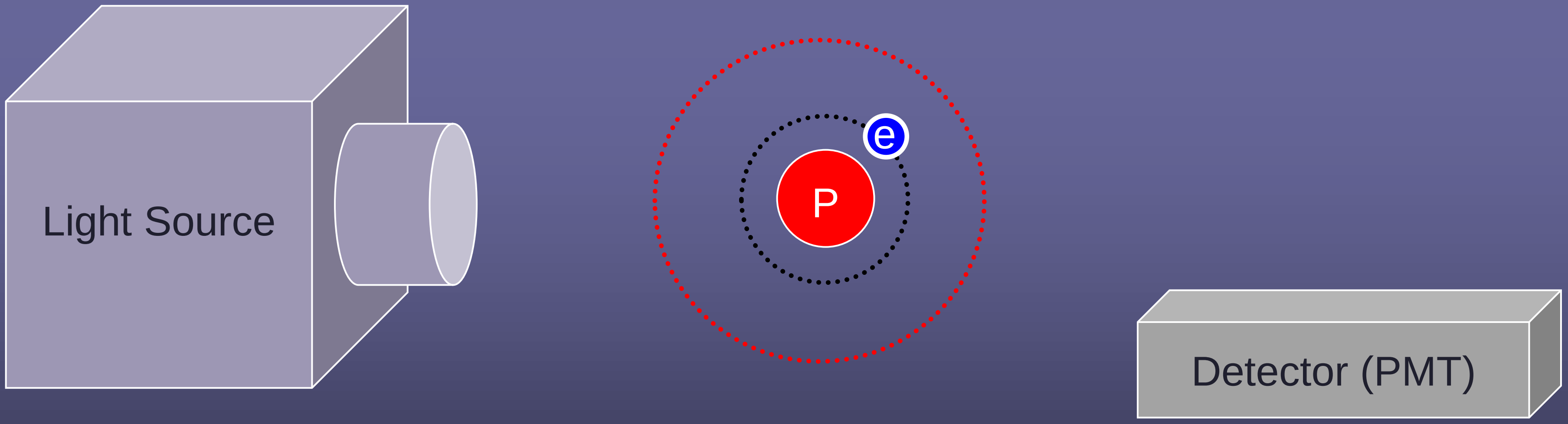

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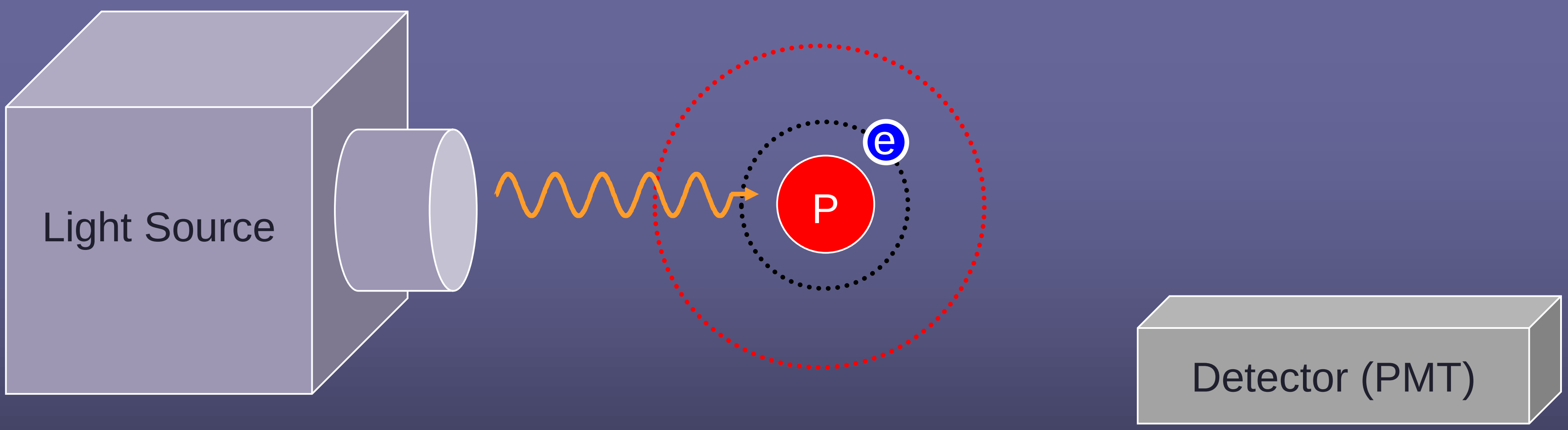

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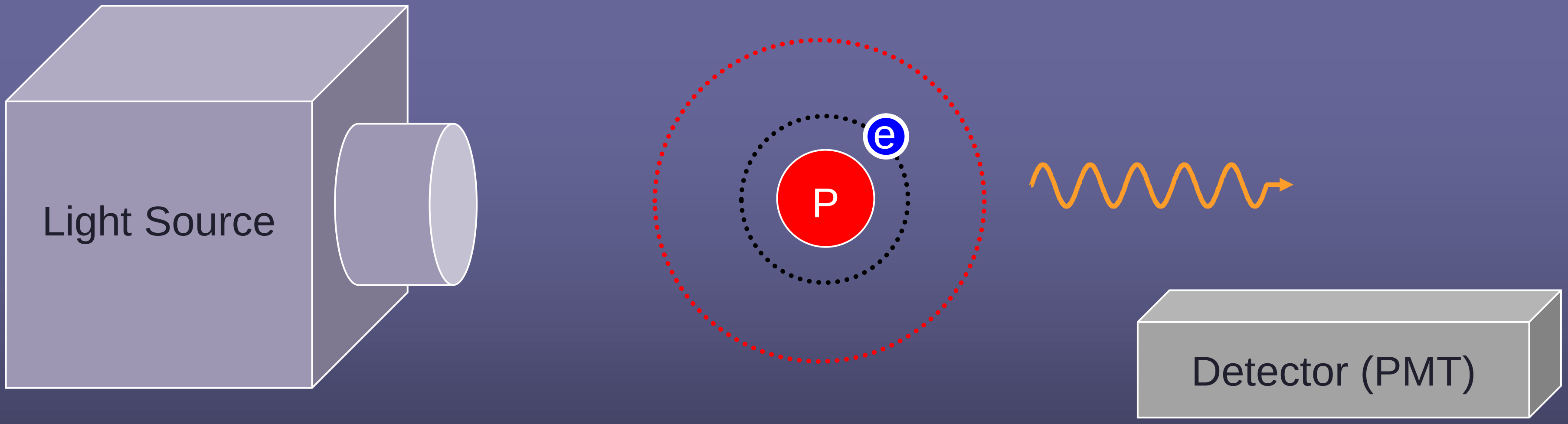

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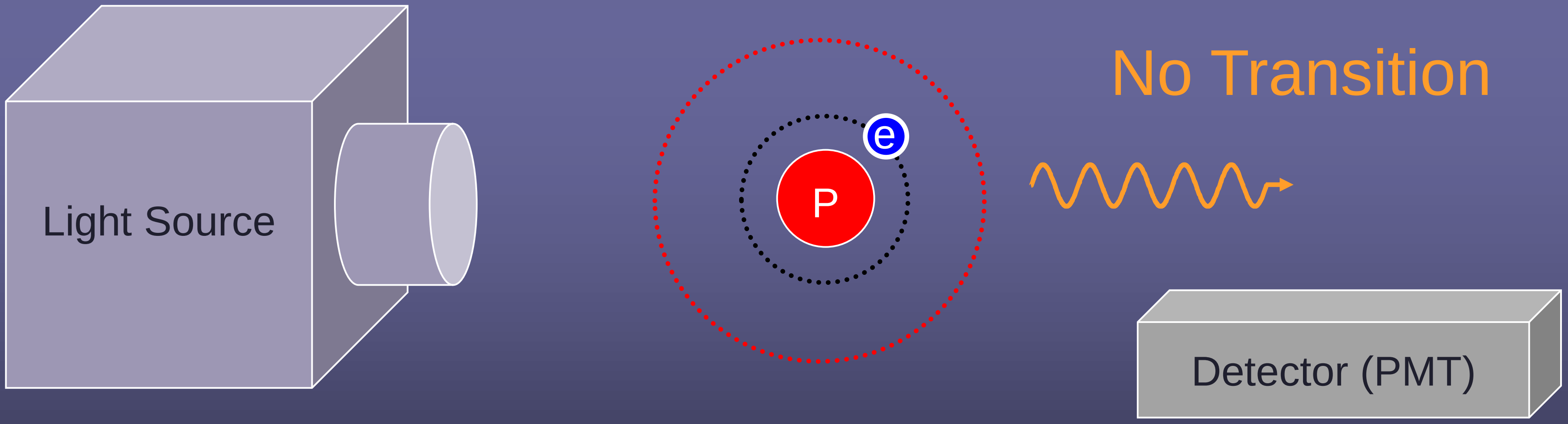

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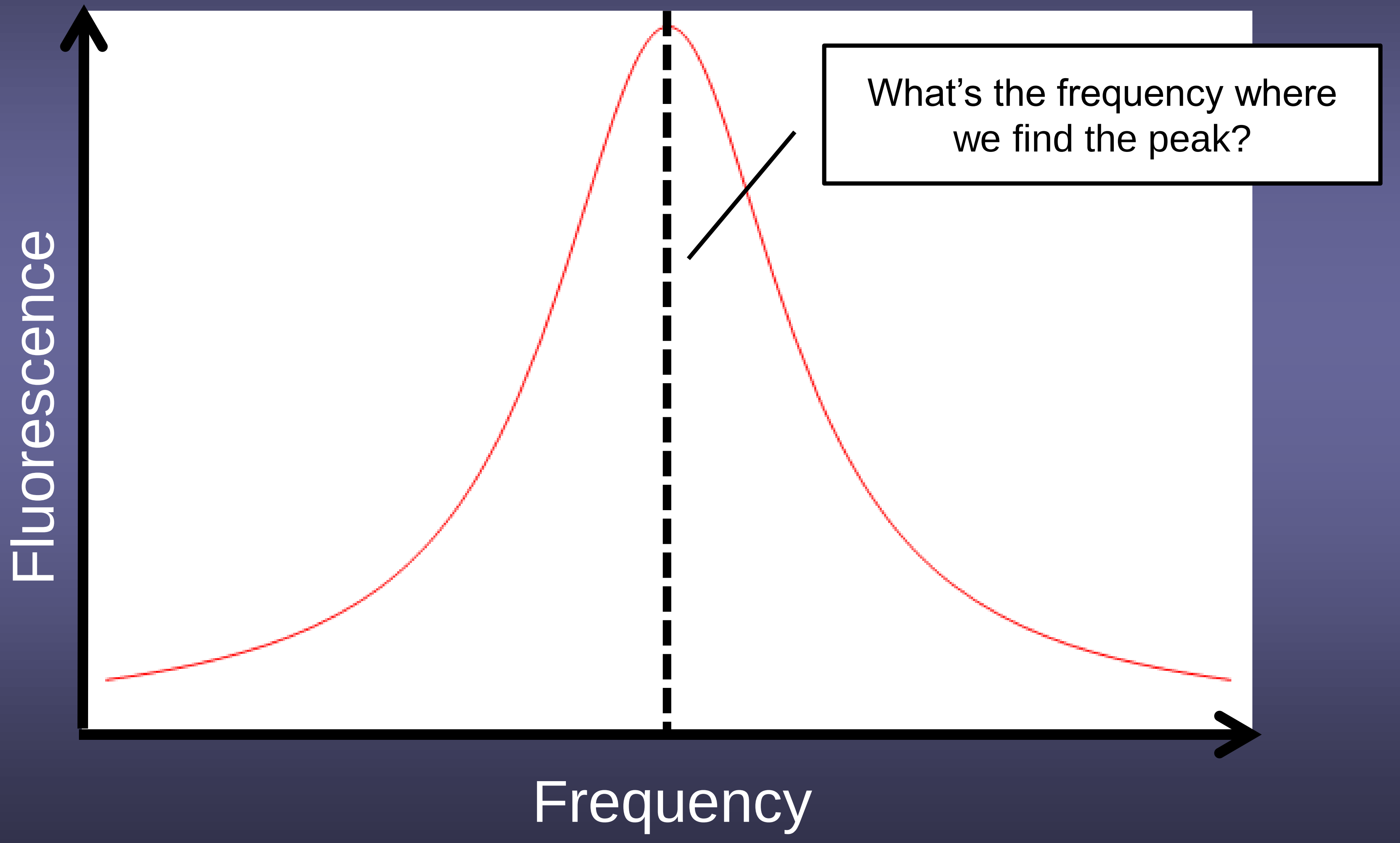
What’s that frequency?



How do we study atoms?

- Frequencies for transitions are in visible region

400,000,000,000,000 cycles per second!

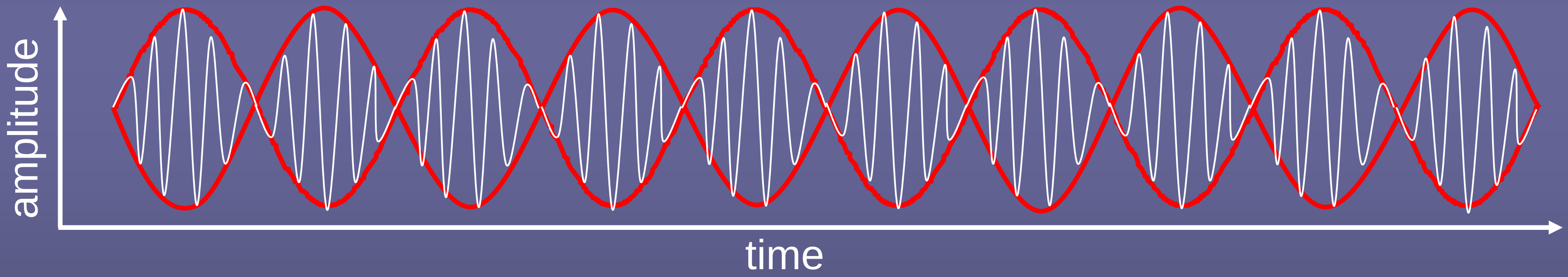
- Modern electronics can only respond at about

10,000,000,000 cycles per second

- To get around this, we use "interference" to produce a measurable frequency

Interference

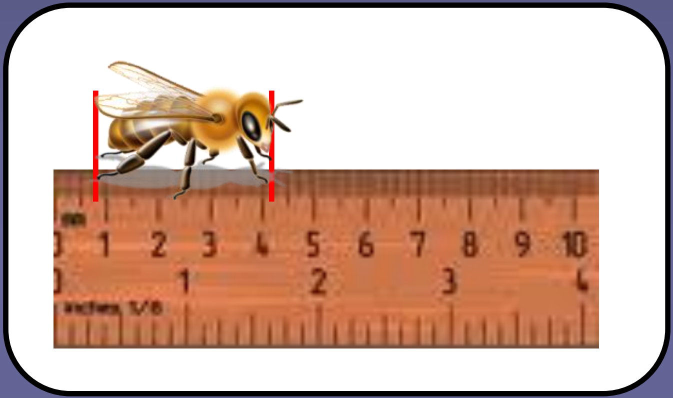
- The rate of a beat is the difference of two frequencies – it results from the interference of two slightly different frequencies
- We hear this as a periodic variation in volume



- If you know one frequency and you know the beat frequency, then you can determine the second frequency
- By interfering frequencies of visible light, we get a beat frequency that is in the radio range – this is measurable

How do we use interference when dealing with optical frequencies?

- We make a “light ruler” – analogous to normal ruler



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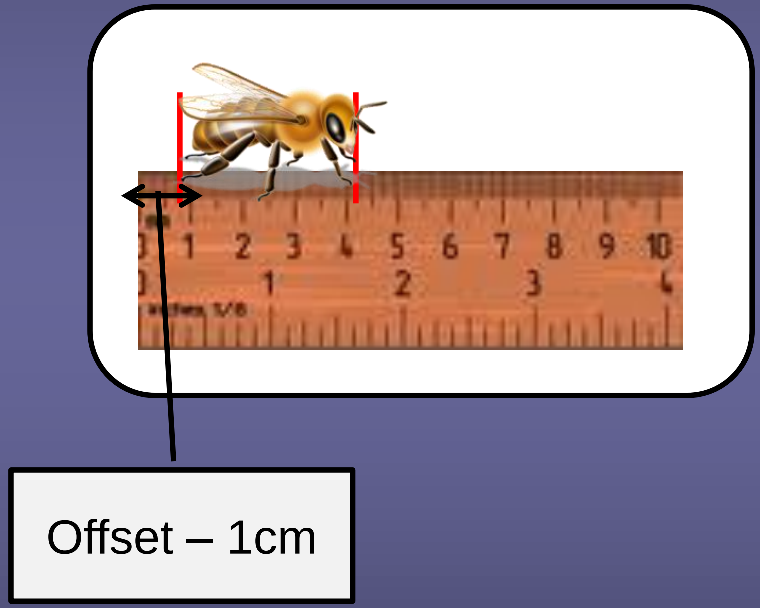

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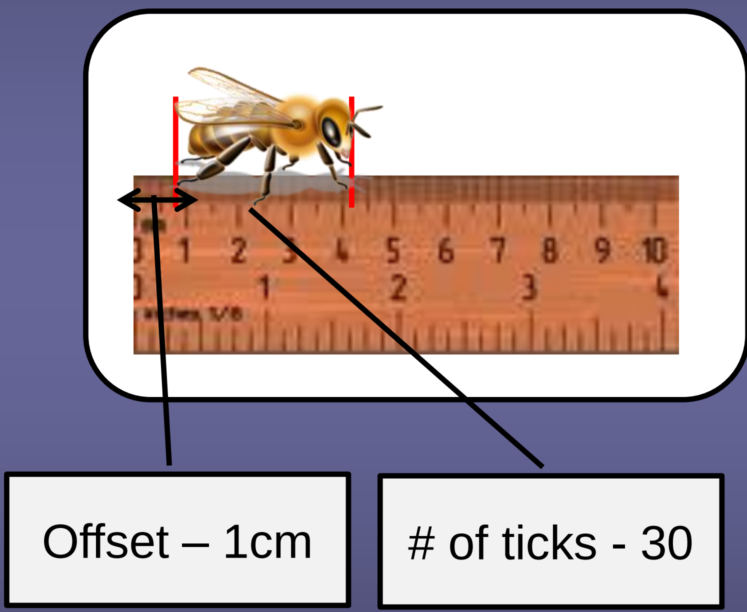

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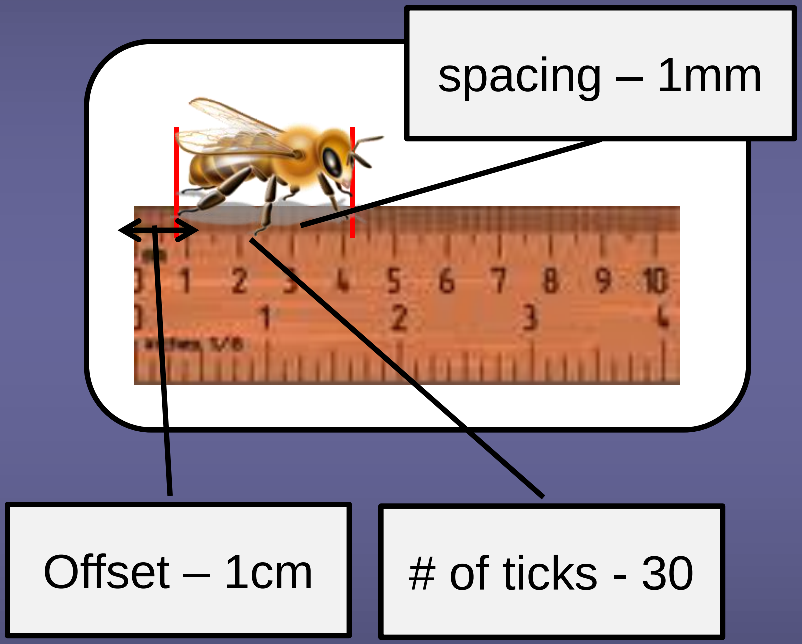

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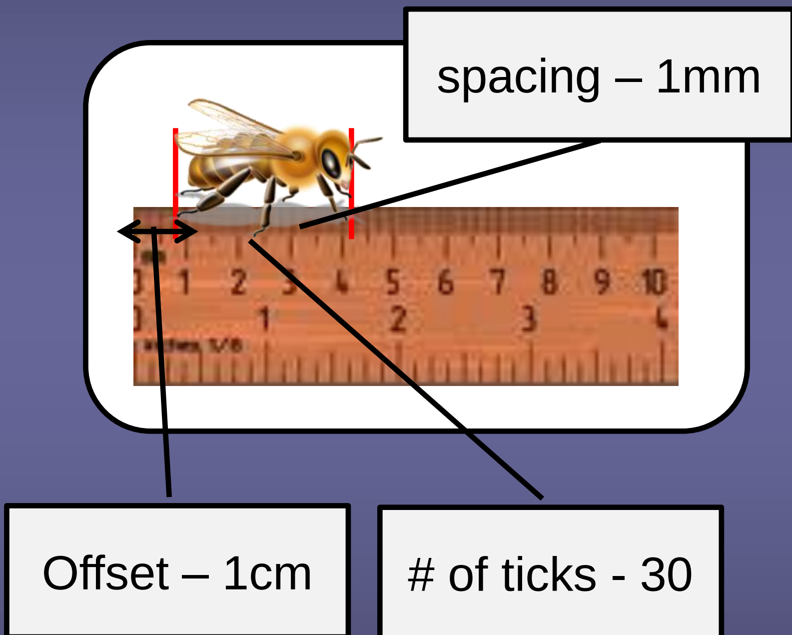

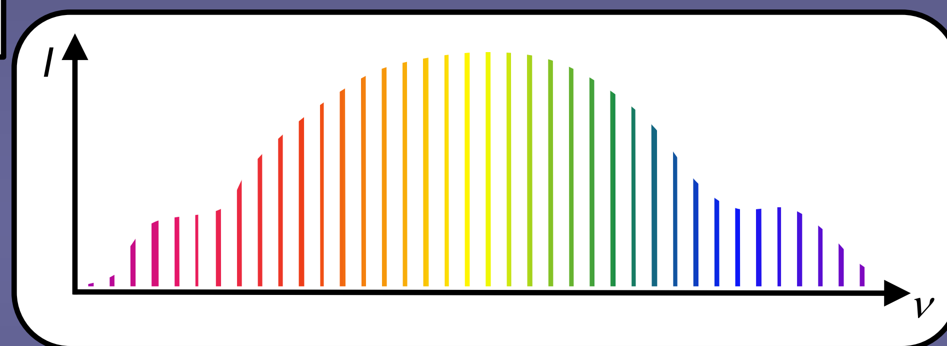

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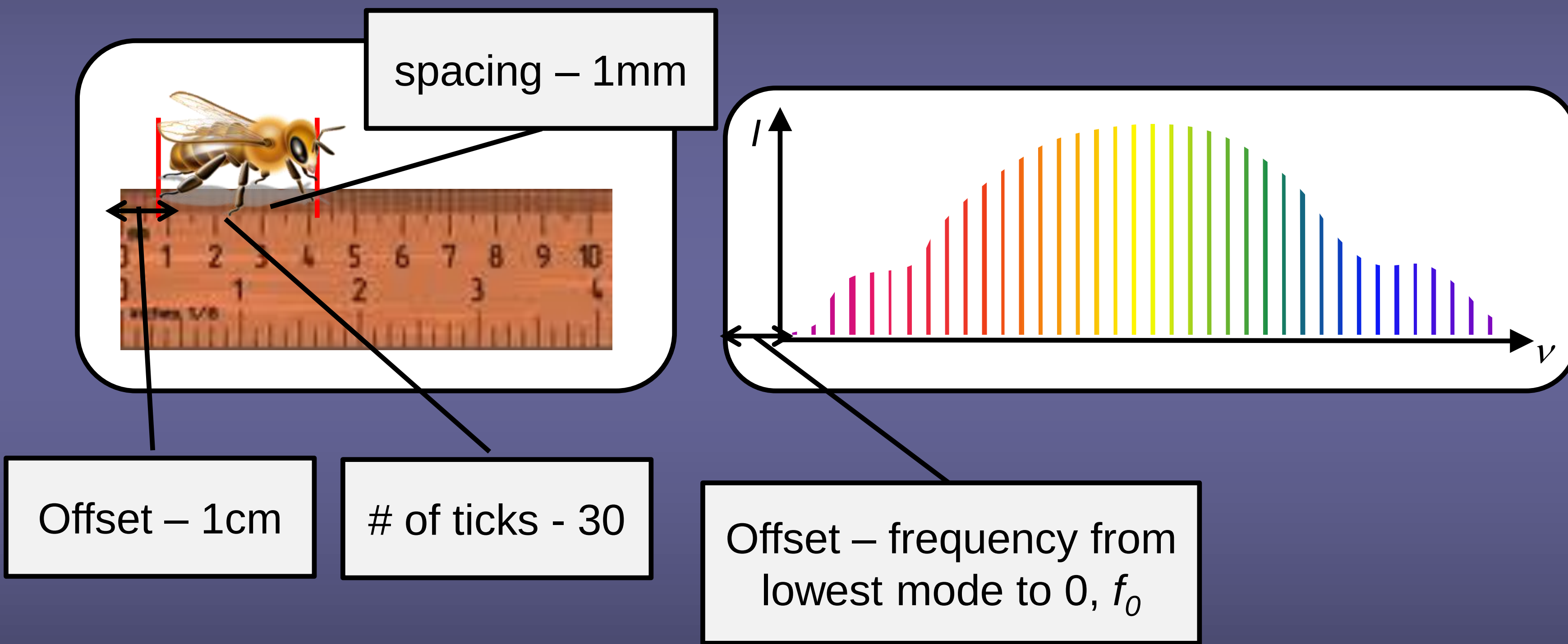

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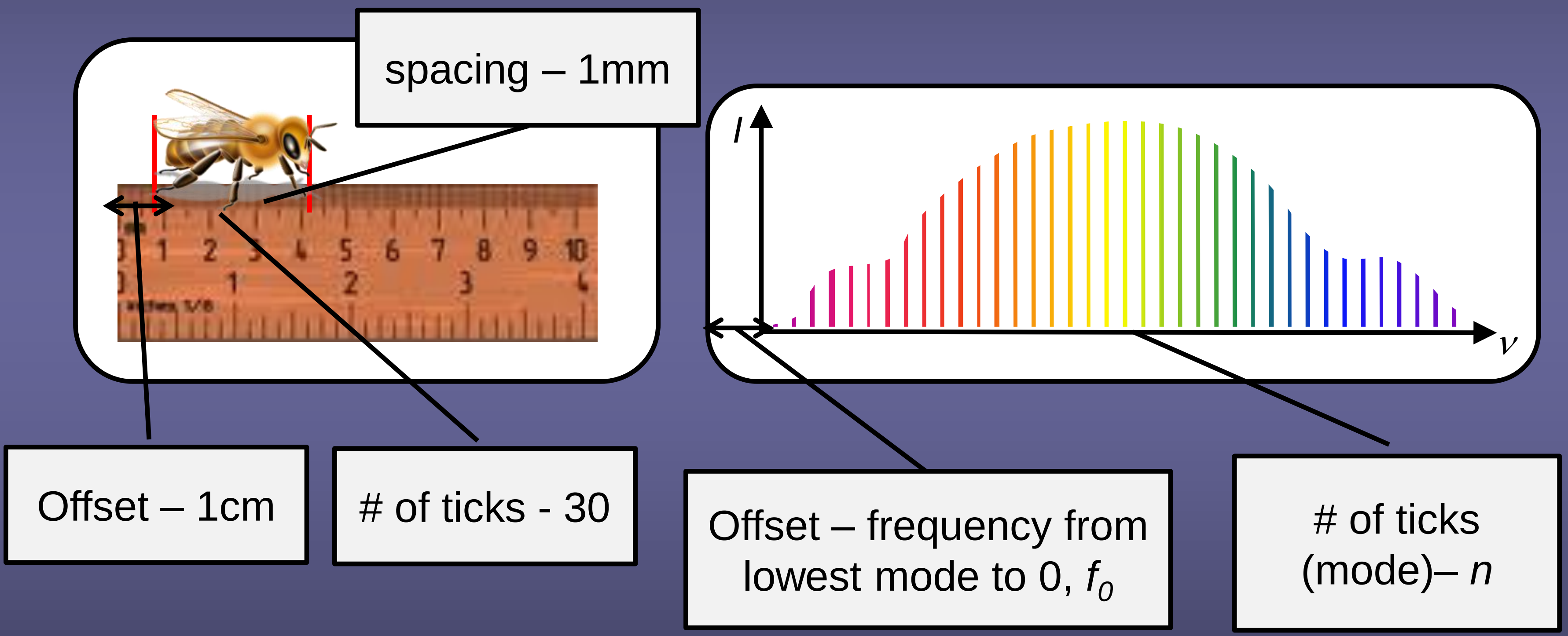

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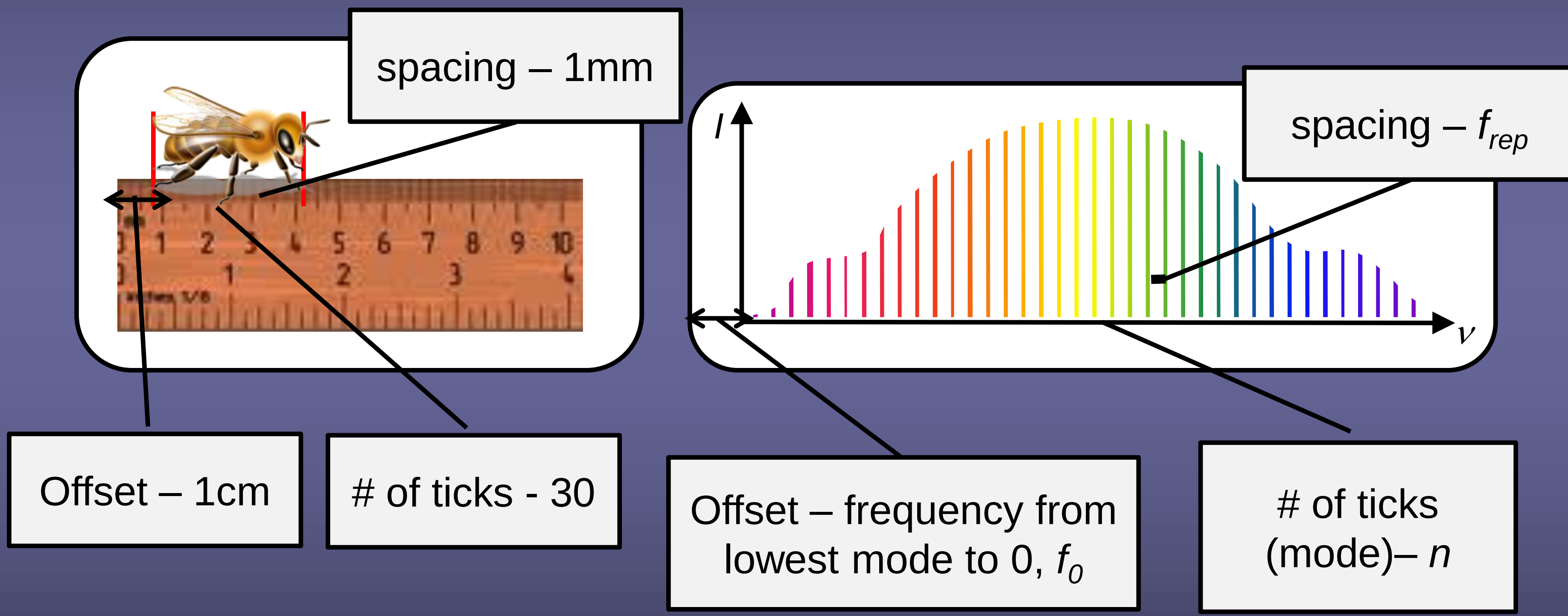

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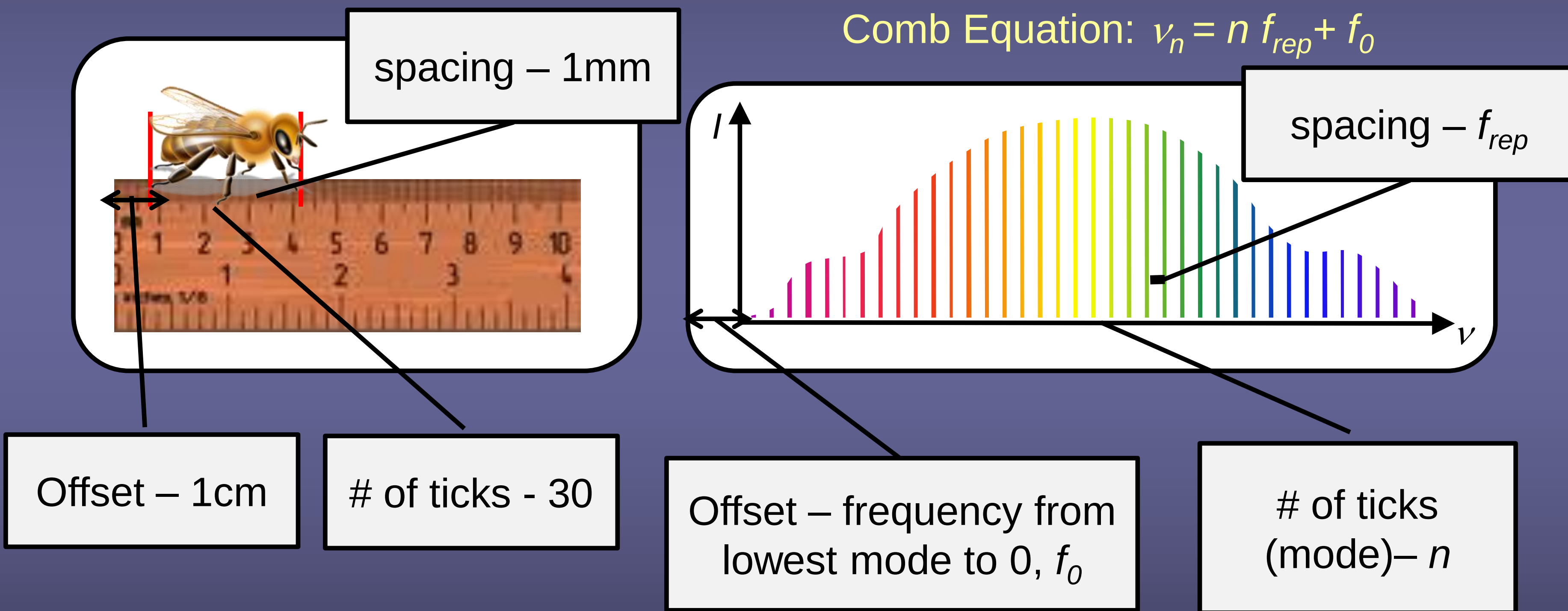

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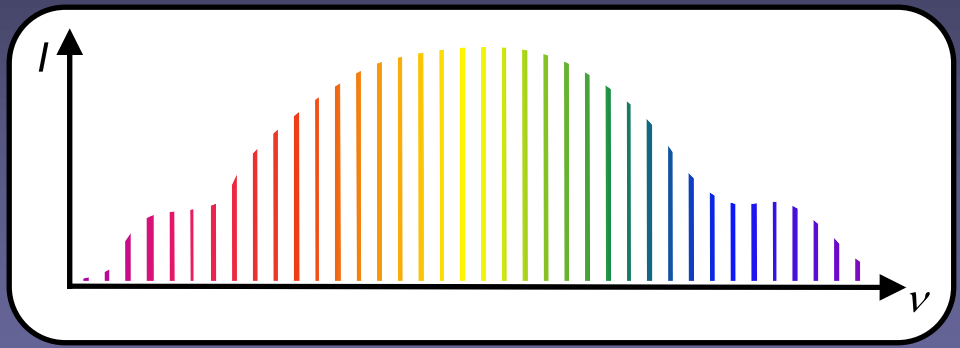
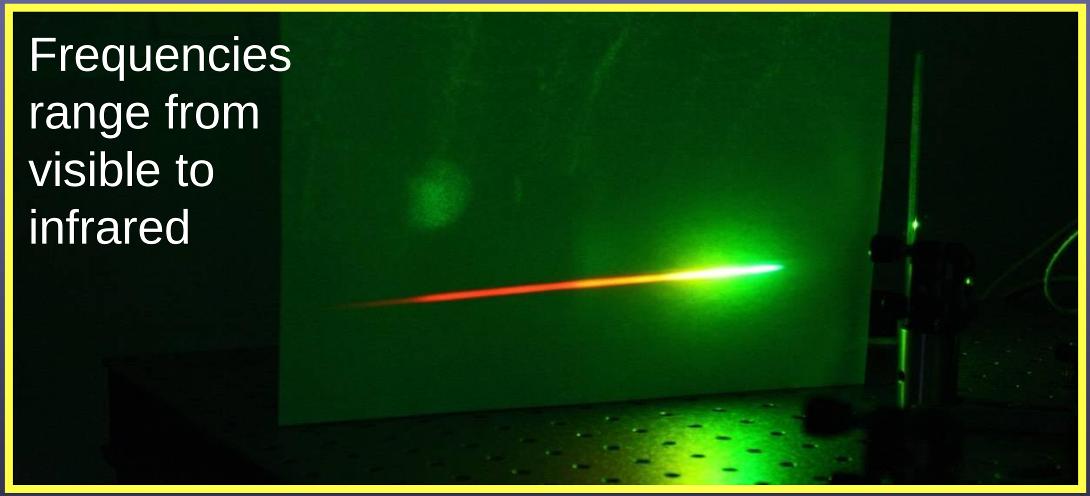
Frequency Comb





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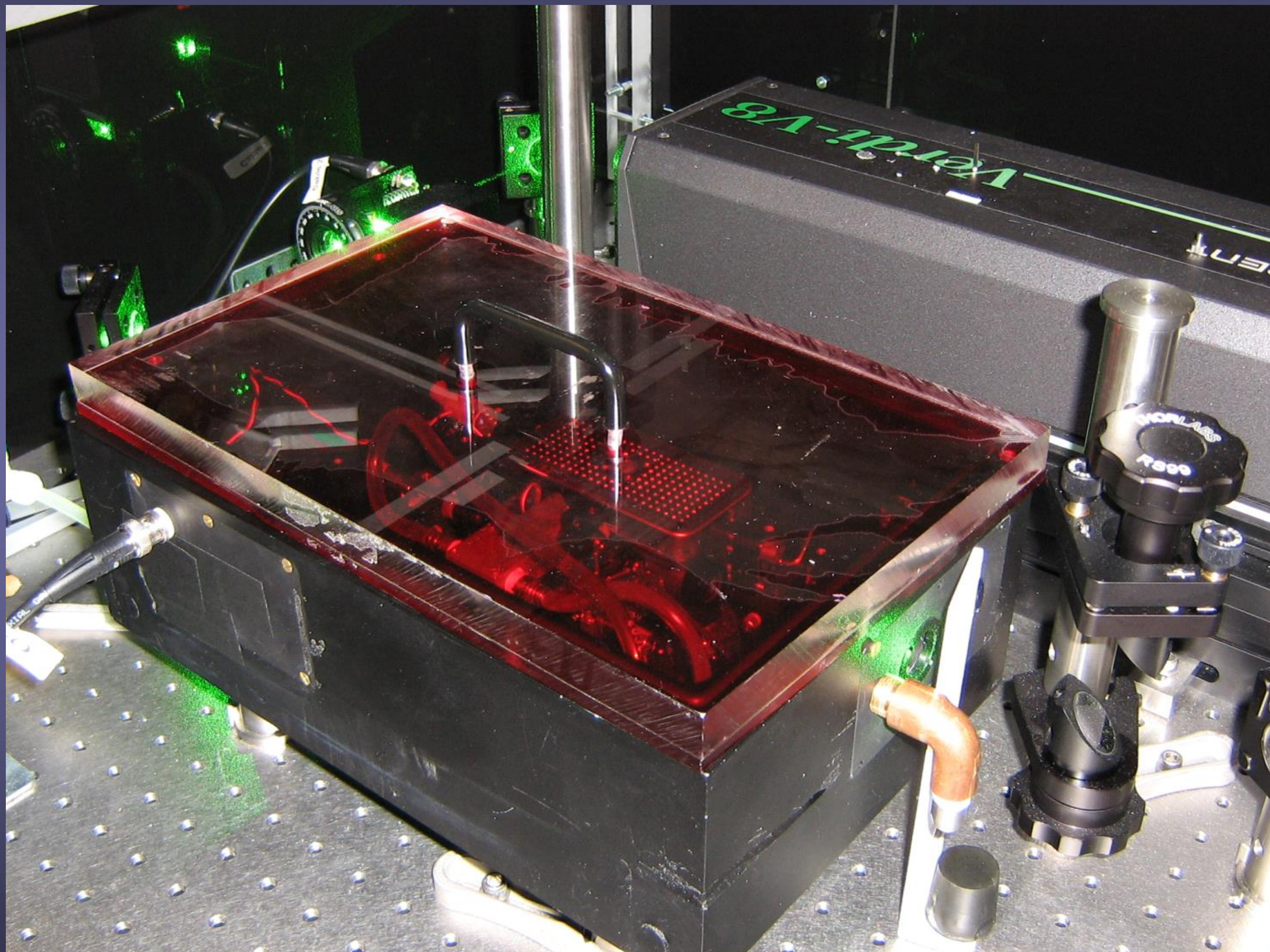

Why lithium?

- It is simple (like a noble gas and an electron)
- Since it is simple, theory is good
- Two stable isotopes
- Disagreement among previous measurements

The Periodic Table of the Elements

1 **H** Hydrogen 1.00794																	2 **He** Helium 4.003
3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012182											5 **B** Boron 10.811	6 **C** Carbon 12.0107	7 **N** Nitrogen 14.00674	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.9984032	10 **Ne** Neon 20.1797
11 **Na** Sodium 22.989770	12 **Mg** Magnesium 24.3050											13 **Al** Aluminum 26.981538	14 **Si** Silicon 28.0855	15 **P** Phosphorus 30.973761	16 **S** Sulfur 32.066	17 **Cl** Chlorine 35.4527	18 **Ar** Argon 39.948
19 **K** Potassium 39.0983	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.955910	22 **Ti** Titanium 47.867	23 **V** Vanadium 50.9415	24 **Cr** Chromium 51.9961	25 **Mn** Manganese 54.938049	26 **Fe** Iron 55.845	27 **Co** Cobalt 58.933200	28 **Ni** Nickel 58.6934	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.61	33 **As** Arsenic 74.92160	34 **Se** Selenium 78.96	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.80
37 **Rb** Rubidium 85.4678	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.90585	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.90638	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.90550	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.8682	48 **Cd** Cadmium 112.411	49 **In** Indium 114.818	50 **Sn** Tin 118.710	51 **Sb** Antimony 121.760	52 **Te** Tellurium 127.60	53 **I** Iodine 126.90447	54 **Xe** Xenon 131.29
55 **Cs** Cesium 132.90545	56 **Ba** Barium 137.327	57 **La** Lanthanum 138.9055	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.9479	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.217	78 **Pt** Platinum 195.078	79 **Au** Gold 196.96655	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.3833	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98038	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (263)	107 **Bh** Bohrium (262)	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (266)	110 (269)	111 (272)	112 (277)	113	114				
				58 **Ce** Cerium 140.116	59 **Pr** Praseodymium 140.90765	60 **Nd** Neodymium 144.24	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.964	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.92534	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93032	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93421	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.967
				90 **Th** Thorium 232.0381	91 **Pa** Protactinium 231.03588	92 **U** Uranium 238.0289	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)

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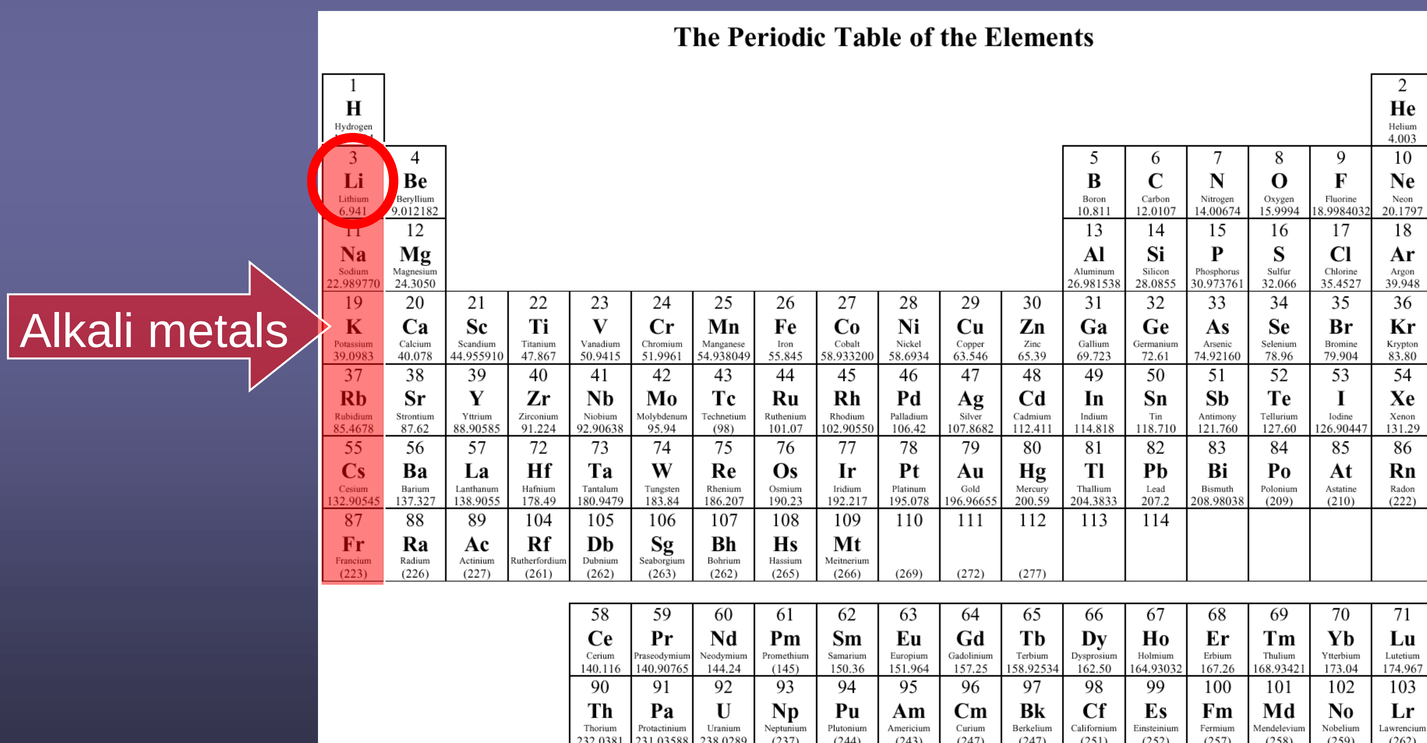
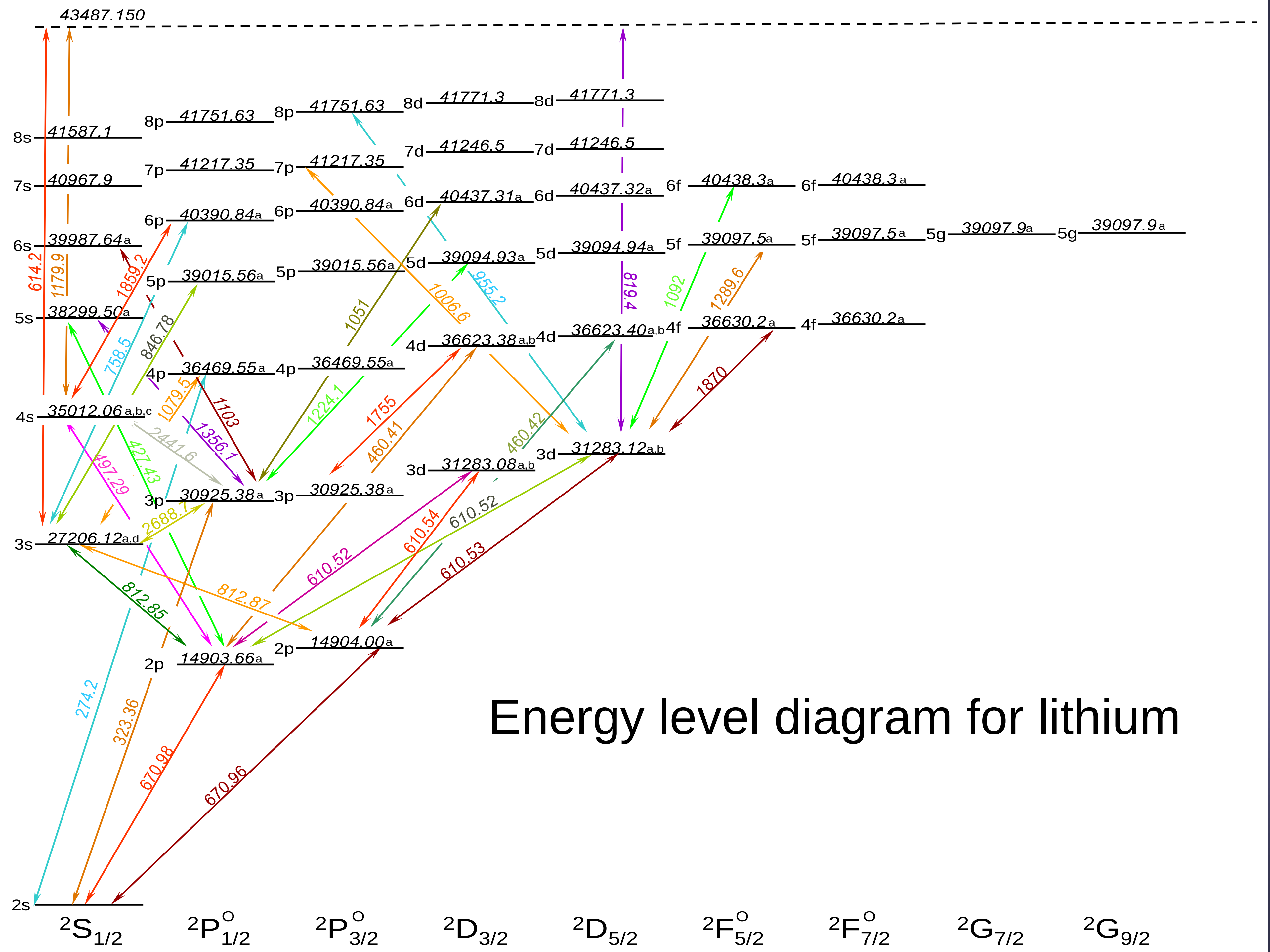
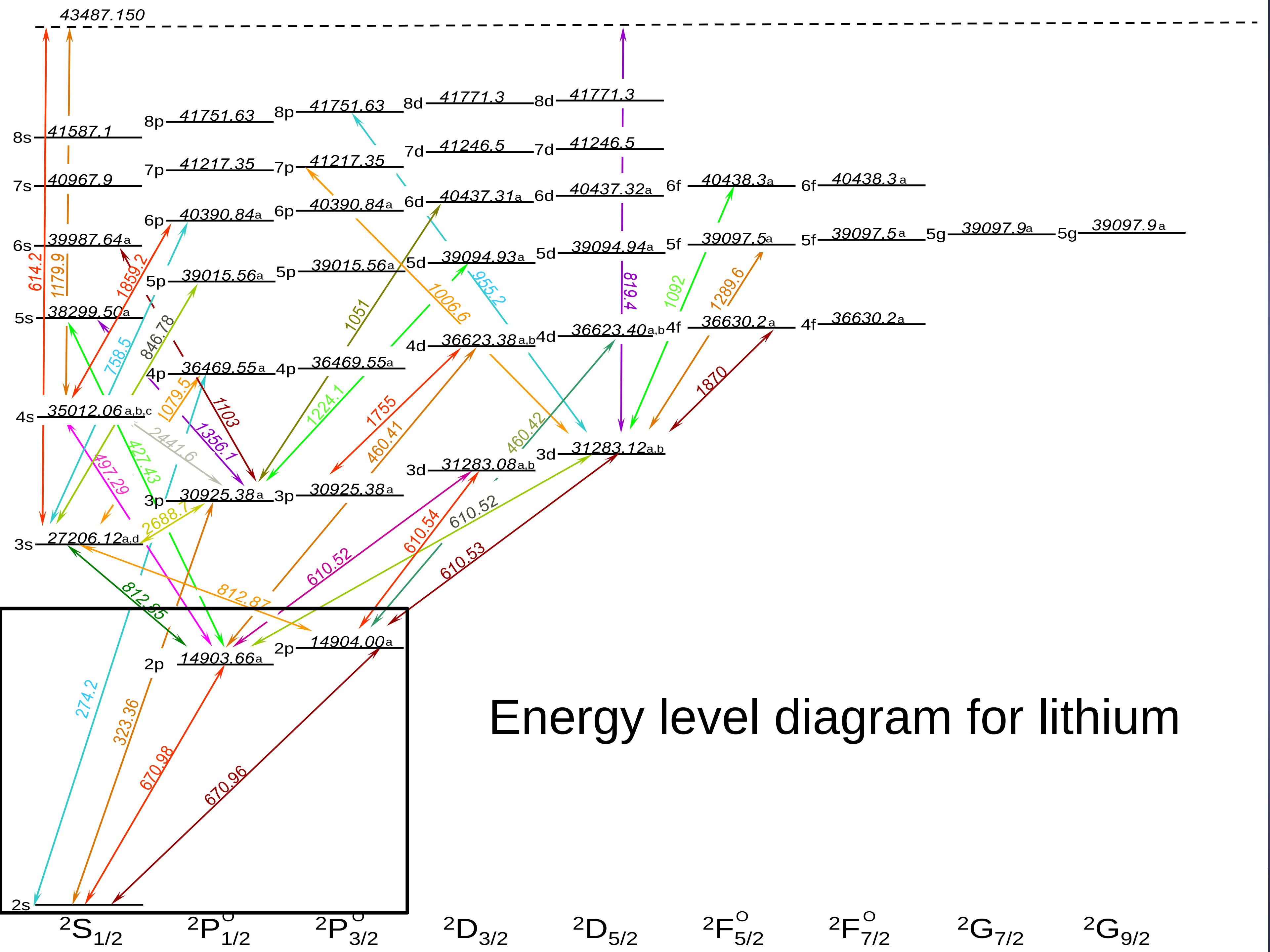




Energy level diagram for lithium



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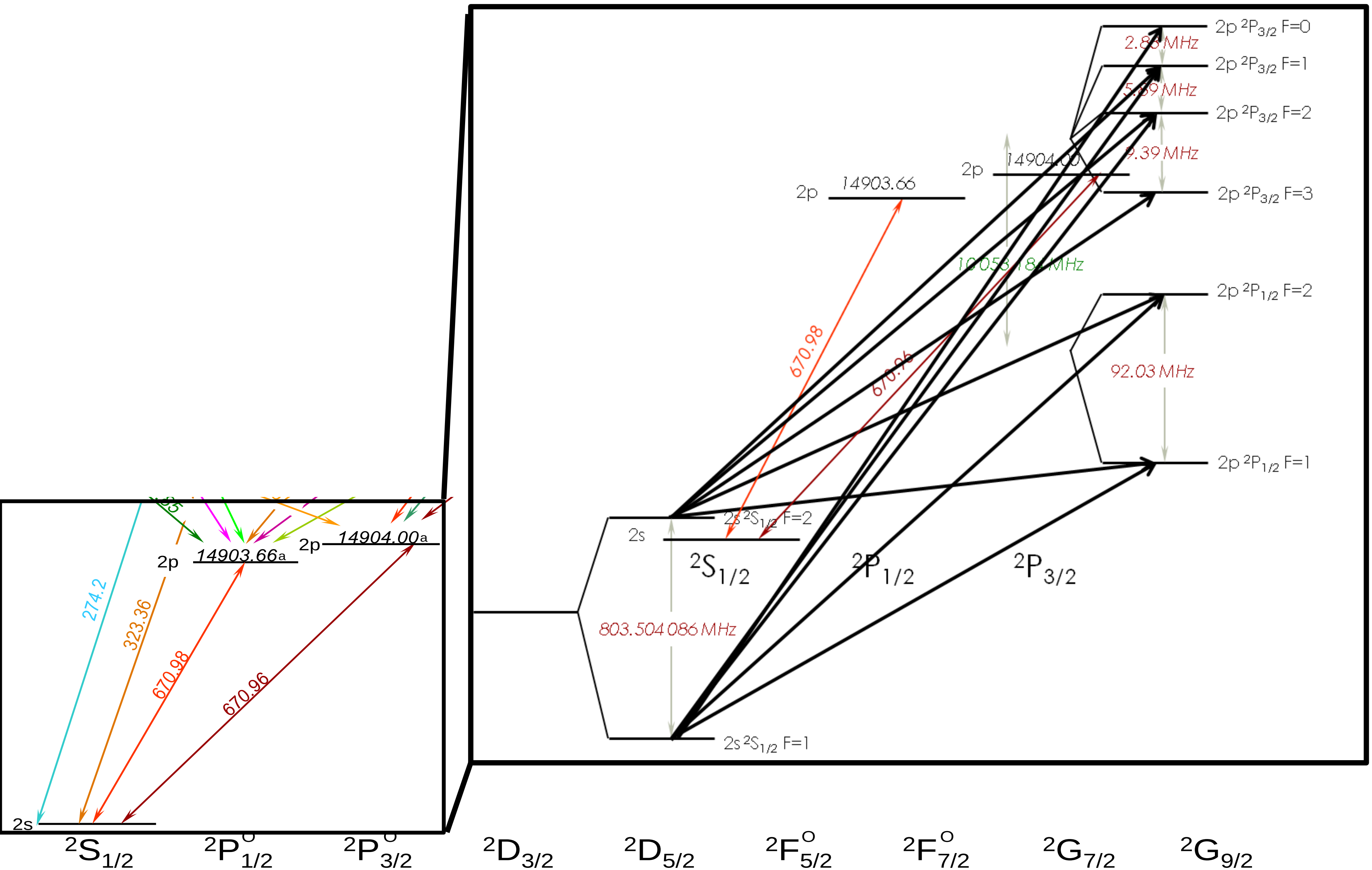

2p ${}^2P_{3/2}$ F=0
2.83 MHz
2p ${}^2P_{3/2}$ F=1
5.89 MHz
2p ${}^2P_{3/2}$ F=2
9.39 MHz
2p ${}^2P_{3/2}$ F=3
2p 14904.00
2p 14903.66
10 053.184 MHz
670.98
670.96
2p ${}^2P_{1/2}$ F=2
92.03 MHz
2p ${}^2P_{1/2}$ F=1
2s ${}^2S_{1/2}$ F=2
2s
${}^2S_{1/2}$
${}^2P_{1/2}$
${}^2P_{3/2}$
803.504 086 MHz
2s ${}^2S_{1/2}$ F=1
274.2
323.36
670.98
670.96
2p 14903.66a
2p 14904.00a
2s
${}^2S_{1/2}$
${}^2P^O_{1/2}$
${}^2P^O_{3/2}$
${}^2D_{3/2}$
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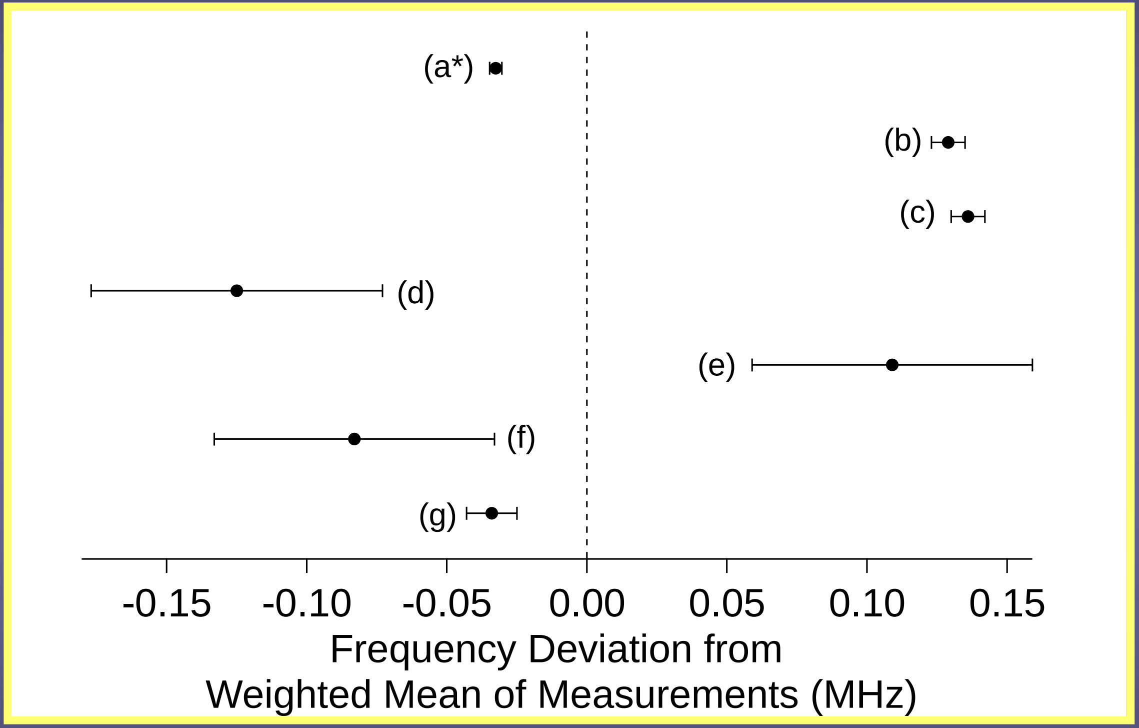
${}^2F^O_{7/2}$
${}^2G_{7/2}$
${}^2G_{9/2}$

Theory has small error bars

^{7}Li D1 Hyperfine Structure Splitting



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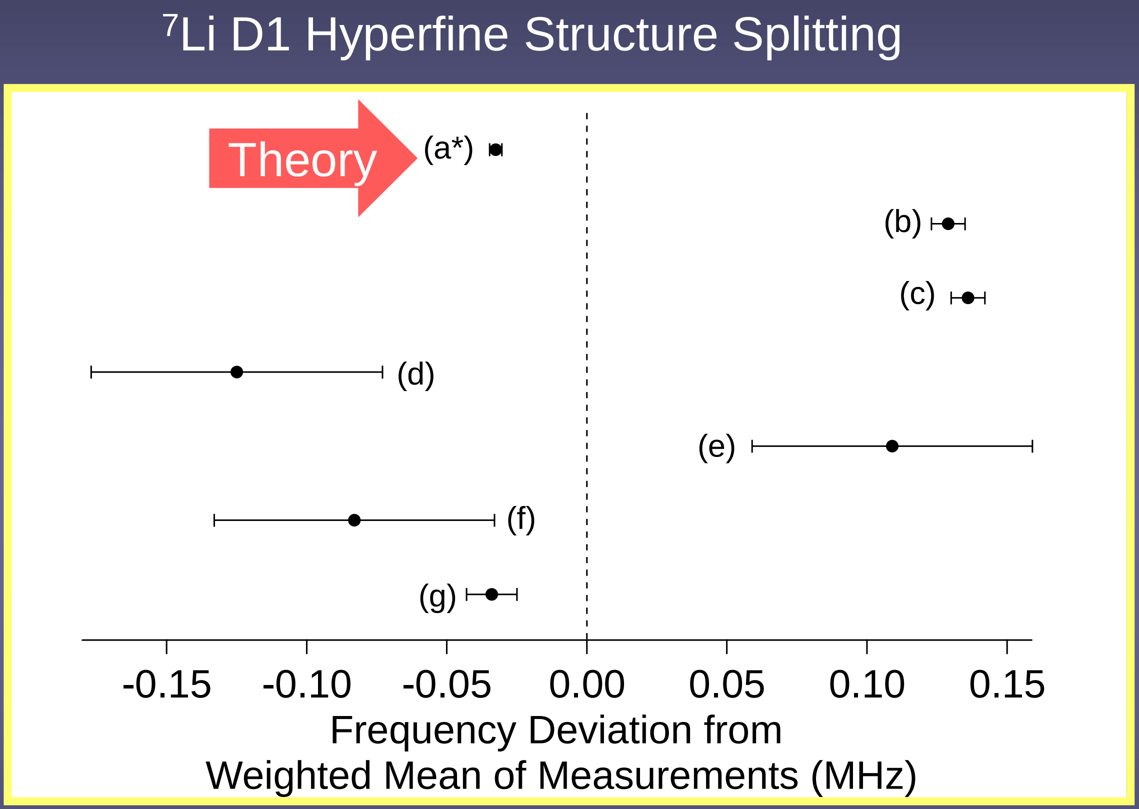
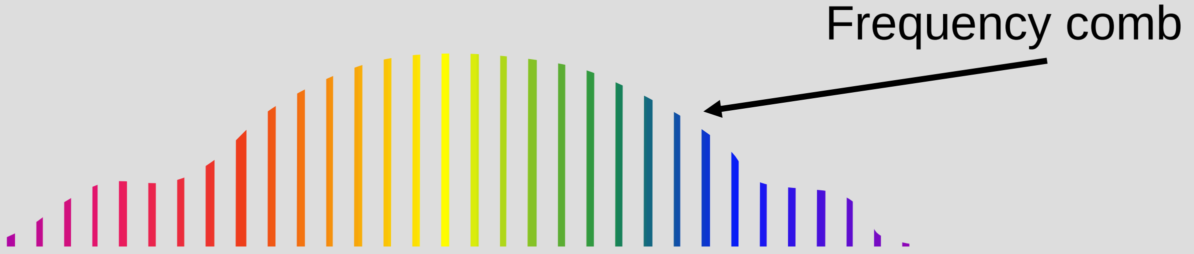


- Error bars for theory are very small – experiment should be able to do better than current measurements
- Possibly incorrect data analysis or systematic effects

Experimental Setup



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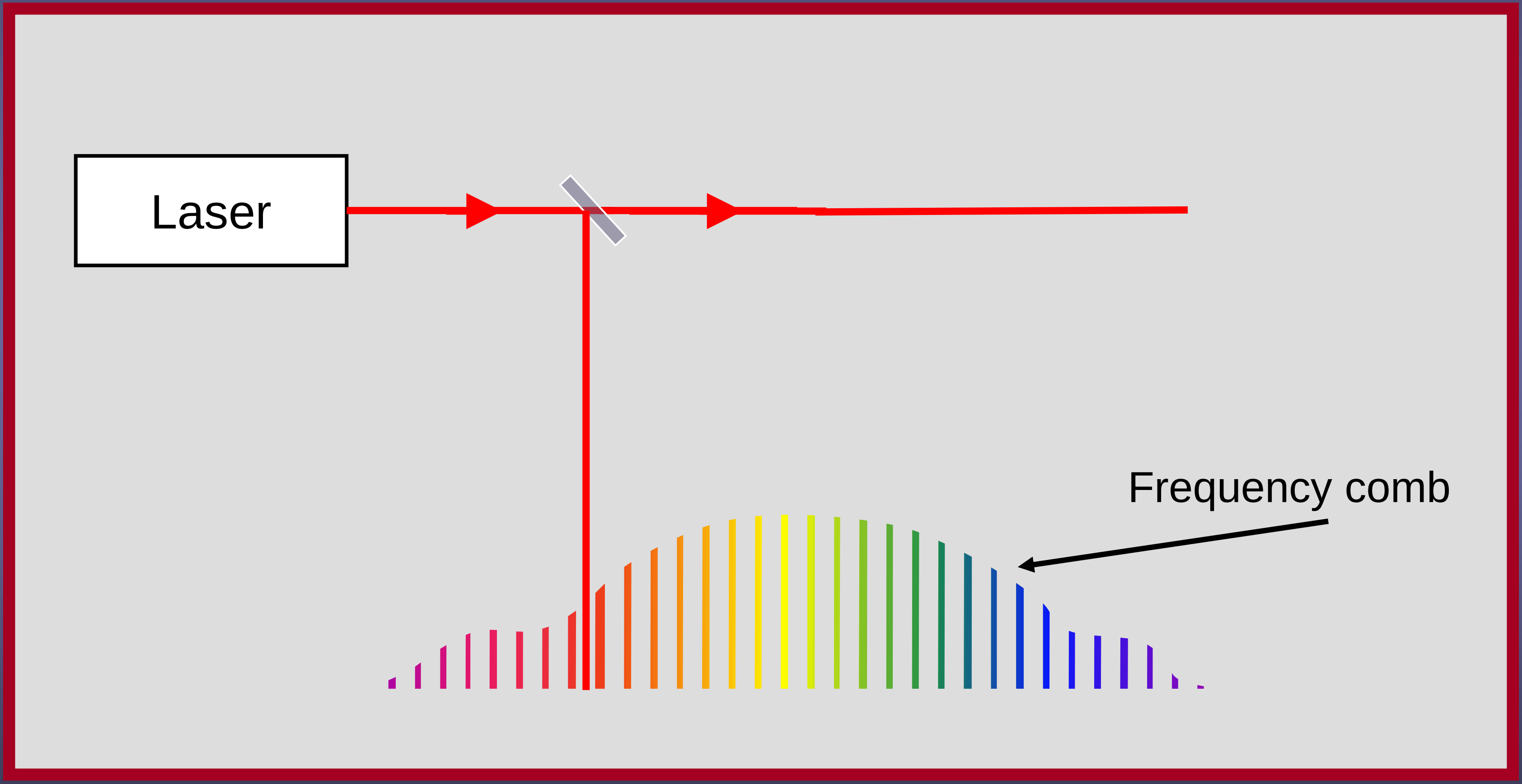

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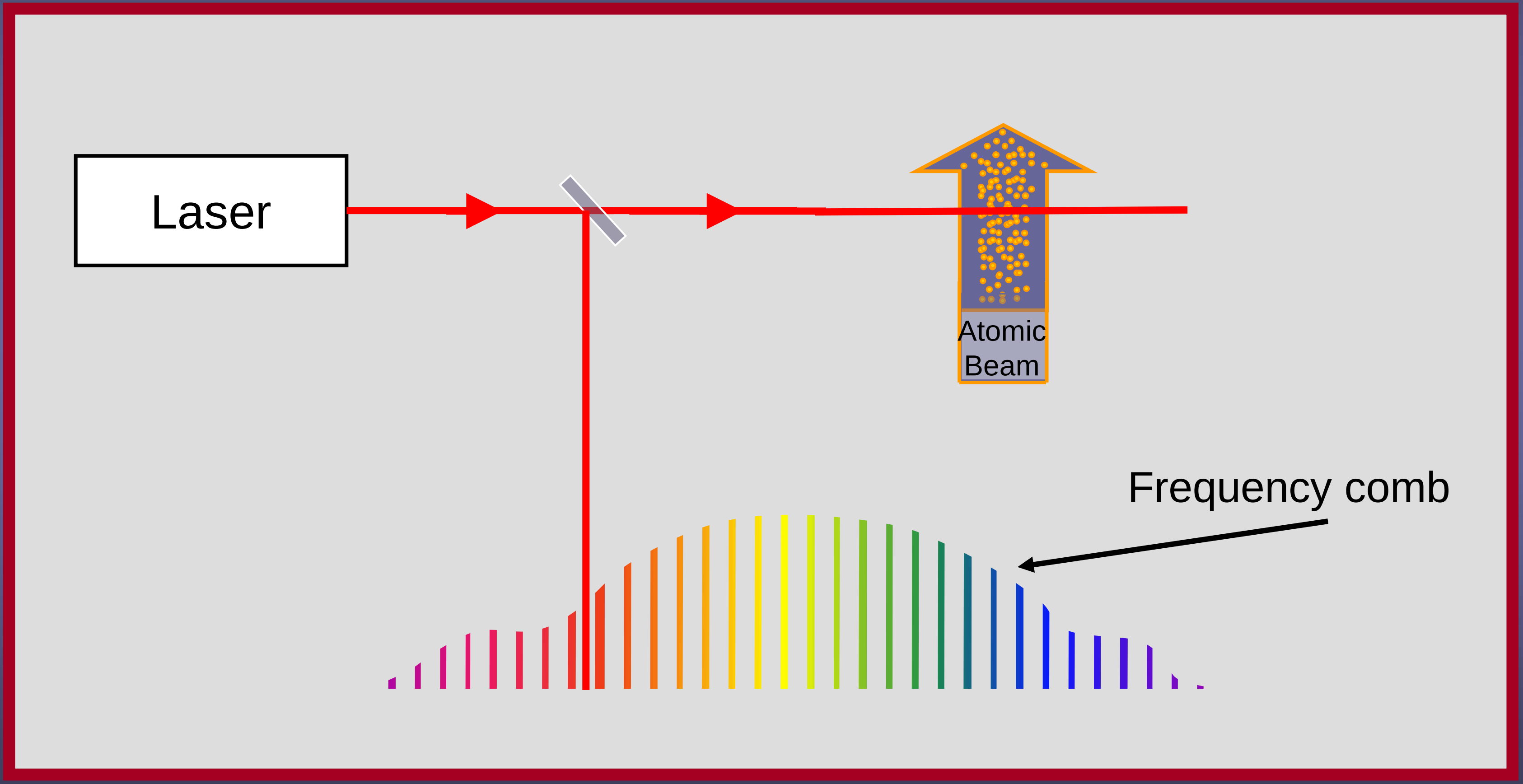

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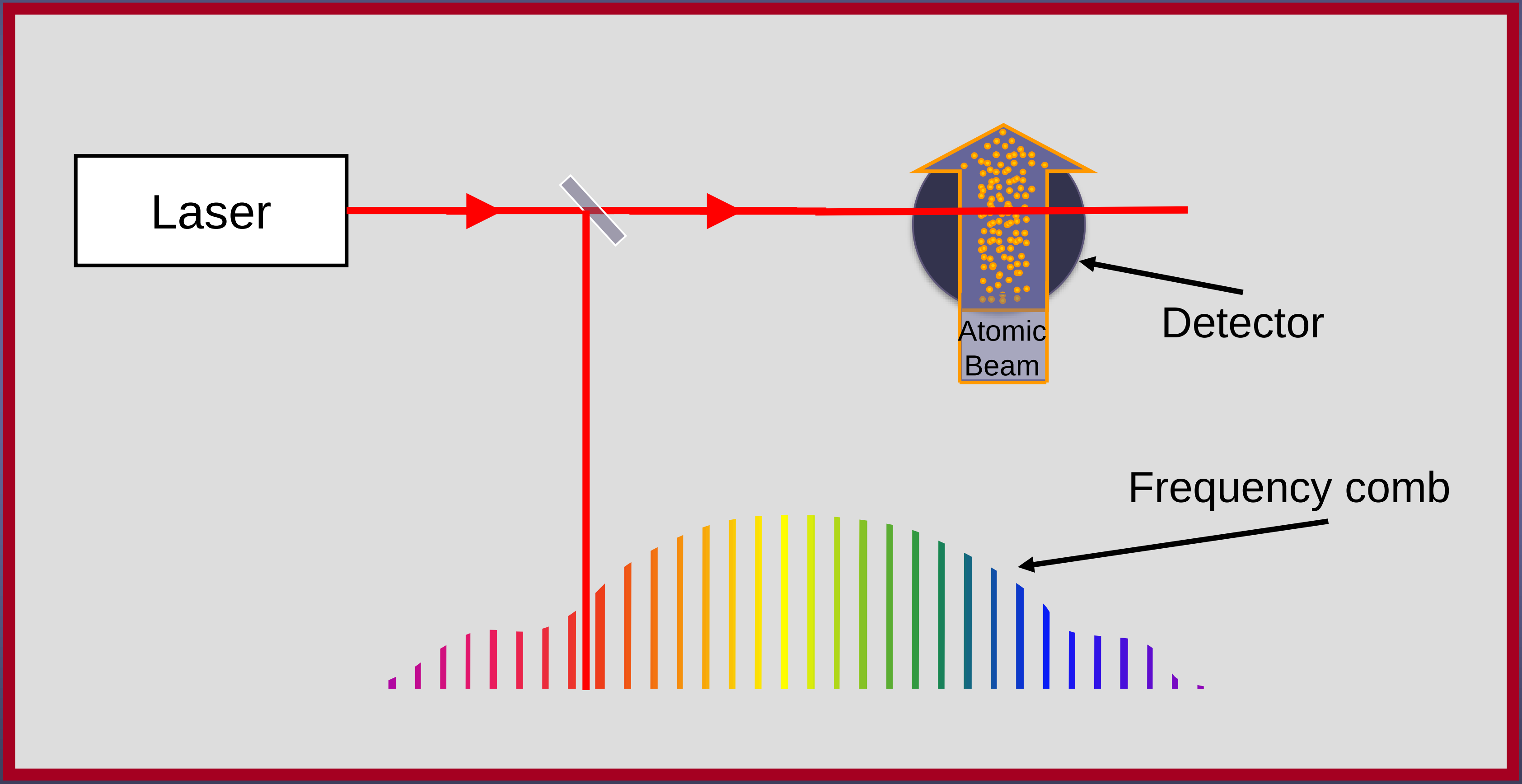
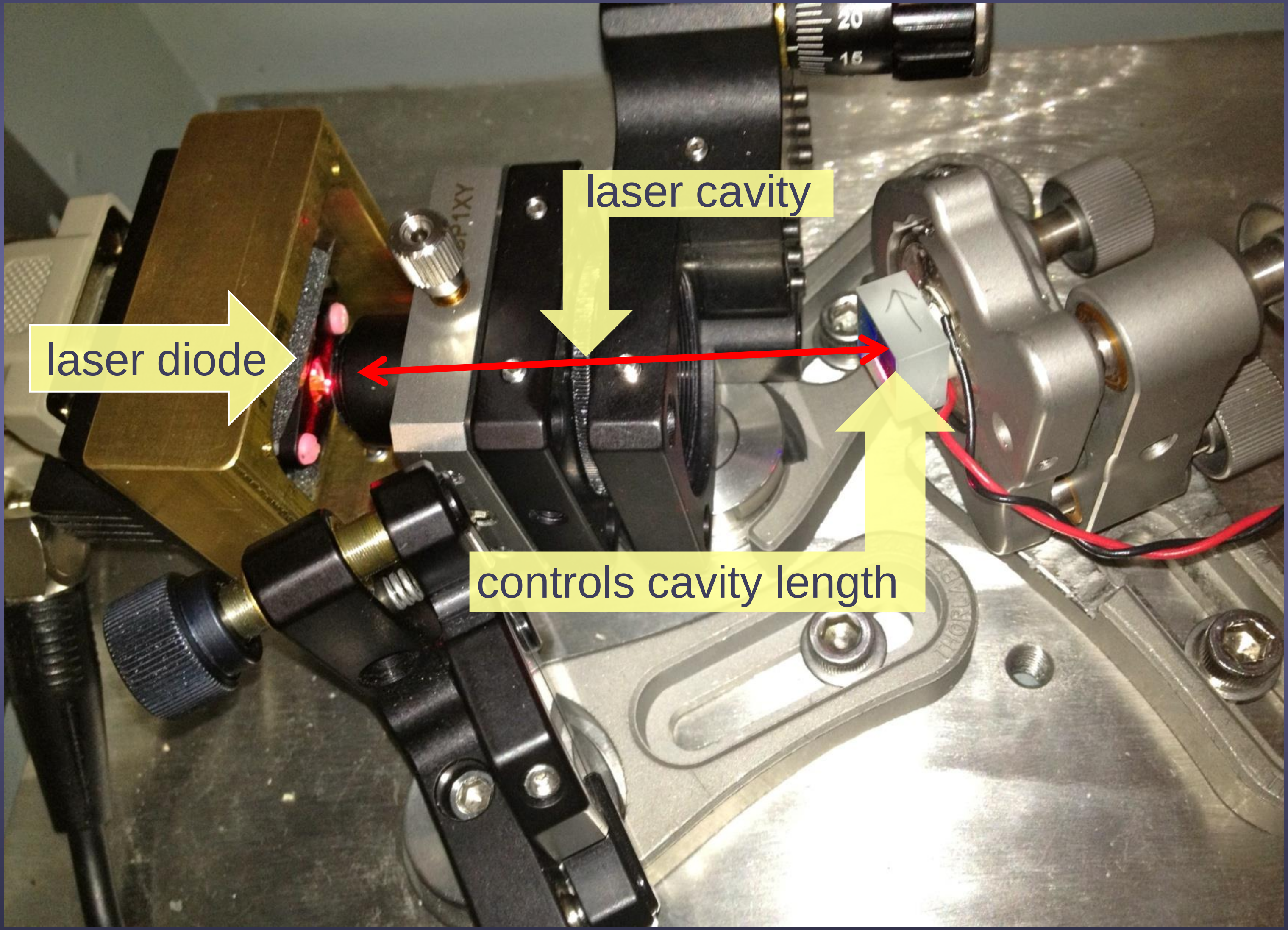
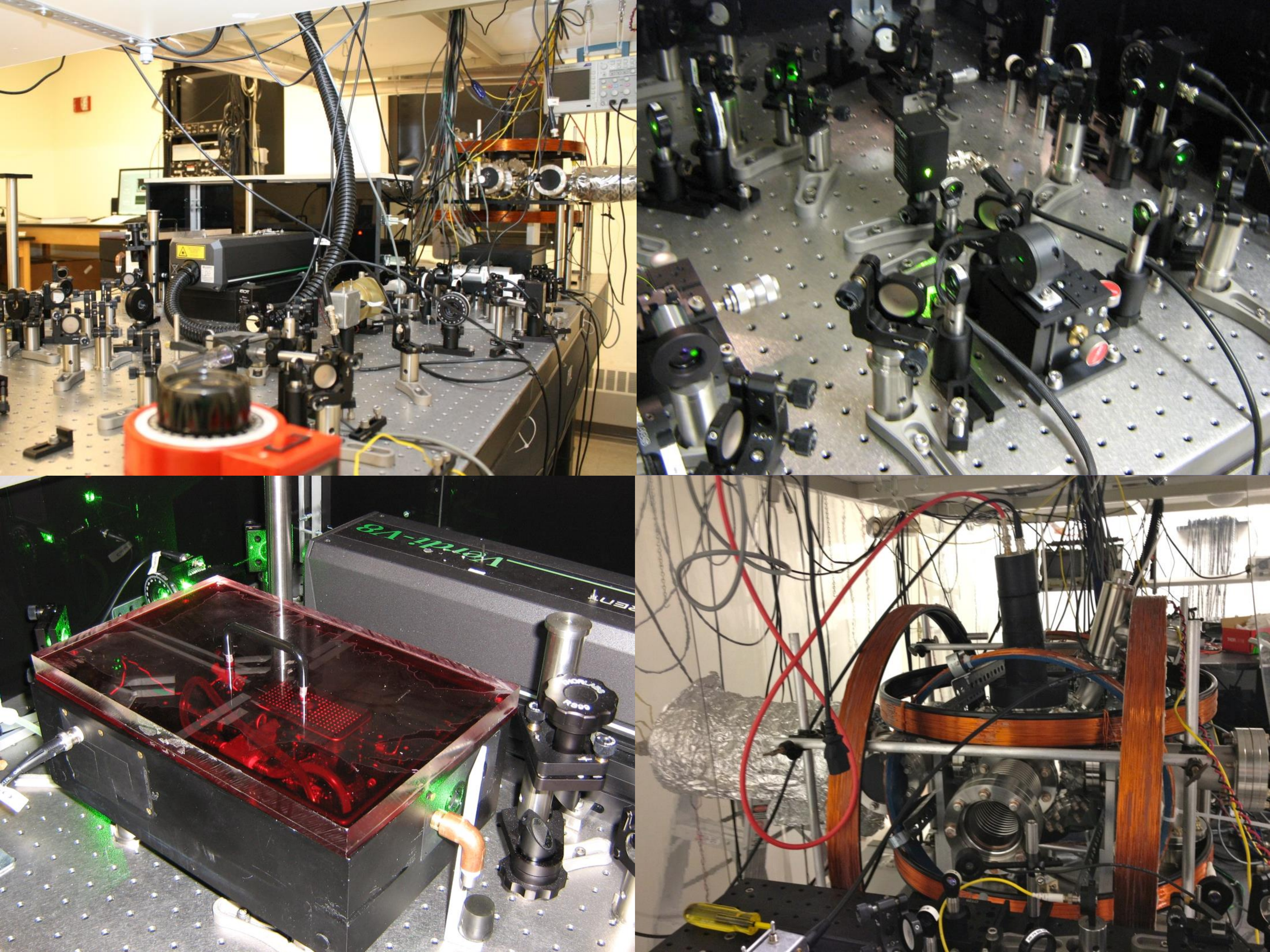
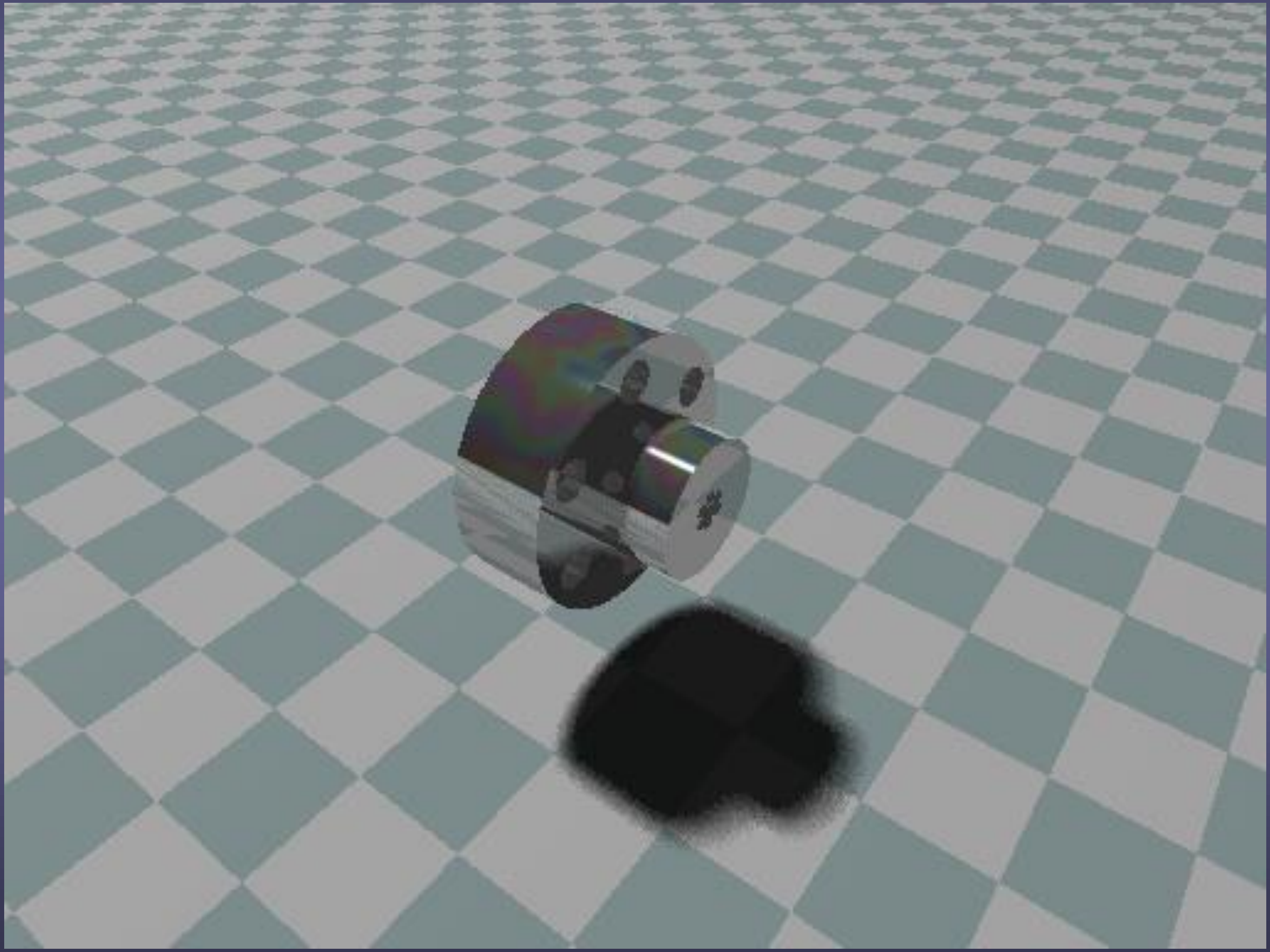


Laser – same kind in a CD player!

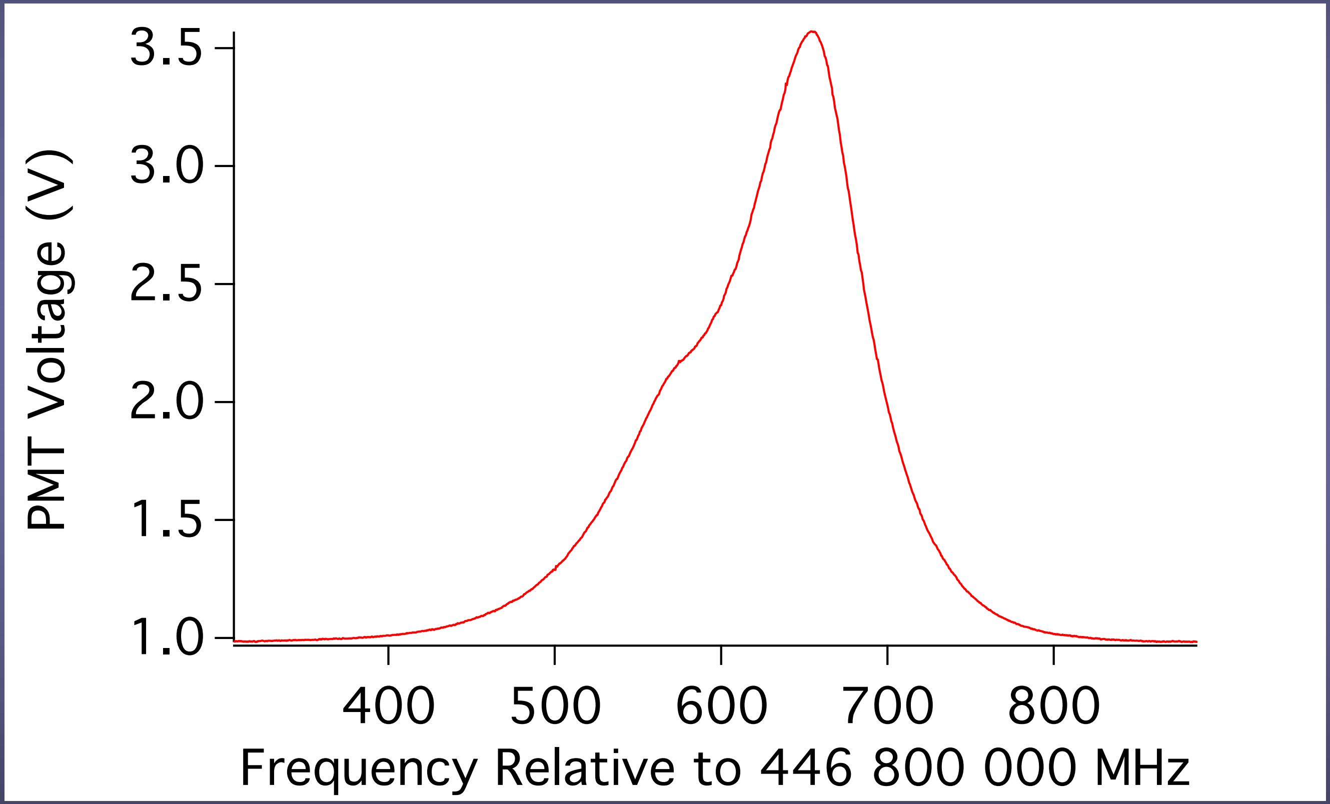



Verdi-V8

Old nozzle

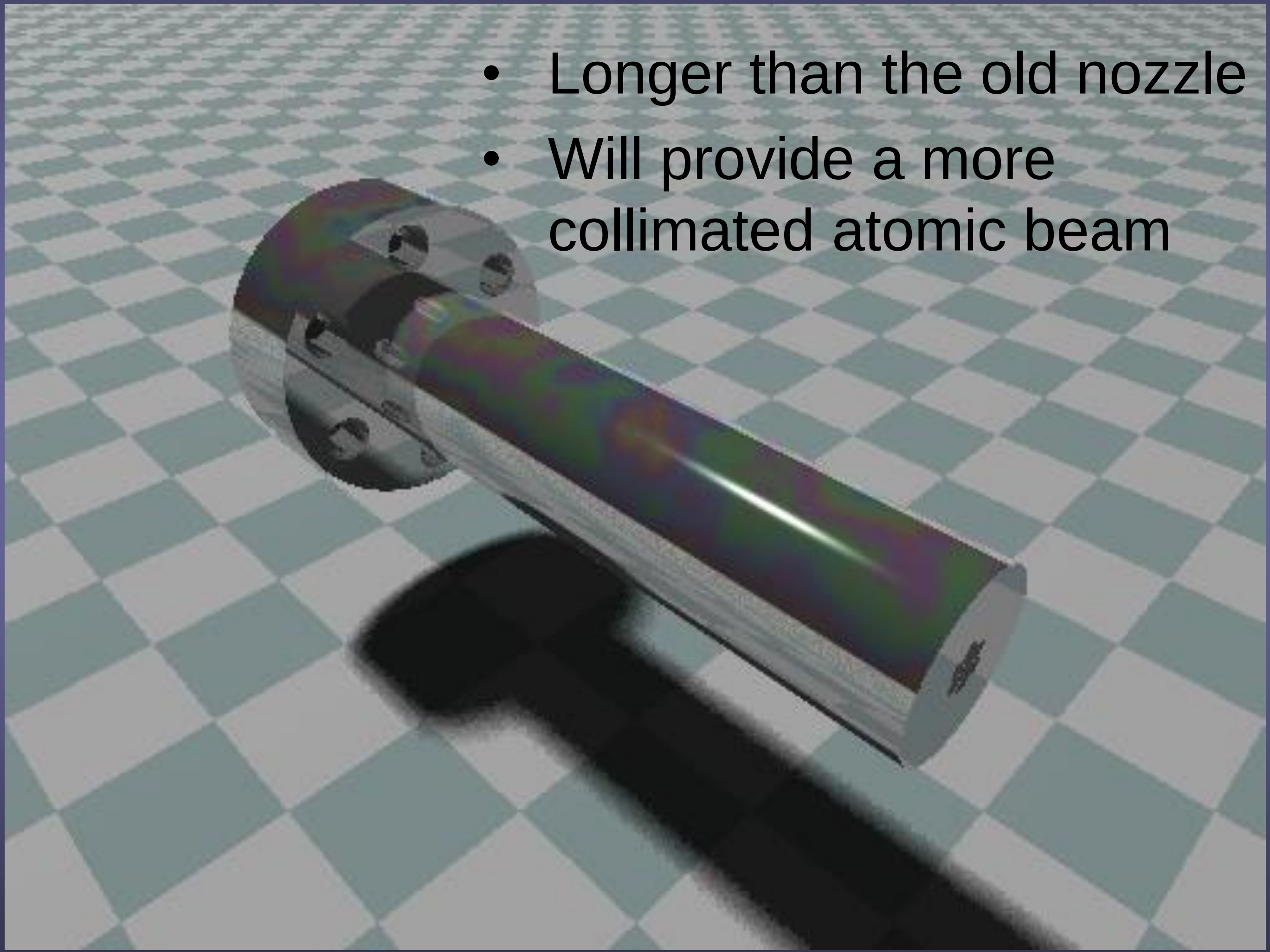


Data from last spring

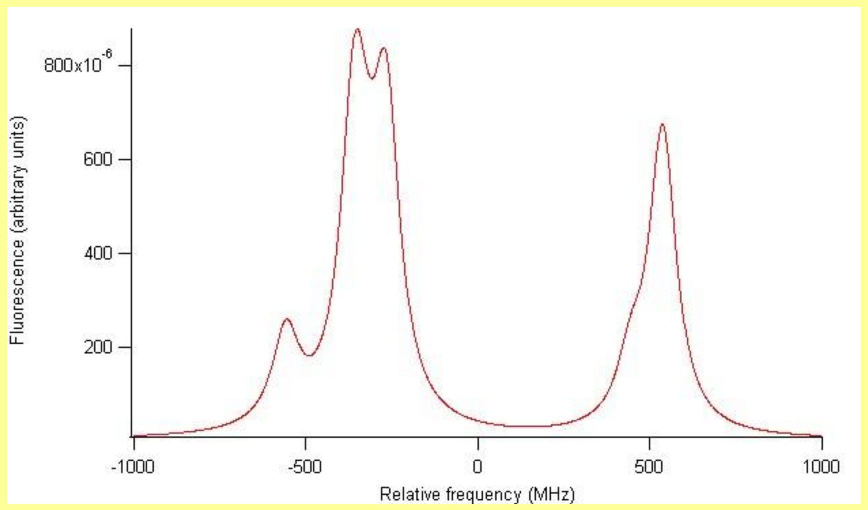


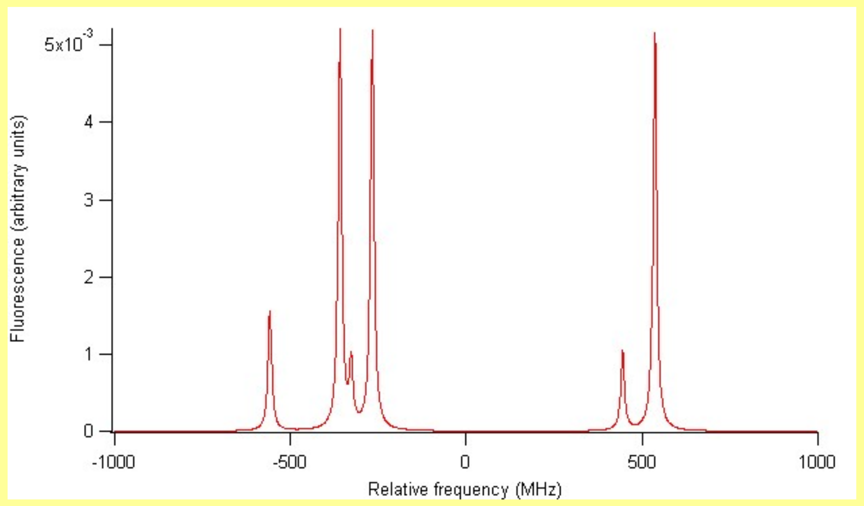
…New Nozzle!

- Longer than the old nozzle
- Will provide a more collimated atomic beam



How will the new nozzle improve the data?





Old nozzle: peaks are less resolved

New nozzle: more structure observed

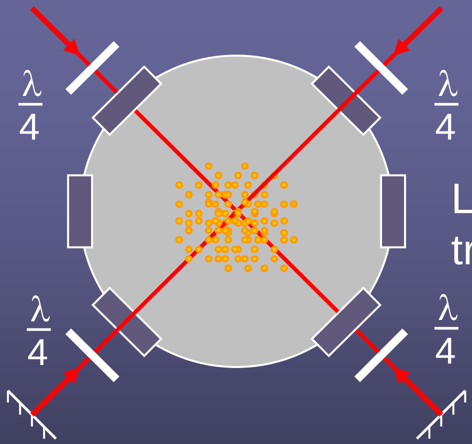
Other changes since old data

- Oven is fixed

- Reloaded the oven with lithium
- Earth's magnetic field at center of vacuum has been compensated with coils
- Improved laser stability

Future Work

- Gather data
- Data analysis
- Laser cool and trap atoms



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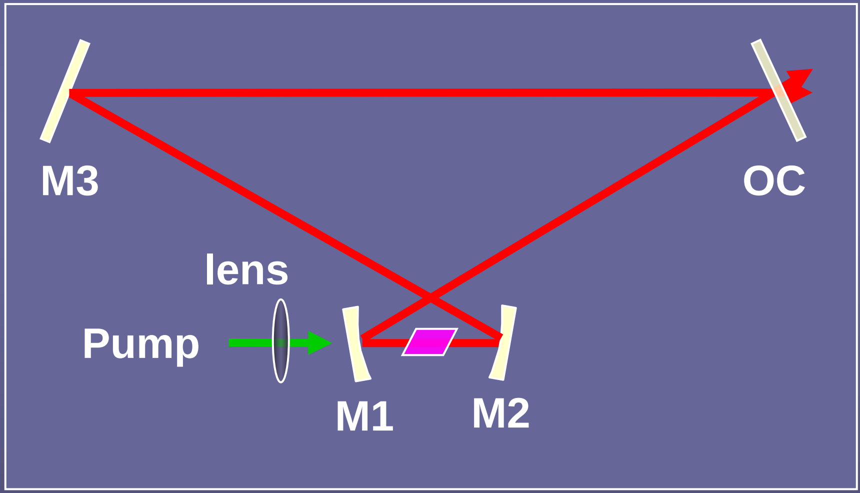
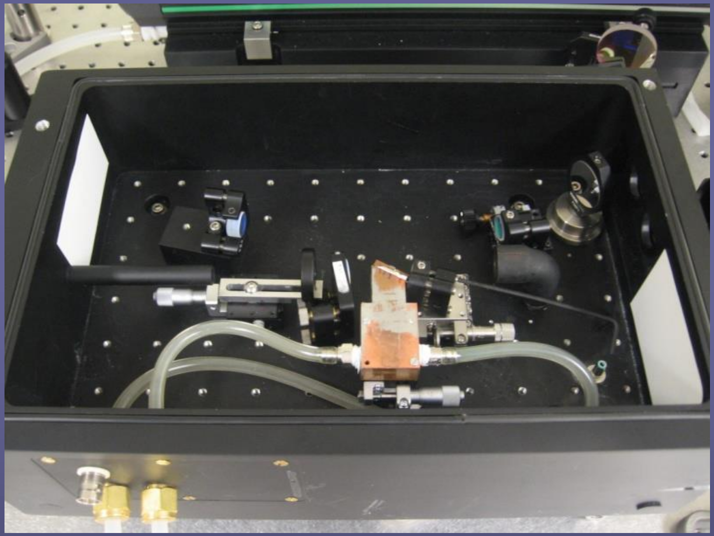
- Peers
- All of you!

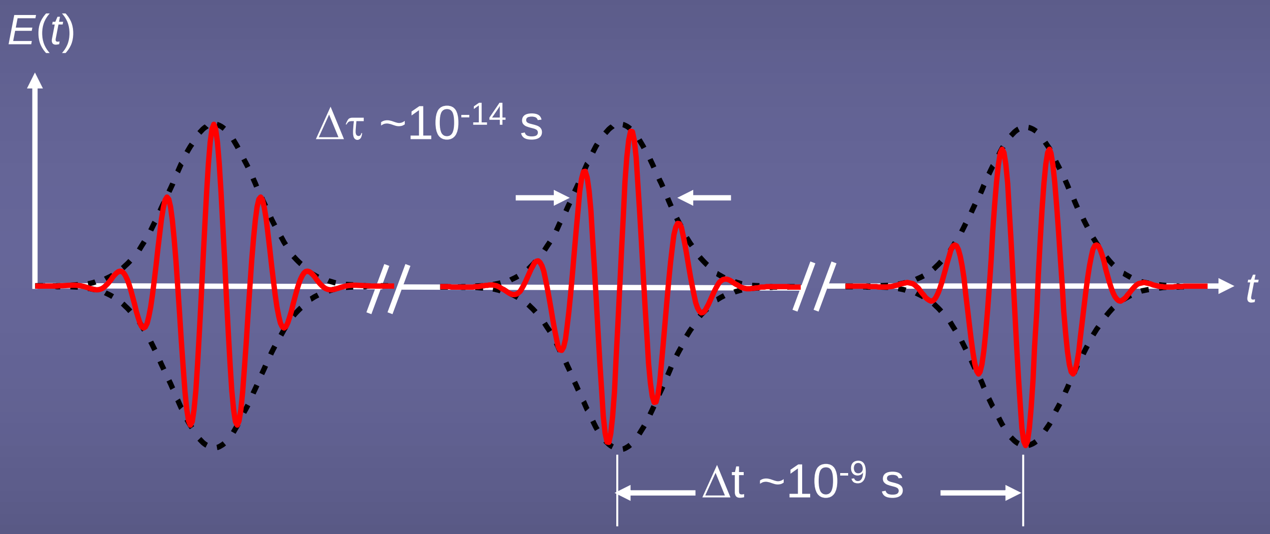
How do we make a frequency comb?





How do we make a frequency comb?

- The comb is produced by a series of ultrashort pulses



- Phase coherence of the pulses leads to interference and the generation of an optical frequency comb.
- Pulses are produced by a modelocked laser